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The Concord Consortium

Perspective:

20 Years of Innovation: Looking Back and Looking Forward

By Chad Dorsey

The past 20 years at the Concord Consortium have seen educational technology history in the making. When we started out in September 1994, Yahoo! and Netscape were both only months old, and it would be nine months before Amazon.com would launch or Sergey Brin would first show Larry Page around the Stanford campus, a new friendship still years from forming Google. The Web may have been in its infancy, but in 1994 the Concord Consortium's founding staff had already been transforming STEM learning through technology for decades. And despite everything we've done over two decades, we're just getting started.

Since our earliest days, we have been igniting large-scale improvements in teaching and learning through technology. Our pioneering work has taken shape in five main strands.

Probes and Sensors. Over 30 years ago Bob Tinker traveled the country with a demonstration of homegrown probeware and an early computer. He opened people's eyes to how technology could bring new dimensions to hands-on science learning—spawning a new industry. Prototypes from our labs directly inspired the motion detectors and fast-response temperature sensors now common in science labs worldwide. Today, five major global companies produce probeware specifically designed for education, and a million students use educational probes and sensors every year.

Online Learning. Though it's hard to imagine, online learning was a novel and groundbreaking concept back in 1996. That year, two separate grants birthed a revolution—we began the first program for online professional development and we planted the seeds for a full online school. These would combine a few years later in the Virtual High School, the nation's first online high school. Teachers and students in 48 countries and 30 states are now part of VHS annually, and online education overall enriches the lives of millions of students each year.

Modeling and Simulation. We recognized early on that computational modeling and simulation make it possible to learn about the many STEM concepts that are too small or too large or that happen on timescales too long or too short to examine directly in the classroom. We created the first multilevel genetics model 20 years ago and built research-grade computational chemistry algorithms into our Molecular Workbench software a decade ago. Today, the dragons from our genetics simulations populate learning games and online learning environments, and Molecular Workbench has transformed learning through more than a million downloads in 150 countries. Our work in modeling and simulation has expanded to enable exploration and experimentation in practically all STEM subjects, including engineering and design.

Online Assessment. When we realized the power of modeling and simulation for learning, we understood that students' use of these tools could be equally powerful for understanding their learning. We began collecting and analyzing log files from models in 1999, remotely identifying patterns of student engagement and investigation as they experimented in our online environments. Our exploration of the potential of models and simulations for performance assessment presaged the fields of educational data mining and learning analytics that are rapidly broadening today.

Mobile Computing. Powerful computers are now ubiquitous in the form of smartphones. Twenty years ago, we saw the earliest signs of this wave as the first mobile computers came on the scene. We recognized the value these devices held for STEM education as we made the first connections between probeware and mobile devices in 1995. Today, smartphones have enough computing power to run our complex molecular simulations and have incorporated ever more probes and sensors as integrated parts of the package. We continue to explore new ways that these devices can help transform teaching and learning.

These strands have continued to bring about new ideas and innovations since our founding, and their promise continues unabated. At the same time, the rapid expansion of technology, devices and capabilities is opening up broad new possibilities for education, which we are actively exploring.

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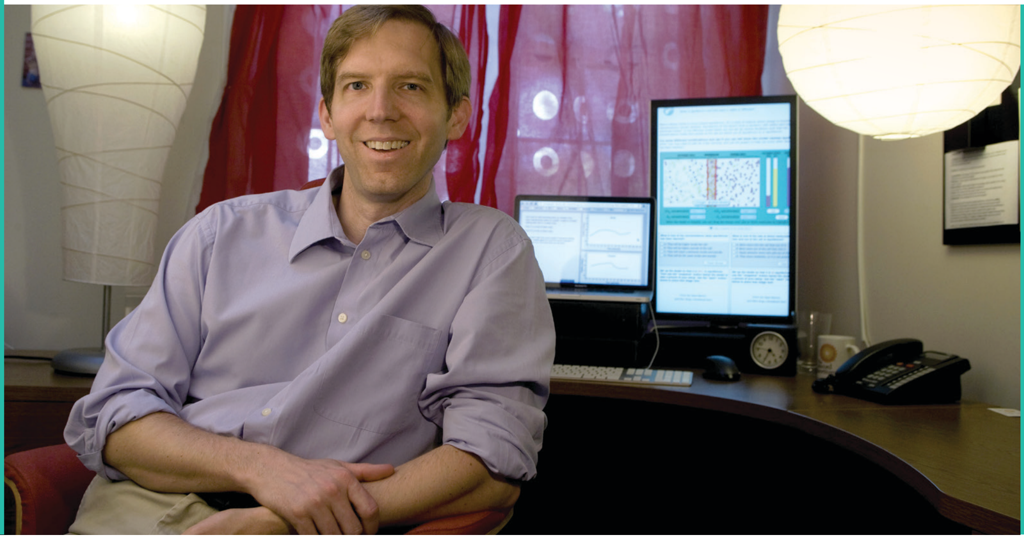

Collaboration. Collaboration is an essential component of the process of learning, as students work in groups to come to new understandings. It is also an essential skill for today's interdisciplinary workplace. While collaboration mediated via technology has long been an established area of research, the transformative possibilities technology enables are just becoming widely available. We're taking advantage of this as we help students build circuits together across time and space, and design collaborative museum exhibits and mobile games to better understand how these technologies can help students work together to improve understanding and develop vital skills.

Performance Assessment. The possibilities that open-ended modeling, simulation and design environments offer for assessing the practices of science and engineering are still largely untapped. Today, data we collect as students design with Energy3D software generates regular breakthroughs in understanding the process of engineering design. We're also using the power of our CODAP data exploration environment to provide deep insight into how students use and learn with data. Other projects are applying the same principles to circuit design, genetics learning, Earth science simulations and much more, employing automatic analysis of student writing, deep mining of student interaction patterns and intricate statistical modeling to forge new methods and understandings.

Feedback. As data from student use of models, simulations and other online environments become available for assessment, they naturally also become available for the purpose of feedback to improve student learning. Through recent and upcoming work, we're exploring how feedback can help improve and encourage student learning, scaffold students as they undertake science and engineering practices and provide useful data to teachers to better inform them and enhance their interaction with students.

Extending and Tracking Learning. As technology becomes widespread, it has finally become truly possible to engage in learning at any time and in any place. Our Learning Everywhere initiative, an international, multi-institution effort is aimed at expanding and tracking learning across diverse informal and formal settings. Museum visitors will be able to enhance their experience with an exhibit through complementary mobile games and virtual environments that pick up where the exhibit left off, permitting their engagement and learning to continue at home or in school or after school settings. Analytics on their use of materials will contribute to our research understanding of how to bridge formal and informal learning.

Mixing and Integrating. Finally, the evolution of technology places us in a position where we can start to look beyond individual components and begin exploring what happens when they become integrated. Our Mixed-Reality work is identifying how learning changes when probeware and simulations are wired to each other for a multisensory experience. Through InquirySpace, we're building platforms and examples that combine models, simulations and probeware with data exploration. And our new Building Models project extends this further by helping students build and examine models and their data to better understand system dynamics.

The Internet-based technological revolution is entering its second phase. Our new focus areas reflect this transition from initial technology development to a new stage of mixing and high-level integration. This will undoubtedly offer new opportunities for innovation as well as surprises. We plan to stay at the forefront of revolutionary digital learning for science, math and engineering, and we can't wait to see what the next 20 years brings.

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directs the ITSI project.

Innovative Technology in Science Inquiry

By Carolyn Staudt

The goal of the National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program is to enhance K-12 students' motivation and participation in STEM subjects and interest in STEM careers. Through our Innovative Technology in Science Inquiry project and its subsequent scale-up grant, both funded by ITEST, we have been working to get students excited about science, technology, engineering and math.

For 20 years, the Concord Consortium has been developing deeply digital tools and learning activities that capture the power of curiosity and create revolutionary new approaches to science, math and engineering education. Our Innovative Technology in Science Inquiry (ITSI) project has assembled many of these activities into an online platform for K-12 teachers to use and customize for their students and to monitor student progress. We have reached over 275 teachers in our participating research sites in Alaska, Iowa, Kansas and Virginia. An additional 420 teachers from across the U.S. and the globe have registered through the ITSI portal. Altogether, over 25,000 students have engaged in scientific inquiry through these deeply digital activities in Earth science, life science, physical science, engineering and math.

Supporting inquiry in the classroom

Inquiry-oriented instruction encourages students to engage in hands-on learning, explore questions about topics they are interested in, collect their own data and explain their results by using the 5E Instructional Model*. One middle school teacher summed up the ITSI activities nicely: "The technology lets the students own the learning. The activities and questions aren't coming from me, but from the framework of the investigation and my students' minds."

The Innovative Technology in Science Inquiry portal includes over 300 free activities with models, simulations, probes, sensors, embedded assessments and ideas for extension activities. Each activity also introduces a specific STEM career by highlighting qualifications, coursework and anticipated starting salary level (Figure 1).

Figure 1. Each activity includes related STEM career information.

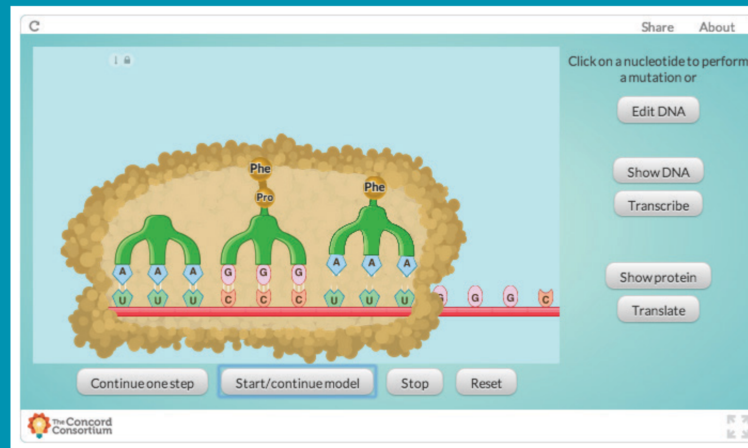

Figure 2. Students make mutations in a model of DNA and observe what happens to the resulting protein.

- **Models and simulations.** Computational models and simulations allow students to see and manipulate the unobservable. They can conduct experiments on otherwise unreachable worlds, peer into the details of chemical reactions, compress centuries and millennia into seconds to unlock evolution's gradual mysteries or manipulate the unseeable world of genes and DNA (Figure 2).

- **Probeware.** Probes and sensors such as motion detectors and temperature sensors extend students' senses and permit them to collect real-world data and see multiple representations of their surroundings unfold in real time (Figure 3). Additionally, digital microscopes allow the youngest students to see and measure the world up close.

Student learning

We measured student content understanding using pre- and post-tests that were customized to the content in particular units (e.g., habitat or gas laws). Tests were multiple choice ranging in length from three to six items. Paired t-tests were conducted to measure increases in students' understanding between the pre- and post-tests.

Students significantly improved in their understanding of the standards-based content. Overall, students increased their estimated score by an average of 0.39 standard deviations (SD). Middle school students had the highest gain at 0.43 SD while elementary students increased 0.34 SD and high school students 0.33 SD. (The average effect size for most educational interventions is typically 0.2-0.3 SD.)

Professional learning community

The Concord Consortium has pioneered online teaching and learning. In 1996, we created the Virtual High School (VHS) and its professional development courses to help teachers design and facilitate VHS courses. ITSI continues this long history and brings new innovations to blended professional learning. Teachers complete over 70 hours of professional development over two summers and the intervening academic year. During the first summer teachers meet for a five-day face-to-face workshop. They complete two short online courses during the fall and spring, and meet again in person for a two-day workshop the following summer.

As a signature part of the professional development, teachers customize existing activities by adding more models or probes; changing questions and reading level; aligning to local or state standards; and more. Teachers also create multimedia video presentations of their classrooms using ITSI activities, and share these VideoPapers with one another to reflect on best practices to enhance inquiry-oriented instructional practices.

Online discussions crossed state boundaries and grade levels due to a climate of trust within the community that increased teachers' willingness to share their classrooms openly. Ultimately, this sense of collaboration and shared goals grew into a vibrant professional learning community on the Schoology social networking site, which supports ongoing discussions about ITSI activities and exploration of teacher-customized activities from exemplars.

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Figure 3. Students predict the temperature when water at different temperatures is mixed and use probes to test their predictions.

Customization: An ESL teacher's story

From lack of background knowledge and vocabulary to lack of laboratory skills, English Language Learners (ELL) face significant challenges in the science classroom. In Iowa's Ottumwa High School, students come from various backgrounds, including Bosnian, Latino, Hispanic, Marshallese and Arabic. While they speak some English, most are not proficient in the language. As an additional challenge, many teachers have not been trained in making science content accessible to ELL students.

Sharon Padget received her English as a Second Language (ESL) endorsement in 2005 and was designated the science teacher for all ELL students at Ottumwa. ITSI was the solution to help students learn to use technology effectively while also learning science concepts. And thanks to the ease of customizing activities, Sharon was able to make the concepts accessible to her biology and physical science students regardless of their ability to read, speak, write or listen to English. The annual science fair gives students an opportunity to practice speaking and serves as a summative assessment. Sharon has seen student improvement in speaking, reading and writing English, as well as in comprehending science concepts. ITSI is now an integral component of the ESL science curriculum.

Customization: Local Yupik activities change the cultural context

The only way to reach the 22 Alaskan villages of the Kukskokwin School District is by airplane, boat or snowmobile. Although many villages are too small to have their own high school science teacher, high-speed Internet has provided the opportunity for these schools to share a science teacher by video teleconferencing. Andrea Pokrzywinski meets with her science classes live each day through a videoconference. She uses the ITSI portal to coordinate hands-on activities at remote sites, providing instructions and modeling the use of ITSI by sharing her desktop over video. Students log into the portal and complete a modeling activity or a data collection lab at their site on laptops. The ITSI portal reports allow her to see the students' work and provide them with feedback on their analysis and observations.

Students in Western Alaska grow up with a subsistence lifestyle and speak Yupik as their first language. ITSI allows Andrea to customize activities, using pictures that draw from local experiences. For example, one lesson asks students to measure the temperature increase of concrete, but there is no concrete in an Alaskan village. So Andrea substituted wooden platforms. She was also able to swap images in the lab to include common surfaces students could measure in their schoolyards. She has found that customized activities enhance student learning.

Scaling up

Our goal is to scale up the ITSI program to reach more teachers and students. Over 30 master teachers have been trained and certified to offer the ITSI professional development program nationwide after our National Science Foundation funding has ended. They were selected from previous professional development participants and have shown a high degree of engagement, quality and quantity of participation. Master teachers like Andrea will continue to offer the Innovative Technology in Science Inquiry professional development program and support the professional learning community as a way to share activities.

* Bybee, R., Taylor, J. A., Gardner, A., Van Scotter, P., Carlson, J., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness.* Colorado Springs, CO: BSCS.

LINKS

Innovative Technology in Science Inquiry
http://concord.org/itsi


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Monday's Lesson:
Exploring Atomic Structure

By Dan Damelin

The Interactions project is developing a new interdisciplinary semester-long course that lays the foundation for deeper understanding in physics, chemistry and biology. This ninth grade course, developed in partnership with the CREATE for STEM Institute at Michigan State University and the University of Michigan, is inspired by the Framework for K-12 Science Education and the NGSS, which encourage students to learn science by engaging in science practices.

The curriculum is based on the idea that much of what we see around us is the result of interactions between atoms and molecules. Many phenomena across multiple fields can be explained using this framework. At the atomic level, the primary interaction is based on electrostatic fields and forces. To understand why, students first need to understand the composition of atoms.

Atomic theory is one of the most challenging topics to address in the constructivist classroom. Our Next-Generation Molecular Workbench interactives are designed to help. They reveal the emergent behavior of atoms and molecules and give students the opportunity to use data from observations to reason about atoms and their underlying structure.

Try these interactives

The "Thomson Experiment" interactive (Figure 1) simulates one of J. J. Thomson's experiments with cathode rays that led to the discovery of the first subatomic particle—the electron.

Apply a high voltage across electrodes made of various metals to produce "cathode rays." The hole in one of the electrodes allows cathode rays to pass through the plate. Adjust the charge on the plates and select different metal electrodes. Did you find that the particles always behave the same way when deflected by the charged plates, no matter which metal was used in the electrode?

Now, compare the behavior of the negatively charged "cathode ray particles" with that of atoms in the "Electron Properties" interactive (Figure 2). Cathode ray particles have much less mass than even hydrogen, the lowest mass atom. Combined with the fact that all metals seemed to produce the same particles, Thomson concluded that cathode ray particles must be part of all atoms. The first subatomic particle to be discovered was called the electron.

Once negative electrons were found, there had to be a positive component of the atom as well. Otherwise, everything would be negatively charged and repel everything else. One possible model, commonly called the Plum Pudding model, postulated that the positive charge was dispersed throughout the atom with the negative electrons floating around in it.

The "Rutherford" interactive (Figure 3) simulates Ernest Rutherford's experiment to test this model. He shot alpha particles—very high-energy, high-speed, positively charged helium atoms—at a thin piece of gold foil. If the positive part of atoms was dispersed, he reasoned, the electric field generated by those atoms would not be strong enough to deflect the alpha particles. However, some particles were deflected and some bounced back from the foil. Only a concentrated charge could generate a strong enough field to do this, thus Rutherford concluded that atoms have a tiny, dense, positively charged nucleus.

These interactives are part of the student investigation: "How can we learn about something we can't see?" Go to: http://authoring.concord.org/sequences/108

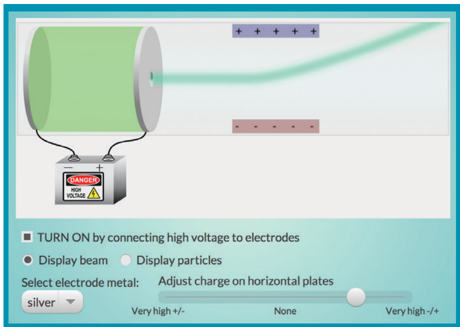

Figure 1. Thomson Experiment: concord.org/stem-resources/crookes-electrodes

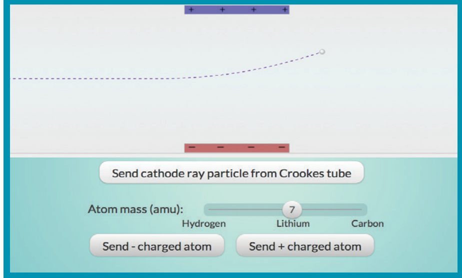

Figure 2. Electron Properties: concord.org/stem-resources/electron-properties

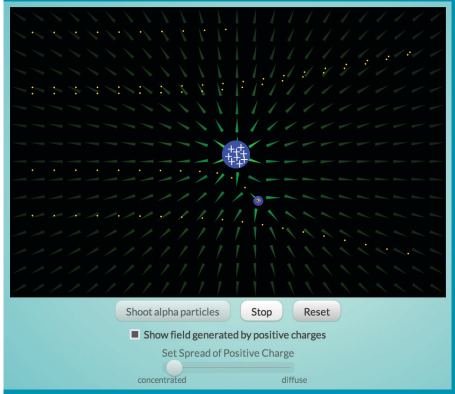

Figure 3. Rutherford Experiment: concord.org/stem-resources/rutherford

LINKS

Interactions
http://concord.org/interactions

Ocean Research

Using Telepresence

By Amy Pallant and Cynthia McIntyre

Oceanographic research is undergoing a transformation—from a distance. While scientists still board a ship and navigate to locations around the globe to collect data, current research often relies on remotely operated vehicles (ROVs) to take scientists and explorers to the ocean floor virtually. What if ocean research went one step further? What if engineers operated the ROVs from the vessel but scientists conducted observations, analyzed data and made research decisions from shore? Thanks to a new project, scientists can test this scenario, and students can also conduct remote research.

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Transforming Remotely Conducted Research through Ethnography, Education and Rapidly Evolving Technologies (TREET) is a collaboration between the Concord Consortium, Woods Hole Oceanographic Institution, the Harvard Kennedy School and the Ocean Exploration Trust to promote interdisciplinary research and education. Funded by the National Science Foundation, TREET combines expertise in ocean science, ethnography, education and technology to investigate how "telepresence" can transform STEM research and education, bringing research experiences to scientists and students who are unable to participate in data-gathering cruises because of the time commitment, expense, logistics or ship space, which is at a premium.

Telepresence refers to a suite of technologies that allows individuals to feel they are present at a location other than their own. Dr. Robert Ballard pioneered the first uses of oceanographic telepresence in the 1990s. Early experiments were often unidirectional—from ship to shore. Now, scientists and students can do more than simply wait at a distant location for data to arrive; they can actively direct what's happening on the ship using voice and text commands.

Early career scientists and undergraduate students

Early career scientists familiar with the use of ROVs (robots tethered to a support ship by a cable carrying power and transmitting data) are working with a group of undergraduate students to conduct multidisciplinary (geochemical, geophysical and biological) investigations of the undersea phenomena at the Kick'em Jenny seamount, the adjacent cold seeps and the Barbados mud volcanoes. Eight students from the University of Idaho, Harvard University and Michigan State University began preparing for this research cruise with an online seminar series during the spring 2014 semester, with weekly topics led by participating scientists regarding the research sites and the tools onboard the ship and the ROV.

The Inner Space Center at the University of Rhode Island. *(Photo courtesy of Ocean Exploration Trust)*

Remotely operated vehicles (ROVs), including Argus (left) and Hercules (right) on the deck of E/V Nautilus. *(Photo courtesy of Katy Croff Bell / Ocean Exploration Trust)*

Students then developed their own research plans exploring changes over time in the topography, variations in biota in the extreme deep sea habitat, the correlation of currents to sediment and gas distribution from the seeps. Their research designs include the use of photomosaics, bathymetric data, water chemistry data, and video and photo images. During the fall 2014 cruise, students were able to participate in ship watches and analyze data that was streamed to shore via satellite—all without going to sea. Indeed, one of the goals of the TREET project is to bring the sea to the students.

At the beginning of the cruise, which traveled to the research sites in the Caribbean from September 25 to October 8, the group worked together at the Inner Space Center (ISC) at the University of Rhode Island to establish work practices and camaraderie comparable to that experienced at sea. The ISC is rigged with multiple large monitors and audiovisual equipment that the students and scientists used to communicate with the engineers aboard the E/V *Nautilus* to direct the ROV *Hercules*. From thousands of miles away, students watched the ROV dives, directing the measurements and sample collection, all in real time. Some of the students and professors then moved to a smaller command center at Woods Hole Oceanographic Institution to test a potential approach using multiple, distributed command centers. Following the cruise, students will continue their analysis and prepare a report of their results for presentation to the team and at professional conferences.

Ethnographic and educational research

TREET wants to understand what it takes to transform future research using remote human-robotic interactions. The ability to prepare for a remotely run deep sea cruise, including educating and training undergraduate students to fully engage in their own research is new. How can these mechanisms be leveraged to advance research experiences for scientists and students? What is it like to conduct research from remote locations? Are these students and scientists as invested in all phases of planning and conducting research, including the challenges of directing sample collection from shore? Ultimately our goal is to lay the groundwork for more people to explore sites from remote locations.

In addition to the ocean science research by scientists and students, TREET is undertaking ethnographic and educational research studies designed to explore transformative ways to conduct research remotely and to investigate whether ocean-based research could be considered a plausible focus for future undergraduate research experiences. Such research is known to benefit students in several ways: they gain an understanding of the research process and how scientists work; they develop data analysis skills and the ability to interpret results; and they are better at integrating theory and practice. Research in ocean science presents a unique challenge for students. Typically, ocean science research consists of two components: (1) the shipboard component for data and sample collection and (2) the land-based component for data and sample processing and analysis. Opportunities for undergraduate students to participate in scientific research by stepping onto a ship are extraordinarily limited. TREET is challenging this limitation. Can we excite and motivate students to consider ocean science and exploration while transforming the need to be aboard a research vessel?

The goals of our ethnographic research are to ascertain and represent the work flow of remote telepresence, including differences from ship-based science data collection; to provide insights into the cultural processes shaping domain-specific human-machine relationships that inform technological solutions from artificial intelligence and robotics; to help early career ocean scientists, some of whom are also mentoring undergraduates, elucidate effective approaches to using remote telepresence in their research; and to support the development of educational seminars for early career scientists and their students as they use remote telepresence to conduct their ocean research.

The future of ocean research points to smaller ships and fewer onboard opportunities for researchers—from undergraduate students to scientists. Can providing remote and open access to data to more land-bound scientists and students be an alternative? Thanks to telepresence, we may soon find out.

The Exploration Vessel (E/V) Nautilus at sea. *(Photo courtesy of Ocean Exploration Trust)*

Cold seeps on the slope of the Kick'em Jenny underwater volcano host an exotic ecosystem. *(Photo courtesy of Ocean Exploration Trust and Sea Research Foundation)*

LINKS

TREET
http://concord.org/treet

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Using Social Networking to Learn Genetics

By Paul Horwitz

The rise of social networking is perhaps the most spectacular—and to many the most unexpected—phenomenon of the 21st century. It continues to have dramatic political and cultural effects around the globe and its impact on commerce is unprecedented. Seventy-seven percent of youth aged 12 to 17 in the United States are a member of at least one social network[1].

All this raises questions for educators. How can social networking best be adapted to create effective learning environments? How broad an impact is this new kind of learning environment likely to have? Can students learn important concepts and skills simply by interacting in a shared virtual environment? How can we assess what they have learned? What are the barriers to using this novel learning modality in schools, and how can they be overcome?

The GeniVille project, funded by the National Science Foundation, was aimed at obtaining tentative answers to questions like these. We integrated our popular genetics software—Geniverse—into a social networking environment called Whyville, which is intended to give tweens aged 8 to 15 opportunities to learn STEM concepts through collaboration and exploration. The result of this union is called Dragons in Whyville.

The Dragons game

To play the game, users enter the Dragon Castle in Whyville. They visit lairs (where wild dragons roam) to solve breeding challenges or go to labs to delve into dragon traits and inheritance. Sixteen challenges present progressively more complex patterns of inheritance, such as incomplete dominance, sex-linkage and polyallelic traits. Each lair challenge focuses on a specific concept and has one or more labs associated with it. Twenty-one labs provide highly scaffolded activities that highlight genotypic to phenotypic relationships, the processes of meiosis and fertilization and the selection of parents based on the need for certain alleles in a pool of offspring.

For the lair challenges, players must produce a dragon with specific traits that will enable it to fetch treasure. For instance, to find a dragon that can fly to the top of a palm tree and grab the golden coconut, players must enter a lair where dragons have the alleles needed to produce wings and arms. Using a special tool, they can "scope" a dragon or an egg to reveal its chromosomes and alleles. This is helpful in deciding, for instance, whether or not two dragons should be bred or if a particular egg should be hatched. While the labs are single-player activities, players can work alone or collaborate in the lairs to breed offspring for the required traits.

Dragons in Whyville and in school

We released the game to the general Whyville population in September 2013 with 10 challenges and 13 labs, plus a pre-test and post-test. In November 2013, we added a second set of six challenges and eight labs that involved more complex forms of inheritance. Finally, in April 2014, we introduced a fast-paced, multi-player or single-player "egg game," designed to encourage students to think about the genotypes of eggs before hatching them.

Since we also wanted to gauge the utility of Dragons in a school environment, in June 2014 we invited four teachers at a local, suburban middle school to participate. After completing their standard genetics unit, 455 eighth grade biology students used Dragons during class time for three consecutive days.

What did we learn?

In the year following the introduction of Dragons, over 140,000 individuals logged into Whyville on a minimum of 10 separate occasions. Of these, 8,460 interacted with the game, about half completing only the pre-test (presumably to receive the Whyville currency of "clams" for doing so). Only 356 players took both the pre- and post-tests.

Of the 455 students who participated in Dragons as part of the school implementation, 311 took both the pre-test and the post-test. (Some students did not complete the minimum of six activities required to unlock the post-test, which accounts for the discrepancy.)

The pre- and post-tests were identical and consisted of 11 questions. Five were designed to characterize the players' attitudes toward genetics and to provide a measure of "self-efficacy" by eliciting their opinions regarding their knowledge of genetics. Students were asked to rate statements on a five-point Likert scale with responses ranging from "Strongly agree," which we scored as 5 to "Strongly disagree," scored as 1. In both the "Whyville at large" population and the school population we found no significant differences between the pre- and the post-test on these questions *except for two of them*.

The only statements on which players changed their answers between the pre-test

How true is this statement?	pre-test mean score	post-test mean score	p-value of difference (two-tailed paired t-test, n = 667)
1. I'm interested in learning about genetics.	3.63	3.63	.50
2. I like genetics.	3.53	3.59	.056
3. I think genetics is useful.	4.17	4.17	.79
4. I am good at genetics.	3.50	3.64	.0026
5. I know more about genetics than my friends.	3.08	3.19	.0006

Table 1. Comparison of answers to questions on pre- and post-test (all data combined).

Figure 1. Dragons must have the right traits to sneak by the troll.

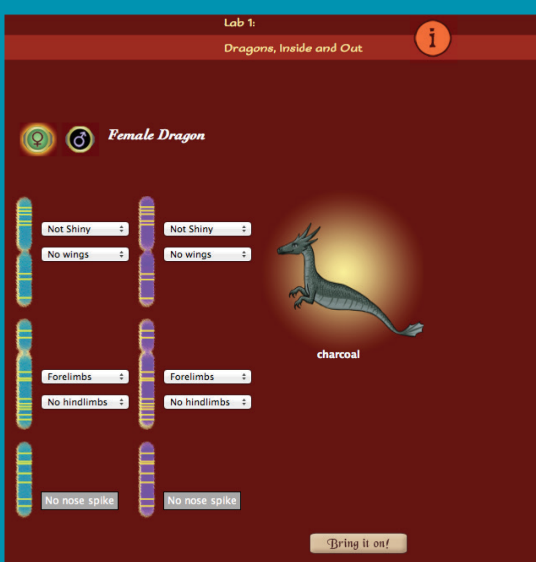

Figure 2. In the first lab students learn the relationship between genotype and phenotype by changing a dragon's alleles.

and the post-test to a statistically significant degree are those that measure self-efficacy, and in both cases students' confidence in their knowledge of genetics increased. Although the differences in the scores are small, they are highly significant for the pooled (Whyville plus school) data, as shown in Table 1[2].

In addition to the pre- and post-test data, we also collected a vast amount of performance data, consisting of time-stamped logs of every action taken by every dragon game player. We can determine, for instance, how many lairs each player entered, how many labs they completed and how many challenges they succeeded at. We can even compute how often they used the scoping tool. Since scoping shows the chromosomes and alleles of dragons and eggs, use of this tool is an indication that the player is thinking genotypically and not concentrating solely on the macroscopic appearance of organisms (phenotypic thinking).

Analysis of the school data demonstrates that students shifted from scoping dragons to scoping eggs over the course of their three-day interaction with Dragons. We interpret this unanticipated finding as an indication that students are becoming increasingly conscious of the importance of genes as determinants of a dragon's traits—a sign that they are learning to think like geneticists. We have not yet analyzed the data from the general Whyville population to see whether they followed a similar learning path.

Our experience in the classroom uncovered a number of barriers that must be faced before the game can be used effectively in that environment. The great value of Whyville—the fact that it is such a rich and engaging environment—means that it offers many distractions to students, making it difficult to keep them focused on the task at hand, thus exacerbating a classroom management problem familiar to every teacher. Technological fixes will have to be in place before the bridge can be crossed between social networking and formal education.

Though our data analysis is not yet complete, we are pleased to note that many kids seem to have enjoyed Dragons, and that their interaction with it has had a positive effect on their self-reported confidence in their knowledge of genetics. It may also have increased their ability to reason like geneticists, though confirmation of this will have to await further analysis.

[1] http://www.pewinternet.org/fact-sheets/teens-fact-sheet/
[2] Both questions show significant gains for the school data alone, but only Question 5 shows significant gains for the Whyville data alone.

LINKS

GeniVille
http://concord.org/geniville

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Developing Assessments
for the NGSS

By Dan Damelin

The Next Generation Science Standards (NGSS) consist of performance expectations that combine three dimensions of learning: science and engineering practices, disciplinary core ideas, and crosscutting concepts. According to the NGSS these three dimensions should be integrated in curricula and assessments. Since previous standards separated content and practices such as inquiry, the new standards represent a significant shift and present a challenge for teachers and the wider assessment community, including publishers and organizations that create standardized tests. New types of assessments are needed.

The Concord Consortium in partnership with Michigan State University, the University of Illinois and SRI is researching and documenting a process for creating NGSS assessments and developing a set of exemplar assessments, targeting middle school physical science classrooms. These exemplars can be used for formative feedback to help teachers understand the progress their students are making in achieving specific performance expectations (PEs).

What implications do the new science standards have for assessment?

- The notion of an assessment "item" needs to be expanded to encompass more complex tasks.
- Assessments should measure all three dimensions of learning specified by the NGSS.
- Teachers should have multiple assessment avenues for gauging student progress toward broad performance expectations.

Typical assessment items involve relatively simple student responses—checking a box on a multiple-choice answer or providing a short written answer to an open-response question. Because NGSS performance expectations by definition include a "performance" aspect to them, assessment items should measure both content knowledge *and* performance. Take, for example, the following NGSS performance expectation:

MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

The disciplinary core ideas in physical science are the relationships between energy, temperature and atomic-level particles. Several crosscutting concepts are addressed here, but the most relevant is "Energy and Matter: Flows, cycles, and conservation." The science practice is "plan an investigation." Thus, an assessment for this NGSS standard must be able to measure an action.

We developed two simulations that are incorporated into a set of assessment items related to this performance expectation (Figures 1 and 2). A single "item" could include a collection of question prompts and student interactions with a simulation. Using these simulations students can plan and carry out investigations. By collecting their annotations of snapshots of the simulations in various states, we can measure their performance. We are also working on logging student interactions with the simulations themselves, and will be exploring how to use this log data to provide further feedback on student strategies used to plan and carry out the investigation.

Another NGSS practice is "developing and using models." The use of existing models, as exemplified by the simulations mentioned, falls naturally into this category, but to measure the development of students' conceptual models we rely on our drawing tool to facilitate their expression. Simulations can provide a way for students to test their models and collect evidence in support of models they have developed. In addition to simulations, we include tabular results of experiments and video clips that demonstrate phenomena, all of which can be used as a basis for evidence in model development.

Developing learning performances

Many of the NGSS performance expectations broadly describe how students will demonstrate knowledge of a disciplinary core idea. The disciplinary core idea cited in a PE often can be linked with one or more additional PEs, so our first step is to identify related PEs and form clusters that we will unpack into an even finer grained set of PEs we call learning performances (LPs) (Figure 3).

Because the NGSS science practices are interconnected, we write learning performances to target a variety of practices that together support the development of the skill or skills cited in the overarching performance expectation cluster. In developing individual LPs we further unpack these, defining characteristic task features that are elements of all related assessment items, as well as variable task features that can change from item to item. We then develop a number of assessment items for each LP, run them through internal and expert reviews, conduct alignment studies to determine how well these align to the original PEs and pilot the items in various classrooms.

After analyzing data from our first pilot, we will develop statistical models to characterize the evidence produced by students and determine how this feedback can be used by teachers in the classroom. We will also use this analysis in the development process to revise and refine our items, scoring rubrics, delivery mechanisms and reporting features.

Our goal is to provide both a detailed description of how to develop NGSS assessment items and a set of example assessments for use in many classroom settings. We hope to provide guidance for curriculum developers who will be embedding formative measures in their materials and to prompt institutions that develop summative assessments to consider new ways of thinking about assessment item design for performance-based standards.

We clustered two energy-related performance expectations:

- **MS-PS1-4.** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
- **MS-PS3-4.** Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

We developed five learning performances specific to Grade 7 for the energy-related PEs above:

Students should be able to …

- **LP 1:** Evaluate the accuracy of an experimental design built to investigate how types of matter influence the magnitude of temperature change of a given sample when adding or removing thermal energy.
- **LP 2:** Plan and carry out an investigation to explore how mass affects the change in temperature of a sample when adding or removing thermal energy.
- **LP 3:** Plan and carry out an investigation to explore the relationship between energy transfer and temperature changes.
- **LP 4:** Analyze and interpret data that describes the relationship between how mass and types of matter affect the change in temperature of a sample when adding or removing thermal energy.
- **LP 5:** Construct an explanation that links energy transferred, the type of matter, the mass and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

Figure 3. A performance expectation cluster based on related disciplinary core ideas and corresponding learning performances that draw on multiple interrelated practices.

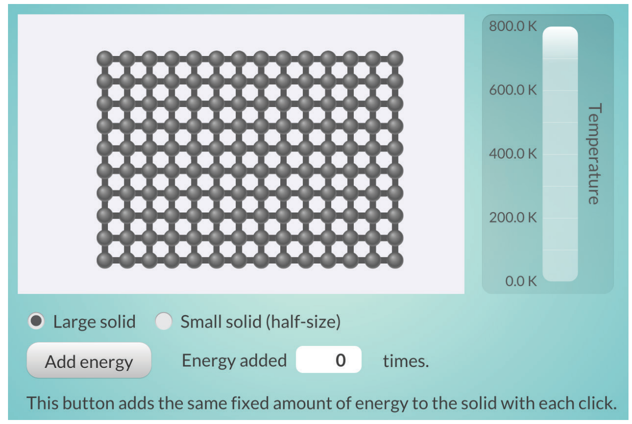

Figure 1. Students use the "Effect of Mass on Temperature Change" simulation to plan an experiment that shows the relationship between mass and temperature when an equal amount of thermal energy is added. The assessment "item" consists of several steps. Students first describe their plan and then run the simulation to implement their idea. They take snapshots of the simulation in various states and use the drawing/annotation tool to explain how the snapshots serve as evidence to demonstrate the quality of their original plan in generating data.

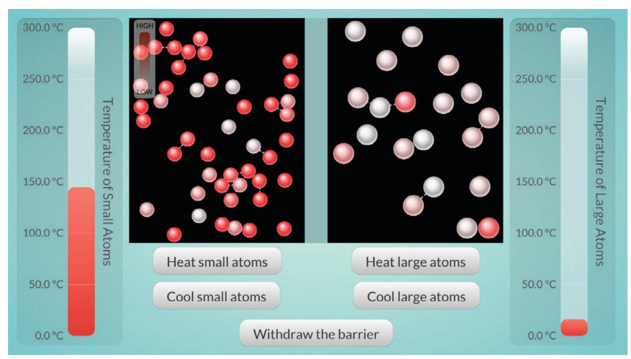

Figure 2. In the "Exploring Thermal Equilibrium" simulation students can explore the transfer of kinetic energy through atomic-level collisions. Students can use this simulation as a tool for planning an investigation, as evidence for the explanatory power of a student model or as a data source for forming a scientific argument.

LINKS

Next-Generation Assessments
http://concord.org/ngss-assessments

Under the Hood:

Rapid Gameplay Prototyping

By Sam Fentress and Richard Klancer

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Paper prototyping is great for designing games. But what do you do when you want to try out a multiplayer game idea too fast paced for a human game master? Recently we used HTML5 + Firebase and Google spreadsheets to develop play-testable mockups of the UI and mechanics of a multiplayer game—all in a few short days.

Our new Learning Everywhere initiative is developing exhibits and mobile learning experiences that provide trackable, co-ordinated learning opportunities around the topic of energy, including renewable energy, energy efficiency and the use of natural resources. The goal is to create activities and exhibits that adapt flexibly to different learning settings—from school to home, after school and museum—for extended learning opportunities. We are currently prototyping and testing a variety of hands-on and virtual activities.

One quick way to try out different ideas is to develop paper prototypes, so we created a variety of games using cards and tokens. We settled on the idea of a fast-paced cooperative game in which communication is key—players talk to each other to send and receive electrical power from their cities. (We were inspired by *Spaceteam*.) Each player's power demand as well as their wind, solar and fossil fuel-based power supplies fluctuate over the course of the game.

With real players we could test our ideas about how to make sharing energy not only challenging but fun. However, we quickly reached the limits of paper prototyping. When we had to manually change everybody's paper "screen" to simulate game play, it was impossible to tell when we got the pace and flow right. We needed computer-based mockups that could be modified quickly and easily—and support multiple players.

One approach was to mock up the user experience in a mobile webapp deployed to GitHub Pages, a simple (and free) static hosting service. Each player's client pushed data to the others by using Firebase, a real-time database service. This meant we could create a multiplayer game in HTML5 without needing to write and deploy a server, allowing us to focus on the game experience alone.

A complementary approach exploited Google spreadsheets' inherent multi-user capabilities to model the game mechanic. Players were each given access to one sheet, which was connected to master sheets and the other players' sheets by formulas. These accounted for the supply, demand and power sharing between players at any moment in game time. To make the game automatically advance at a steady clip we wrote a small Google Apps Script, which runs on Google servers and is able to read and write to spreadsheet cells.

Teachers in a KidWind Senators workshop playtested this version, and although they could only type numbers into a grid, we could tell from their laughter that they enjoyed the challenge of keeping their cities from blacking out. We knew we were on the right track, and have merged the spreadsheet game mechanic into the web-based game. We're now working with FableVision to add some fun artwork. An alpha version should be available soon.

We started by paper prototyping and quickly moved to a web-based energy transfer game.

LINKS

Learning Everywhere
http://concord.org/learning-everywhere

Innovator Interview:

Bill Finzer

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Q. Tell us about your background.

A. I wrote my first computer program for statistics education in 1979. It was a game called "Guess My Bag" for the 8K Commodore PET. You drew colored balls from three bags and tried to figure out which bag you were drawing from. I've been working on stuff like that ever since.

Q. Why not just have students use professional data analysis packages for learning?

A. The first time I showed Fathom to a group of data analysis practitioners I dragged a point on a scatter plot, and someone aghast asked, "Are you really changing the data?" Software designed for learning gives the learner opportunities to change things and see the effect. Fathom has this dynamic manipulation capability at its core and became one of the most highly respected computer learning environments for teaching statistics and math from a data-driven point of view.

Q. You've collaborated with legendary math educator Marilyn Burns. Tell us about that.

A. Marilyn and I became friends with our shared interest in teacher professional development. She told me repeatedly "you have to be in the classroom" in order to understand what's possible with teachers and students. Though I agree, I'm never able to do it—partly because of temperament and because the programming I love to do takes so much time.

Q. You started out as a programmer?

A. Not at all. My training was in physics. Out of grad school I worked at the Lawrence Hall of Science, leading teacher workshops. After a year, I knew I needed more teaching experience, so I helped start an alternative school, where I encountered my limits and learned I needed good people to mentor me. I was lucky to find such people at San Francisco State University and Xerox PARC.

Q. Say more about Xerox PARC.

A. I worked in Alan Kay's Smalltalk group. It was fantastic to work with the interdisciplinary team—from artists to computer scientists—he assembled. We were using, and helping to develop, one of the first GUIs! I was there the day Steve Jobs toured, but of course I had no idea where that was going to go.

Q. Describe CODAP [Common Online Data Analysis Platform].

A. Cliff Konold and I realized we could embed games in Fathom and TinkerPlots and have the games be the sources of data. This led to the Data Games project where kids analyze their game data to figure out how to improve their score. CODAP was based on the realization that in order for students to work with data, curriculum developers need easy access to data analysis tools and an environment that can be embedded in their materials.

Q. What is the new role of data in education?

A. People encounter data in all aspects of their lives. Data science is the union of ideas, skills and practices that come from math, from a discipline and from computational thinking. Data scientists help turn data into useful stuff, whether for business, science, government or education. Data science education will help students become data scientists.

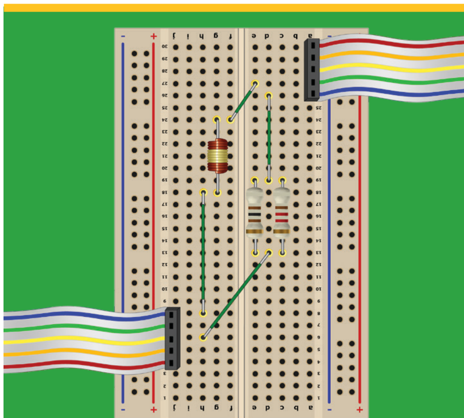
Q. What's exciting about the Concord Consortium and Concord West?

A. There are so many wonderful people who are passionate about learning and about technology as a tool for learning. It's an exciting, stimulating environment! Putting together a team in the new Concord West is rewarding, and with today's high-bandwidth channels we feel very connected to Concord East.

The Concord Consortium

25 Love Lane, Concord, MA 01742

The Concord Consortium is happy to announce the following **new grants** from the National Science Foundation.



The breadboards of teammates are connected.

Teaching Teamwork

Collaboration and communication are critically important skills in the 21st century STEM workforce, yet schools and colleges continue to reward students primarily for their individual test-taking ability, in part because assigning grades to separate team members is so difficult. In a new project with Tidewater Community College, CORD and ETS, we will teach electronics students how to work effectively in teams, both face-to-face and remotely. Students modify and measure realistic simulations of electronic components and circuit boards that are linked together over the Internet. They work on their own piece of the circuit and can see their teammates' work. We will monitor students' actions and communications, analyze the data and report on the performance of each individual student as well as that of the team as a whole.

Supporting Secondary Students in Building External Models

Although modeling is one of eight NGSS science and engineering practices, students rarely construct models in secondary science classrooms. Our goal is to create a systems modeling tool and instructional materials to support students in grades 6-12 in building and using models to explain and predict phenomena in a range of disciplines. The new modeling tool—plus data from Next-Generation Molecular Workbench simulations, sensor-based data from experiments and more—will be embedded in our Common Online Data Analysis Platform (CODAP), allowing students to manipulate and analyze multiple sources of data. As students compare the output of their own model with other data sources, they will revise their computational models and refine their conceptual models.

Enhancing Scientific Argumentation through Automated Feedback

With ETS and the University of California, Santa Cruz, we are developing automated scoring models for scientific argumentation for secondary school Earth science content on climate change and fresh water availability. An interactive score reporting system will provide customized individual feedback to students and class-level snapshots to teachers. Professional development resources will help teachers use automated diagnostics to improve instruction and assessment practices. We will investigate when and how feedback can be effective in promoting learning.

Water SCIENCE

In our new Water SCIENCE project, middle school students from Arizona, Pennsylvania and Massachusetts will engage in project-based learning about water-related STEM topics and careers. Students will use the cameras built into tablet computers with an innovative mobile app to perform water quality analyses and aggregate results on a data-sharing platform. They will also design and conduct classroom engineering projects to improve water quality.

Teaching Environmental Sustainability

We are developing a new curriculum for high school environmental and geoscience classes around a GIS-based web application to analyze real data on environmental impacts regarding land use and water quantity and quality. We will update the Stroud Water Research Center's Model My Watershed app with new environmental datasets and integrate new low-cost sensors to allow students to collect and upload local data. Students from urban and rural schools in five states across the U.S. will engage in a systems approach to problem solving through hands-on activities.

Embodied Explanatory Expressions

How does body movement support student reasoning about critical science concepts that have unseen structures and unobservable mechanisms? A new project seeks to identify types of body motion that enhance causal explanations for observable phenomena. With researchers at the University of Illinois at Urbana-Champaign we explore whether Embodied Explanatory Expressions (EEEs) can be integrated into the control structures of online simulations utilizing motion sensing input devices. The goal is to identify EEEs that support scientific reasoning in three areas of science with unseen mechanisms and structures: molecular interactions, heat transfer and Earth systems.

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