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The Concord Consortium™

Perspective:

True Blended and Flipped Learning

By Chad Dorsey

Today's conversation about technology in education rings with promise as educators discuss "blended learning" and "flipping the classroom." New ages in education always introduce their share of new terms and ideas, and this one is no exception. These bring energy to the discussion and help people engage with technology in ways they hadn't previously. But these terms can be thought of in several ways.

Blending labs and learning

One of the most critical issues in science and engineering learning today is the disconnect between labs and other instruction. Any science teacher who has seen students burst into class asking, "Is this a lab day?" understands the magnitude of this concern. Even in the best classrooms, students see investigation and hands-on activities as separate from the rest of their "regular" learning. And even established labs can be practically devoid of learning, as twenty students follow a preordained recipe in hopes of reproducing identical, already-known results. Such practices only reinforce the idea that science is about devouring and re-telling information.

In deeply digital materials, the line between learning and labs evaporates entirely, and original student discovery is the norm. Students use models and simulations to engage in digital inquiry on topics that must otherwise be relegated to lecture. Everyday phenomena fold naturally into instruction as probes and sensors bring a new dimension to hands-on exploration. In deeply digital curricula, *every* day is lab day, and students move seamlessly between individual exploration of a topic via computer, investigation of phenomena via probeware, whole-class discussion, student-student collaboration, and teacher-led summary and explanation.

Blending data collection and analysis

New Concord Consortium projects are pushing the boundaries of this blending. InquirySpace will be an entirely new learning environment that erases the boundaries between data collection and analysis and brings collaboration to the fore. Students will view, combine, and compare data from multiple experiments instantly to manipulate and explore patterns and relationships that were once almost entirely out of reach.

With tools like this, whole classes can collect data for a joint experiment in minutes. Data capture will turn playful investigation using a model or simulation into an opportunity for rich analysis of underlying mathematical models. Such deeply digital affordances make inquiry highly accessible for students, highlighting their individual contributions and building a strong understanding of the processes of collaboration and scientific discovery.

Blending probes, models, and assessment

More meanings for "blending" come into play when we consider what the marriage of simulation and probeware offers for learning. Charles Xie describes our experiments with mixed reality and the creation of the Frame (see page 8). This example combines the power of models with the engagement of real-world exploration through probeware to offer perhaps the most forward-looking vision of what deeply digital materials might offer.

Deeply digital curricula also permit the blending and blurring of what are often thought of as set curricular lines. They permit collection of important data about student performance in a way that opens the door to true formative assessment (as opposed to the myriad of summative assessments that masquerade under that title today). Real-time information about student thinking can open up entirely new horizons for teachers, demonstrating student misconceptions, generating new questions, and helping guide the direction of classroom discussion at prime learning opportunities, when important student ideas may be most malleable. The feature article in this issue (page 4) documents our development of technology to support these real-time formative assessment feedback loops.

Digital media bring special views into individual student learning and permit important flexibility. When instrumented and designed properly, simulations can transform students' everyday experimentation into true performance assessment. If student performance data indicate that a new instructional variation is more effective than the original, teachers can change the materials easily and immediately as the next period's students settle into their seats.

Flipping the role of teachers and students

Deeply digital learning can also help bring new dimensions to "flipping" in the classroom. For many, this term indicates that students listen to or watch a lecture outside of class and then work on exercises with a teacher in class. But we believe technology should offer much more than this slightly enhanced variation on transmissivist pedagogy. In deeply digital learning, the role of both teachers and students should be redefined entirely and the process of learning should occur in rich new ways.

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In deeply digital curricula, every day is lab day. The line between learning and labs evaporates entirely, and original student discovery is the norm.

We know from learning research that students retain misconceptions about science even after hearing the most skilled and veteran lecturers. And we know that inquiry is critical to truly understanding science. By moving inquiry to the center of instruction and personalizing instruction for all learners, deeply digital curricula can cut directly to the activities that make the most difference and engage students in the practices of science the next-generation science standards and new AP curricula will require.

In deeply digital learning, teachers are guides to students as they explore, experiment, and engage with new concepts. They help students move through and unpack ideas for themselves and aid them in synthesizing knowledge. Explanation has its place, and may even take the form of a digitally supplied commentary. But more often than not, the value of lecture is most evident when teachers lead carefully targeted class discussions at critical learning moments. This is deeply digital learning at its best, technology-enhanced student learning mediated by great teachers. Indeed, in deeply digital curricula, teachers are not replaced by technology, but become essential as guides and careful interpreters in a classroom where students are brought as close as possible to the content and practices they learn.

Flipping students' roles with seamless collaboration

Deeply digital learning also presents exciting opportunities to flip students' roles in learning. When all students have access to resources via technology, collaboration can be built into the fabric of all curricula. Ad hoc groups of students can work on different parts of a problem. A whole class can generate a set of ideas quickly and individual students can explore and add to the ideas. Detailed dashboards and real-time views into what students are doing throughout the learning process permit teachers to direct collaborations deftly and tailor new learning opportunities for individual students or subgroups.

In fact, the power of collaboration is an area that deeply digital curricula have barely begun to tap. It is a frontier so exciting that it merits significant time and energy. Skilled teachers have for ages facilitated highly effective collaboration in their classrooms—digital curricula should be able to make this process easier, determine new and more effective patterns of collaboration, help distribute these patterns to anyone, and facilitate teachers in enacting them in classrooms across the country.

Building collaborative learning opportunities into curricula is one of many examples of important new ways we can explore the incredible possibilities of digital resources for learning. At a critical time such as this, when society is making great strides in digital learning, we must not grow complacent or slow our investigation into how technology can improve education. On the contrary, we must keep generating as many new and innovative ideas as possible. Only through this process—by blending innovations together to form entirely new creations and continuing to flip our own expectations upside down—will we ever truly reach the potential of deeply digital learning.

LOOPS

Offers a Lens on Learning

By Kimberle Koile, Nathan Kimball, and Sarah Pryputniewicz

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Imagine you are a student. Your teacher gives you a handheld instrument, but the instructions for using it are lost! You're told that it displays a graph of position vs. time when plugged into your computer, and you're asked to take some measurements. What would you do?

Groups of students were given the chance to find out. They were given these instructions and a motion probe as they embarked on "Missing Manual," the first activity in the motion and graphing curriculum developed by the LOOPS (Logging Opportunities in Online Programs for Science) project. There are known challenges for teachers engaging their students in this kind of independent learning. LOOPS has been investigating how best to address these challenges.

The Missing Manual activity is one of four activities developed by the LOOPS project that challenge students to think like scientists and experiment freely to gain skills in independent problem solving. As students progress through the activities, they learn how to graph a motion story on position vs. time graphs, define a frame of reference, explain the difference between position and distance, and calculate the speed of an object from a graph of its motion.

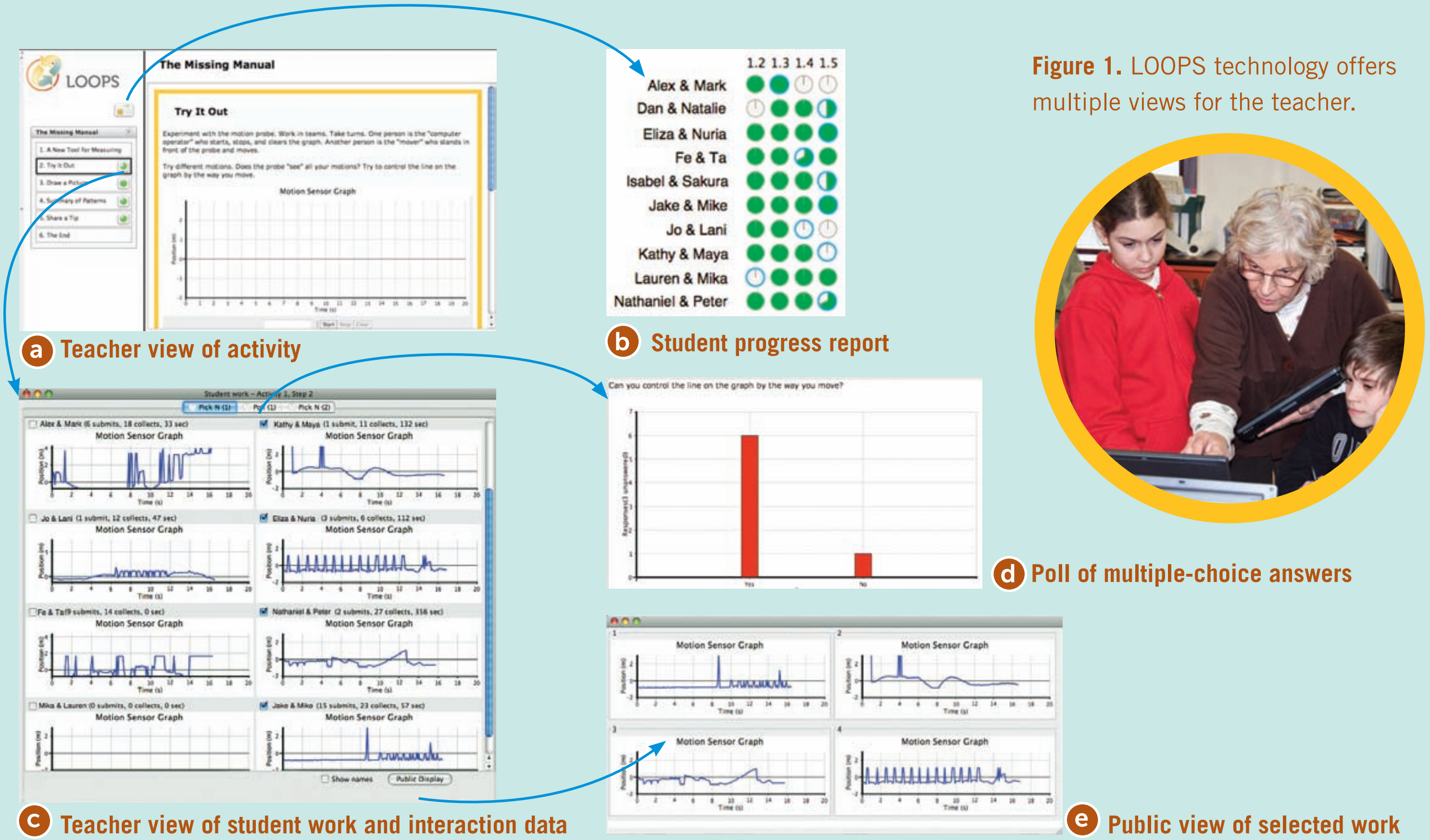


Figure 1. LOOPS technology offers multiple views for the teacher.

Addressing different learners

Curricula such as Missing Manual, in which students are cut loose to investigate on their own, have been tried for decades. While appealing to a certain type of student, others may not know where to begin and may become frustrated. This curricular approach, however, offers the potential to develop independent investigation skills, as long as students are given the support they need.

Funded by the National Science Foundation, LOOPS is researching how teachers can best monitor and support diverse student learning using instantaneous electronic feedback about each student's investigations and thinking. We believe that the classroom can be a community of learning mediated by the teacher, with individualized scaffolding for each student. Sixth-grade students in two suburban Boston middle schools helped us test this hypothesis. In the Missing Manual activity, they used a motion probe, a wirelessly connected laptop computer, and software that embeds probes and models into online activities.

Modeling a scientific community

After students had a chance to play with the motion probes and get a sense of how they work, the teacher brought the class together to share what they had done and to discuss what they had learned. The students had different ideas about how the probe measured motion. Several students advocated for the idea that the probe measured back-and-forth motion, while some thought it measured side-to-side motion, and others, up-and-down motion or even a combination of motions. The teacher projected some of the graphs and explanations on a screen at the front of the class and engaged the students in a discussion. Let's listen in on part of that discussion between the teacher (T) and one of her students (S):

T: (Pointing to where the position vs. time graph line goes up.) Am I going toward the probe or away from the probe?

S: Away.

T: (Pointing to where the line goes down.) Then, what's here?

S: Closer to the probe.

T: (Pointing at the next incline of the line.) Then I jumped right here. If this is going away, why is that jumping? What's the difference?

S: Going away it goes up, and jumping…

T: Do you think when you jump it goes up, too?

S: Yeah.

T: (Turns to the class.) Okay, can we test that? How many people think it goes up when you're jumping? What kind of a line do you get when you jump?

With student work and discoveries as the focus of classroom discussions, as in the above exchange, the class is transformed into an authentic scientific community in which experimenters test and examine the validity of scientific claims, sharing data in order to make sense of it and to examine hypotheses about how things work. These class discussions are opportunities for students to cast a critical eye on data and ideas. The discussions also serve to reignite experimentation or bring closure to the big topics in the curriculum.

LOOPS enhances the classroom experience by enabling these discussions to take place in real time. There is little lag between student experimentation and community examination of results.

Viewing student progress in real time

Students complete activities on their computers using instruments such as motion probes. They submit their predictions, data, observations, and reflections to the teacher's machine in real time using a local

Figure 2. Students draw a graph to match a story and "play" it to move the dog.

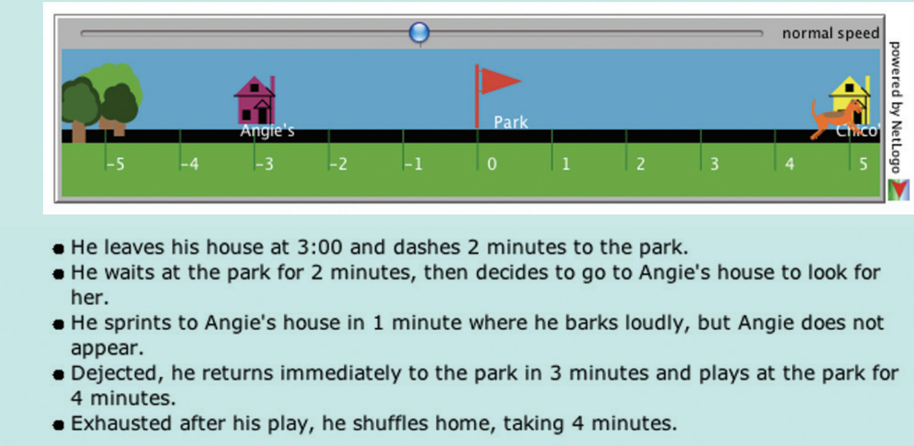
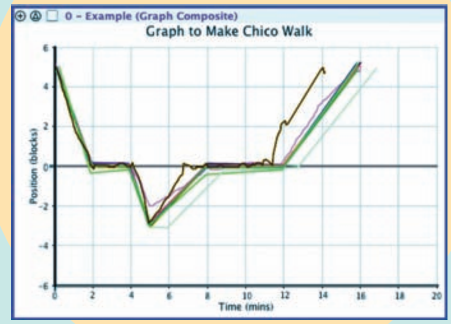


Figure 3. Composite of student answers is visible to the teacher. The expected answer is shown in green.

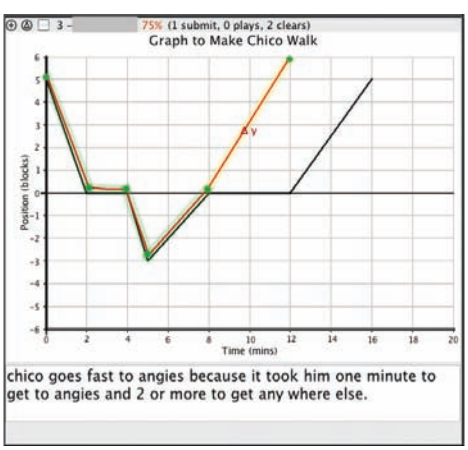


wireless network. Using LOOPS technology on a mobile tablet computer, the teacher receives that data while circulating throughout the classroom observing individual student work. LOOPS enables teachers to work closely with student groups as well as with individual students with different learning styles.

With this wealth of information a teacher can pinpoint individuals who may need assistance. She also can share student work with the class—anonymously if she chooses—by displaying selected work on a classroom projector.

Figure 1 shows examples of information available to a teacher in the Missing Manual activity. The teacher can view the activity (Figure 1a) and see how far students have progressed by looking at pie charts that represent the fraction of steps completed (Figure 1b). A blue border on the pie chart tells the teacher the step on which each student is working. The teacher can also see all student work for a particular activity step (Figure 1c). Such work may include graphs (hand drawn or produced by interacting with computer models or probes), text answers to open-response questions, or histograms of multiple-choice answers (Figures 1c and 1d). The teacher may view a student's history of submissions and select particular submissions for classroom display. In Figure 1e, the teacher has selected four graphs to project anonymously to the class.

Figure 4. Comparison of a student answer with expected answer shows error in last segment.



Viewing summary information

The amount of information that technology makes available can be overwhelming, especially when students are encouraged to reflect and improve on their work and resend it to the teacher. To help manage the data, LOOPS provides summary information, such as how many experimental trials each student has completed and how far each student has progressed through the activities.

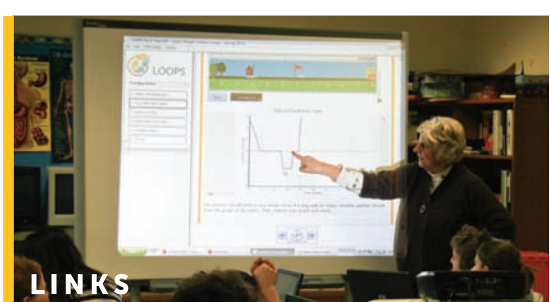
In one of the activities on graphing position versus time, for example, students use a model to create a graph based on a story. Each student, or student pair, draws a graph and then "plays" the graph to move a dog along the model's display in order to check how well the graph matches the story (Figure 2). The students submit their graphs to the teacher, who can see a composite of all student graphs (Figure 3), as well as compare each student's graph with the expected answer (Figure 4). The composite gives the teacher a sense of class understanding as a whole; the analysis of single graphs gives the teacher information about each student's understanding.

Supporting classroom interaction

With any new technology, questions arise about how best to use it. How often should teachers project and discuss student work with the whole class? At the beginning of a class? Several times during class? How often should teachers work with students individually, using real-time information to identify students who may need help?

We hypothesize that frequent discussions could help answer student questions more quickly and bring closure across the class. But fewer discussions could give more time for independent work and a more natural flow to the class. In this year's classroom trials, we're investigating the difference in pedagogy and effectiveness of these different approaches.

With LOOPS, students and teachers can stop, look, and listen. The question is—how often works best?



LINKS

LOOPS
http://concord.org/loops

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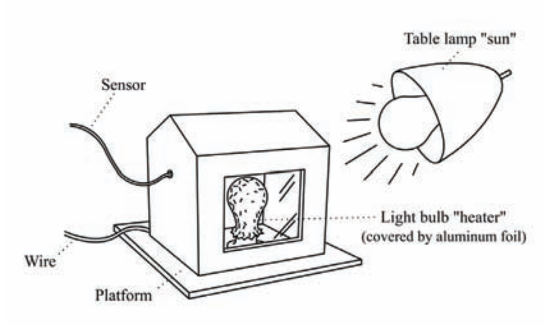
Monday's Lesson:

Build and Test a Model Solar House

By Edmund Hazzard

The "E" in STEM stands for engineering, of course. The importance of engineering education is now widely accepted, but it is not widely incorporated into the school curriculum. Teachers and students need more projects that are modest in length, tackle real-world problems, and are connected to science and math, as well as to engineering standards.



The Model Solar House, developed for the Engineering Energy Efficiency project, meets these criteria. Students explore the basic concepts of heat transfer and energy conservation in a real-world setting—home heating. In this three- to four-day activity, they use a template to build a simple house from cardstock and measure its heat loss. Then they repeat the test with added "solar" input to determine how much heat energy the sun contributes to keeping their house warm.

Getting started

Materials for the Model Solar House are readily available—cardstock, foam core poster board (for insulation), acetate (for windows), scissors, and tape. A fast-response temperature sensor is essential, since it's used to detect air and surface temperatures and must respond quickly. The parts for the heating source—a 40 W bulb in a standard socket—are inexpensive but require some assembly.

Human thermostat

Heat flow requires a temperature difference. Since we can't lower room temperature, the house is heated 10°C above room temperature to imitate a real-world outdoor temperature of about 10°C (50°F). This is sufficient to show dramatic differences, especially as the house design and insulation are improved.

Almost all residential furnaces and boilers are constant-power sources: they're either on or off. The amount of heating is adjusted by how much of the time they're on, and this is controlled by a thermostat.

In the Model Solar House, the 40 W bulb acts as the constant-power furnace. The bulb is covered in aluminum foil, which cuts down on radiative emissions (light and IR) so that almost all the heat energy is transferred to the air by conduction and convection. Students act as "human thermostats" by watching the temperature graph and turning the heater bulb on and off to keep their house temperature within a narrow comfort range (+/- 0.2°C). The percentage of time on multiplied by the bulb wattage gives the power requirement.

To mimic the sun, position a 300 W incandescent bulb in a gooseneck lamp about 20 cm away to the "south" of the house. Use solar noon for either a winter (90 - latitude - 23½°) or summer (90 - latitude + 23½°) condition. Leave the "sun" on while the heater bulb inside the house is cycled on and off within the comfort range. The difference in power requirement from the initial test gives the solar gain for the house.

Use a chart to compare student team results, and hold a discussion on the variations and the solar gain. (Note that students often like to make this a competition— that's okay!)

Making connections

The close analogy to real houses presents an opportunity for rich conversations. Students are often unaware of the basic features of their own house heating—type of fuel, type of heating system, how a thermostat works, house orientation, solar gain. Have them find their home heating bill, apply energy conversion factors (e.g., 400 gallons of oil multiplied by 130,000 BTU/gallon = 52 million BTU = 15,200 kWh), sort out the difference between power and energy, and deduct summer hot water heating (if the same source) to find their actual house heating energy consumption.

Team	No sun (watts)	With sun (watts)	Solar contribution (watts)
Polka Dots	30	10.5	19.5
4 Reals	38.4	30.8	7.6
Myrtle Turtle	20	14	6
Matt & Sam	25.2	16.7	8.5
Cowboy Jim	27	19	8

Extensions

In the full month-long curriculum, students design, construct, and test their own houses (with different shapes, roofs, number of windows, etc.), using the same simple materials. They also explore the various mechanisms of heat transfer—conduction, convection, radiation, and heat capacity—with hands-on or model-based experiments.

Try it out

Go to http://www.concord.org/activities/model-solar-house to download the PDF version of this activity.

LINKS

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

Framing
Mixed-Reality Labs

By Charles Xie

Charles Xie
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Laboratory experiences are indisputably a fundamental part of science education. In order to understand the concepts at work in an experiment, students must place the data they collect into a conceptual framework. However, there is often a wide gap between the raw data and the abstract concepts under investigation. For example, to understand heat transfer measured by a thermometer, students must imagine the invisible flow of thermal energy; to understand the intensities measured by an electromagnetic field sensor, they must visualize an electromagnetic field. In these cases, "heat" and "field" are the conceptual frameworks. A lab would have limited educational value if it could not bridge data and the underlying concepts.

The Mixed-Reality Labs Project funded by the National Science Foundation has set out to develop cyberlearning technologies that promise to narrow the gap for students between data and concepts. Our key strategy is to seamlessly combine the visualization power of simulations and the investigation power of sensors to enhance the learner's perception of reality. Simultaneously supporting inquiries in both the virtual and physical worlds, this integrated approach transcends the limitations of real labs while retaining their tangibility to make learning physically relevant to students.

Frame technology

We have recently invented a unique technology to showcase a large class of mixed-reality labs. The Frame technology is based on the fact that the frame of a computer screen *is* the natural boundary between the virtual world and the physical world and is, therefore, an intuitive user interface for certain human-computer interactions. Compared with other interfaces, the Frame allows users to interact with the computer from the edges of the screen (Figure 1).

In our vision, the Frame is an adjustable structure that can "frame" several kinds of display screens (hence the name). A variety of sensors can be plugged into slots on the Frame. Each sensor slot registers a port number so that the computer knows from which direction the signal comes. If sensors are wirelessly connected to a mobile computer, the entire system becomes portable.

By running a simulation in full screen mode, the data from sensors on the Frame looks as though it's "transmitted" into the simulated scene in real time. For example, moving a hot object close to the Frame where there are temperature sensors creates an input to an ongoing heat transfer simulation, which then produces a visual effect *as if* heat could flow into the screen from the hot object. Similarly, directing a light beam onto light sensors on the Frame can create a scenario *as if* light could shine into a virtual world to warm up a solar house or start photosynthesis in a leaf.

The Frame technology follows the typical way we conduct real experiments, namely, by allowing students to change variables in a system and observe how it responds to those changes. Unlike a real experiment, however, the inputs are applied to change a virtual system. Unlike a virtual experiment, the inputs come from the real world. Bridging the two worlds, the Frame takes advantage of learning opportunities in both worlds.

Three types of frames

The Frame is a flexible technology because many different displays can be framed, as the following illustrations demonstrate.

Detector

The Detector Frame converts a tablet computer into a mobile device that can detect changes in the real world and augment the signals with virtual reality. For instance, when a framed tablet approaches a heat source, it will show a flow of thermal energy on the screen as if the screen were thermally sensitive (Figure 2). In this case, the Detector Frame translates obscure raw data into a more understandable and visually appealing picture using computer visualizations. Compared to showing numbers or graphs of data from the sensors, this mixed-reality lab extrapolates the data to the virtual world to provide the contextualization necessary to understand their meaning.

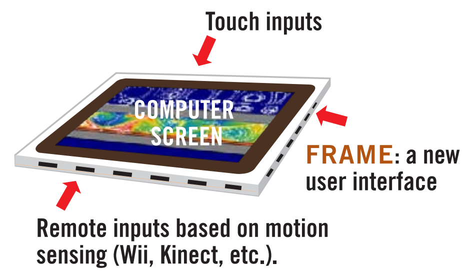


Figure 1. Interacting from the edges.

Workbench

The Workbench Frame converts the flat LCD display of a computer into an experiment station. A mixed-reality wind tunnel with one or more anemometers measures

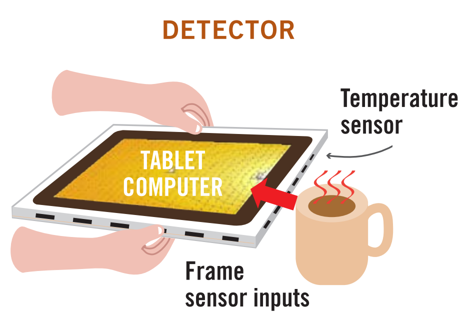


Figure 2. Mixed-reality thermal imaging.

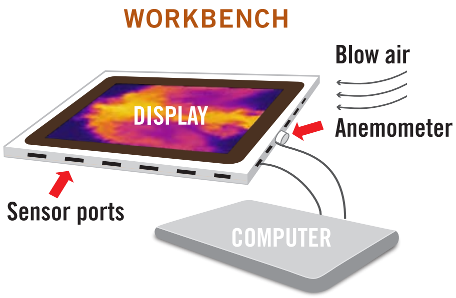


Figure 3. A mixed-reality wind tunnel.

the intensity of air streams as the student blows and creates inputs to a running computational fluid dynamics (CFD) simulation visualized on the screen (Figure 3). This lab can teach forced convection, wind turbines, airfoils, and more. Students can explore relationships between real air speed data and virtual flow patterns (e.g., streamlines, vortices, or turbulences).

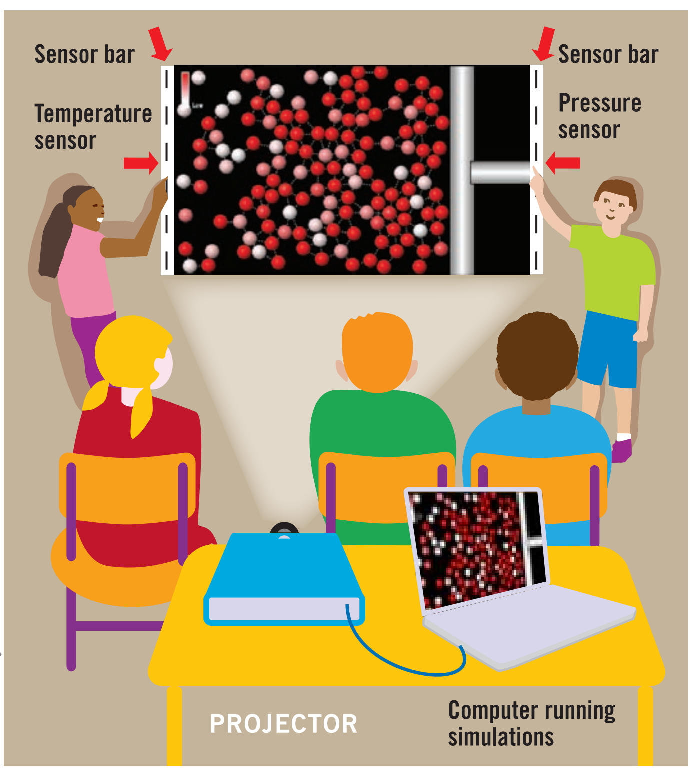
Projector

The Projector Frame turns a projector screen into a magnified lab on the wall. Sensor bars are mounted on the wall to frame the projection area. Figure 4 shows a mixed-reality atomic microscope projected onto a screen. Temperature and force sensors translate students' actions on the sensor bars into signals that are then used to adjust variables such as temperature and pressure. In the gas simulation shown in Figure 4, a student can push the piston to compress the gas by exerting a force on the sensor bar. Another student can heat up or cool down the gas by moving a hot or cold source to where the temperature sensor is located. The actions of these two students can be performed at the same time, creating an interaction between them mediated by the simulation. For example, while one student is compressing the gas, another student can simultaneously explore how much she should heat up the gas in order to push the piston back, which leads to understanding the Ideal Gas Law in a collaborative setting.

Looking ahead

In purely virtual experiments, students interact with simulations through clicking or touching widgets on the screen that represent physical variables. Mixed-reality experiments replace these graphical widgets with multisensory inputs (such as light, heat, or pressure) that are semantically integrated with virtual and physical elements. This technology could help students build stronger mental associations of perceived facts and visualized concepts.

Mixed-reality applications depend on sensors to detect the changes caused by users or the environment. Although sensors are now an important and ubiquitous part of smartphones and tablets, the number and types of sensors supported by those devices are—and will continue to be—limited. Manufacturers are unlikely to include all the sensors on the wish list of science education. But imagine a future when you can buy "frames" or cases for your computers that will have customized sensors. Our Mixed-Reality Labs project is paving the road for that future.



ILLUSTRATIONS: JAN STREITBURGER

Figure 4. A mixed-reality atomic microscope.

Figure 5. Frame prototypes built around our Energy2D simulator. (a) A tablet thermal imager near a jar of hot water. (b) A tablet thermal imager near ice cubes. (c) An LCD display as a thermal imager showing the forced convection by a hairdryer. (d) A projector screen as a thermal imaging wall heated by two jars of hot water at the right edges of two areas representing materials of different thermal conductivities.

DEMOS

Watch videos of the Frame at: http://energy.concord.org/energy2d/e2dmr1.html

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A Drake's Tale:

Genetics Software Gets a Lift from Gaming

By Frieda Reichsman and Trudi Lord

Many of us learned about dominant and recessive genes in a humdrum high school biology class. Some of us may still recognize the terms and symbols twenty or thirty years later—are your eyes bb or Bb? But, as it turns out, a very small number of traits in humans and other animals, plants, amoeba … you name it … involve the dominance mechanism of a single gene with just two alleles. (An allele is a variation of a gene, like the B or b in the above example.) The more biologists discover about the mechanisms of inheritance, the fewer traits we can point to that involve only one gene or can be illustrated using a simple Punnett square. In fact, biologists are compiling information about our genes at an astounding rate. As the process of sequencing DNA improves, the science of biology is dramatically changing.

Modern biology showcases both the relatedness and complexity of genetic interactions across virtually all organisms. For example, you may be surprised to learn that humans and fruit flies share a core set of genes comprising 60% of their genomes, and further, that 90% of mouse and human genes are similar to each other. As for complexity, there are at least eight genes that control eye color, and by the way, two individuals with blue eyes *can* have a child with brown eyes. Today's students may be the first with access to enough information to break out of the Punnett square box and explore the many different ways in which genes act and interact. Students who use our Geniverse software and curriculum attain the keys to unlock the mysteries of the genetic code. As they discover polyallelic, multigenic, and sex-linked traits, they develop a broader and deeper knowledge of genetics.

Playing the game

Geniverse immerses students in a game-like environment where they are challenged to sort out the genetics of a mythical organism, the drake (Figure 1). Drakes are essentially a smaller version of a dragon, and are a model species that can help solve genetic mysteries in dragons, in much the same way as the mouse is a model species for human genetic disease. In fact, the Concord Consortium began the exploration of the genetics of dragons with the GenScope project led by Paul Horwitz in 1992, followed by BioLogica in 1998, and then GENIQUEST in 2007. With Geniverse, we are adding elements of gaming to this engaging approach to learning genetics.

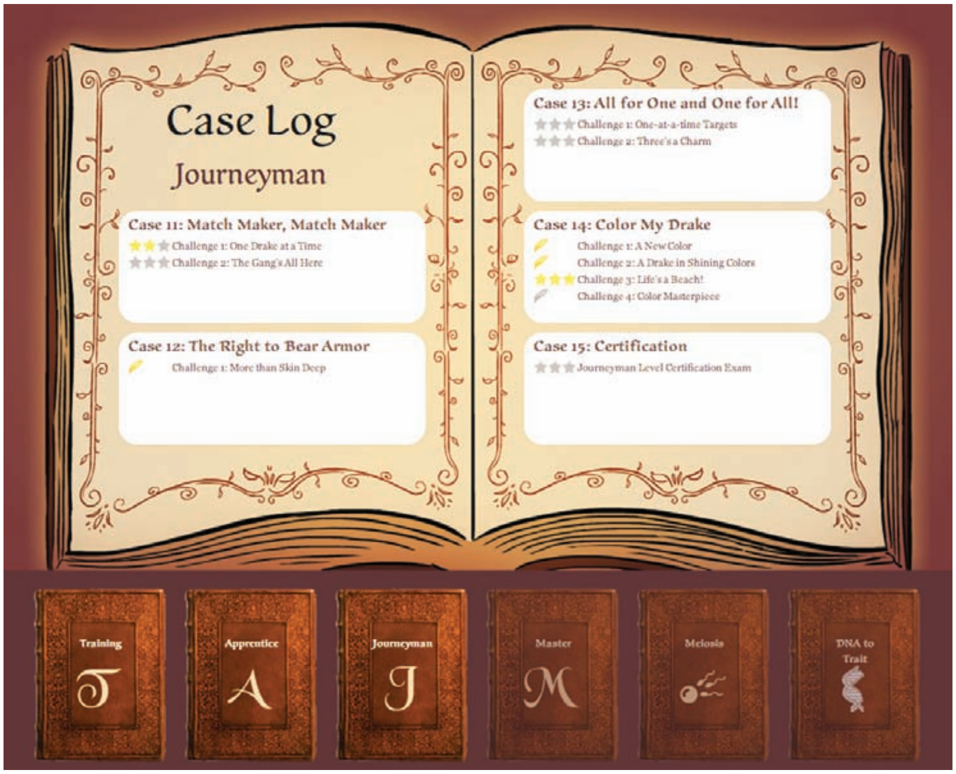
To become a Master breeder in the Drake Breeders Guild, students must learn the tricks of the trade to produce a variety of drakes, which they can do only by understanding the ways that drake genes interact and are inherited. Students explore the genetic landscape by doing experiments, looking at the data, drawing tentative conclusions, and then testing these conclusions with more experimentation. Thus, despite moving through a fantastical world, students are engaging in an authentic, experiment-driven approach to biology.

Figure 2. We would like to thank the anole lizard for donating its traits to the Geniverse project.

Figure 1. Determining the pattern of inheritance for color is challenging for students.

To progress through the Guild, each student solves a series of "cases," moving from training level to Apprentice, Journeyman, and ultimately Master. By the time students reach the game's finale, they have encountered genes that have more than two alleles, genes whose alleles are not fully dominant or recessive (known as incomplete dominance), genes that exhibit different patterns of inheritance in males and females (X-linked genes), and a trait that is influenced by three different genes.

Students learn that while drakes are mythical creatures, the drake genome comes from real-world animal models, including mouse, lizard (Figure 2), and stickleback fish. For example, tough exterior drake "armor" plates are encoded by a real gene involved in generating some typical properties of skin: in anole lizards, scales; in humans, hair



and sweat glands. There are four alleles of the armor gene. Their pairwise combinations can yield from zero to five plates. Armor illustrates that there are a variety of versions of a trait (phenotypes) that can be present in a population, even though any individual can only have two alleles (one from the mother and one from the father).

Both simple and complex traits are packed into the three pairs of drake chromosomes. Geniverse includes standard dominant/recessive traits (drake wings, forelimbs, and hindlimbs). Two trickier forms of dominance round out the collection of simpler traits: a rostral horn, which is a sex-linked trait, and horns on the top of the head, a recessive trait. The last one slays the common misconception that the presence of a trait is always the dominant condition.

As one of the final tests of their ability to uncover genetic mechanisms, students must fully explain the genetic control of the eight possible drake colors that result from the interaction of three genes. Students conduct breeding experiments both individually and in small groups (because not every student has access to drakes of every color), and publish their results in the *Journal of Drake Genetics*. Because this level of complexity goes beyond the usual learning goals for introductory biology, one might assume that student interest is lost or declines at this late stage of the game. But the opposite is true. One teacher described her students' excitement: "My kids are pumped about color! The more they are learning, the more they can't wait to figure out how this all works. It's a great program!"

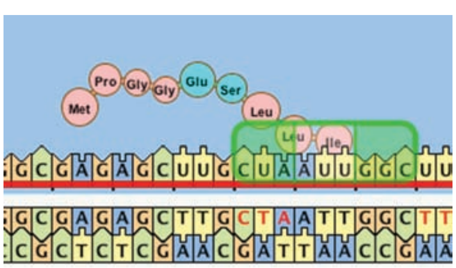


Figure 3. Students set the DNA sequence and watch as a protein is formed from amino acids.

DNA and genes

Current development of the Geniverse software involves illuminating the molecular path from genotype to phenotype, that is, from the DNA that makes up a gene to the trait it encodes. At strategic points in their fantastical journey, students use a simulation of meiosis—the process of formation of gametes (sperm and egg cells)—which enables them to follow the many possible reassortments of parental alleles into gametes. Some of the mechanisms of genetic inheritance and diversity are thus revealed. As students progress, they will delve deeper and deeper into the underlying genetic code, digging down to the DNA sequence level using a protein synthesis simulator (Figure 3) and a database of drake DNA sequences populated with real genes. Students will make small changes in a gene sequence and learn how such seemingly minute changes can either drastically affect an organism's physical appearance and metabolic functions or have no effect at all. When the Guild summons all drake breeders to help cure a genetic disease, students will use these tools to track down the cause of the disease.

Rather than memorizing terms and working through problems with selected data, students who play Geniverse learn to reason their way through a genetic challenge by crafting experiments that probe for information and answers, generating their own data sets and conclusions. The topics of inheritance, meiosis, and DNA-to-protein are frequently taught as separate units in traditional biology courses, making it difficult for students to connect their biology class to the real world. Geniverse helps teachers and students weave these topics into a meaningful tapestry, enabling students to better understand the big picture. And who doesn't like playing with dragons?

LINKS

Geniverse
http://concord.org/geniverse

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

Disruptive Science

Coming Soon to Your Phone and Tablet

By Robert Tinker

Jan is interacting with a computer model of molecules while simultaneously recording the temperature of a cup of water using a sensor. The model shows molecules condensed into a formless mass of atoms randomly slipping past one another at a speed that depends on the temperature of the real water. As Jan cools the water with dry ice, it turns into solid ice. At the same time—because the model is connected to the experiment through the sensor—the molecules in the model line up in regular arrays, still jiggling but locked into a crystalline structure.

Disrupting STEM Education

After a few moments of exploration with this model, students like Jan can understand important concepts: that liquids are disorganized masses of atoms, that solids are rigid arrays of atoms, and that temperature relates to the amount of random motion, even in liquids and solids. They can also observe that molecules attract one another and that the liquid-solid transition relates to the interplay of this attraction with the random motion.

This snapshot of a lesson illustrates how fundamental ideas of atomic motion, temperature, and the structures of liquids and solids can be taught without recourse to equations, specialized vocabulary, or appeal to authority. This is but one example of a disruptive force in science education—the use of highly interactive science-based computer models to change what content we teach, how we teach it, and when it is introduced. This sketch also shows how basic concepts of science and engineering can be conveyed to learners earlier and in a way that is so vivid and obvious that concepts learned this way would last a lifetime.

In light of this capacity, science educators need to rethink their educational strategies, the topics they teach, and the optimal sequence of topics. The current hodgepodge of facts, vocabulary, and trivia could be replaced by a sequence of fundamental ideas taught conceptually and then gradually augmented by mathematical descriptions.

All middle school students could develop a better command of key science concepts than most of today's college science students. They would understand concepts such as light-matter interactions, heat and temperature, biological and stellar evolution, the strength and structure of materials, and quantum mechanics. In high school, they could deepen their understanding through a semi-quantitative treatment of these concepts. They could, for instance, understand the central role of energy conservation, the relation between energy and temperature, the connections between potential energy and forces, chemical reactions, and protein function.

This kind of disruption of the standard science topics does not fit well into today's glaciated science curriculum. The encroachment of standards and high-stakes assessments has frozen the science curriculum in place. The standards are merely a reflection of current practice, and no more. Textbooks reflect these standards, tests measure their most superficial aspects, and their structure and content directly drive almost all curricular choices. Consequently, there is no role for quantum mechanics in middle school, almost no chance that the strength of materials will find its way into precollege teaching, and little likelihood that teachers will move away from familiar approaches and content.

What can we do? The Concord Consortium plans to appeal directly to kids in and out of school worldwide with free, playful, attractive learning activities based on models and sensors. Thanks to the emerging HTML5 standards, which make it possible to run our computational models online, these activities will be easily viewed on every tablet, phone, and computer that has a modern Web browser. These will be available to schools also, and a groundswell of demand from students and parents could influence schools.

Thanks to Google's generosity and the power of HTML5, we're bringing Molecular Workbench to Web browsers everywhere and paving the way for the "textbook of tomorrow."

The Google grant

A new grant from Google.org allows us to take the software and probeware that has made us famous and optimize it to work in a browser. The Google grant funds the conversion of our award-winning Molecular Workbench software to the next-generation version, which will work on any computer with a modern Web browser, and links it to probeware as well (see also "Under the Hood" on page 14).

Molecular Workbench (MW) is not a single model, but a tool for making hundreds of highly interactive models that involve atoms and molecules for important systems in all fields of science and engineering. Based on a decade of funding from the National Science Foundation, we have already used the Java version of MW to make hundreds of model-based learning activities.

The Google grant allows us to make accurate scientific models available in a browser, and also open the activity-creation process to anyone who can make a Web page. Teachers and curriculum developers will be able to add goals, background, instruction, help, challenges, and assessment items to create an effective learning tool.

At the model level, we will create a cataloged set of free plug-in models. Anyone will be able to take any model and drop it into their Web page. So, if a teacher already has a Web-based lesson about osmosis, she can add one of several MW models of osmosis from our model bank. And if the right model is not available, the teacher can make her own. This could be as simple as starting an existing model in a different state or creating a new Molecular Workbench model.

We will also create a set of Web versions of our best Java-based Molecular Workbench activities. Because these activities will be Web pages, they can be used directly or easily modified by teachers and authors to fit a broad variety of educational contexts.

We are particularly proud of the fact that the models and activities will be completely free and open for any use. Students, teachers, districts, and commercial publishers will be able to use and modify both the models and the model-based activities. We hope that millions of learners and educators worldwide will take advantage of this great resource. Please follow our progress and help us spread the word.

Watch our progress

Two new videos feature the original Molecular Workbench and document the beginning of the conversion of our software from a Java application to Web-based software. View them online at http://mw.concord.org/nextgen

Charles Xie, developer of the Classic Molecular Workbench, describes how "first principles," fundamental physical laws of nature coded into the Molecular Workbench engine, ensure scientific accuracy.

Stephen Bannasch describes the power of the modern Web browser to bring science to life and reduce barriers for using the next generation of Molecular Workbench in schools.

LINKS

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

Next-generation Molecular Workbench
http://mw.concord.org/nextgen/

Under the Hood:

Streaming Arduino Data to a Browser

By Sam Fentress and Scott Cytacki

Sam Fentress
(sfentress@concord.org)
is a Software Engineer.

Scott Cytacki
(scytacki@concord.org)
is a Senior Software Engineer.

What if you were reading a blog or working through an online lesson and you could just plug in your sensor and start taking data or interacting with models right in your own browser?

Here at the Concord Consortium, our interest in sensors goes back (way back!) to the early 1980s when Bob Tinker and Stephen Bannasch developed the earliest sensor prototypes and ignited an industry. Since then, we've been obsessed with making sensors that are easy to use in the classroom. Our newest interest is embedding them directly into rich online curricula. We've already done this using applets as an intermediary to read data from commercial USB sensors and display them in graphs in the browser.

When we think of hackable, fun, multi-probe sensors, though, we naturally think of Arduinos—we are open-source geeks after all.

In thinking of ways to display Arduino data in a browser with the minimum amount of fuss, we considered our existing applet technique, but applets don't work in all schools or on mobile devices. Instead we could simply use the common Ethernet Shields (or the new Arduino Ethernets) to send data directly to the browser.

With this idea in hand, it was quick work to hack a generic Arduino Server example to send back values of the analog pins and create a Web page that would rapidly poll the Arduino for data. A few lines of code later, we had a working example, usable with any Ethernet-capable Arduino on any browser (Figure 1).

With the Web version of this article, you can try it yourself!* You'll just need to upload a tiny sketch to your Arduino, plug it in via an Ethernet cable, and you'll be able to start plotting sensor data in the graph right here in the online article. Voila.

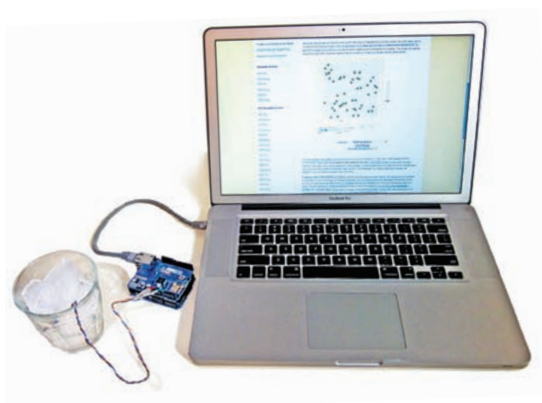


Figure 1. Sending temperature data to a model in the Web version of this article.

Since all the interesting code for dealing with data is in JavaScript, it's easy to modify and play with right in the browser.

We can't wait to come up with new ways to integrate this into online content. As a first demo of this, we connected the temperature data to the next generation of our Molecular Workbench software, so that you can see the atoms speed up as the temperature increases. Try it out yourself online.

JavaScript code

```
//connecting Arduino to a molecular model
window.onload = function() {
  var arduino = new ArduinoEthernetCom( {frequency: 2} );
  var atomicModel = $(‘iframe’)[0].contentWindow.model;

  arduino.addObserver(function(pinValues) {
   var pin0 = pinValues.A0,
    temp = (((pin0 * 5) / 1024) - 0.5) * 100; // TMP36 sensor calibration
    atomicModel.temperature(temp);
  });

  document.getElementById(‘runButton’).onclick = function() {
   arduino.start();
  }
}
```

LINKS

Online version of this article (to test your Arduino)
http://concord.org/publications/newsletter/2012-spring/under-the-hood

* You'll find technical details and links in the Web version, too.

Innovator Interview:
Frieda Reichsman

(freichsman@concord.org)

Q. What brought you to the Concord Consortium?

A. I was a postdoc at UMass Amherst, studying cell-to-cell communication in the fruit fly embryo. One day, across a crowded lab, I spotted my first 3D molecule on a computer screen and fell in love! After working with Eric Martz, an international leader in molecular visualizations and a terrific mentor, I created a company called Molecules in Motion to create visualizations for textbooks and online courses. Dan Damelin found my work, then I consulted on the Science of Atoms and Molecules project and joined the Concord Consortium in 2008.

Q. You have a Ph.D. in Molecular and Cellular Biology. How did you decide to study science?

A. I had always wanted to teach, but what made my day was team practice for varsity basketball, volleyball, and lacrosse. I became a department co-chair of Recreational Arts—a fancy name for gym class—at a K-12 school. My goal was to make class collaborative and fun. When I enrolled in an exercise science program at UMass Amherst, I discovered I needed coursework in chemistry, physiology, and math. I found myself taking all the courses I had feared in college. The first math course was taught by a veritable poet of math. I loved it. I had a similar experience with chemistry and statistics. I kept being drawn back to the molecular level where I could get answers to my questions about how stuff worked. I discovered that although science had seemed hard and incomprehensible, it actually made sense and is quite beautiful.

Q. What makes the Concord Consortium unique?

A. The Concord Consortium has the same appreciation for the beauty that becomes so apparent when you understand science at a deep level. And it's coupled with cool technology, which I love, not to mention incredibly creative, thoughtful people.

Q. Can you describe the projects you're currently working on?

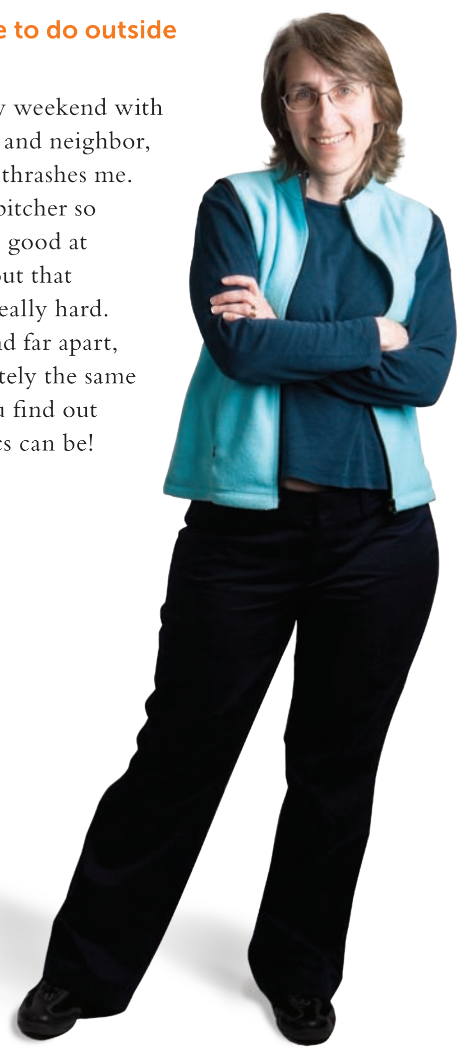
A. I had come across Paul Horwitz's dragons online, so it's amazing that I now get to lead two projects that focus on dragon genetics! The software brings to life both simple patterns of heredity and much more complicated ways traits are inherited. In GeniGames, we're investigating the effect on student motivation and affect when we incorporate various gaming aspects into Geniverse.

The Rhode Island Technology Enhanced Science project allows middle school and high school teachers to attend summer trainings to learn how to use our Investigations software, in which we can embed many different models, simulations, and sensors.

I'm also working on a new project with Joe Kracjik at Michigan State University and others at the University of Michigan. Joe's been a pioneer in teaching inquiry-based science and scientific argumentation. Our goal is to develop interdisciplinary activities that help students visualize and understand the electrostatic forces that shape their world, and to explore how their learning unfolds over time.

Q. What do you like to do outside of work?

A. I bowl nearly every weekend with my 75-year-old friend and neighbor, Nancy, who routinely thrashes me. I used to be a softball pitcher so I thought I'd be pretty good at bowling, but it turns out that candlepin bowling is really hard. The pins are skinny and far apart, and they're approximately the same mass as the ball, so you find out just how vexing physics can be!



The Concord Consortium

25 Love Lane, Concord, MA 01742

NEWS FROM THE CONCORD CONSORTIUM

InquirySpace

Thanks to a new grant from the National Science Foundation, we're working to overcome a major barrier to effective student inquiry in the classroom. Students often have difficulty finding patterns in a series of experiments performed under varying conditions.

InquirySpace will integrate three proven technologies—the versatile modeling environments of NetLogo and the Molecular Workbench, real-time data collection from probes and sensors, and the powerful visual data exploration capabilities of Fathom and TinkerPlots—into a coherent, Web-based environment enabling rich, collaborative scientific inquiry.

This package of tools should greatly expand the range of theory-based investigations that secondary students can undertake. And by integrating the software into a single environment that runs in a Web browser, we'll reach more students in diverse schools.

Understanding Sub-Microscopic Interactions

We are delighted to partner with Joe Kracjik at Michigan State University and others at the University of Michigan on a new project funded by the National Science Foundation. We will use Molecular Workbench and other models to support high school students in developing an integrated understanding of the forces and interactions between atoms and molecules. Understanding such interactions is critical for many STEM disciplines (chemical bonding in chemistry; electricity in physics; structure and function of molecules in biology; and mineral transport in earth science—just to name a few).

Our research focuses on tracking how students' ideas develop along a learning progression. We will explore which types of representations help students connect macroscopic and submicroscopic phenomena to the underlying scientific ideas that explain them.

Grant from Nellie Mae Education Foundation

The Nellie Mae Education Foundation has awarded the Concord Consortium an unrestricted grant for helping us build capacity and share our free, open source learning activities with an even wider audience. Special thanks to Concord Consortium board member Greg Gunn who facilitated this gift.

The Nellie Mae Education Foundation is working to reshape public education across New England to be more equitable and more effective—so every learner graduates from high school prepared for success. With new approaches expanding learning beyond the school calendar and walls, all learners can develop skills and knowledge for life in our changing world.

Software Developers and Cloud Engineer Needed

We're looking for talented Software Developers to help us create innovative student activities. Join our agile software development team and be part of a creative community of geeks and science, math, and engineering fanatics. We also need a Rails Cloud Engineer to maintain our presence in the cloud. Apply now. **http://concord.org/about/careers**

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