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vol.18 • no.1 • Spring 2014

The Concord Consortium

Perspective:

Forging the Future: a Three-fold Path

By Chad Dorsey

We are at one of the most exciting—and critical—junctures in the history of educational technology. Rapidly developing technology platforms and devices open doorways for new applications and bring futuristic scenarios into daily reality. Huge venture capital investments and intense interest from education communities fuel an atmosphere of high expectation and excitement. Lessons from decades of learning research amplify the potential for new ideas to make a true difference. We increasingly feel ourselves standing on the brink of something very big.

However, we've been at this brink before, only to see the moment's potential pass unrealized. In order to ensure that we seize this opportunity for meaningful impact, we must cultivate a number of possibilities simultaneously.

Building the future through directed development

Educational technology (so-called "cyberlearning") has become widely supported by federal dollars, especially for STEM learning. This funding—primarily from the National Science Foundation (NSF) and the Department of Education—provides the lion's share of support for the work that we at the Concord Consortium and most of our colleagues do regularly. It also represents the nation's most vital source of new ideas in educational technology. Yet as important as this funding is, it leaves some very wide gaps.

Funding from these agencies is focused on one area: basic and applied research, which is designed to build knowledge and to inform policy and practice. These paired agendas, essential as they are, move on a deliberate timeline that typically measures its progress in units of decades. Yet this work plays against today's societal backdrop of radical technological transformation, where changes and new ideas—in devices, startups and even in classrooms—occur on practically a monthly basis. Other sectors recognize the need to address working solutions rapidly, and most invest between 2% and 10% of their overall expenditures on novel R&D. In contrast, education invests barely 0.2%. Further, almost none of this proportionally minuscule investment goes toward directed development to solve specific problems and needs.

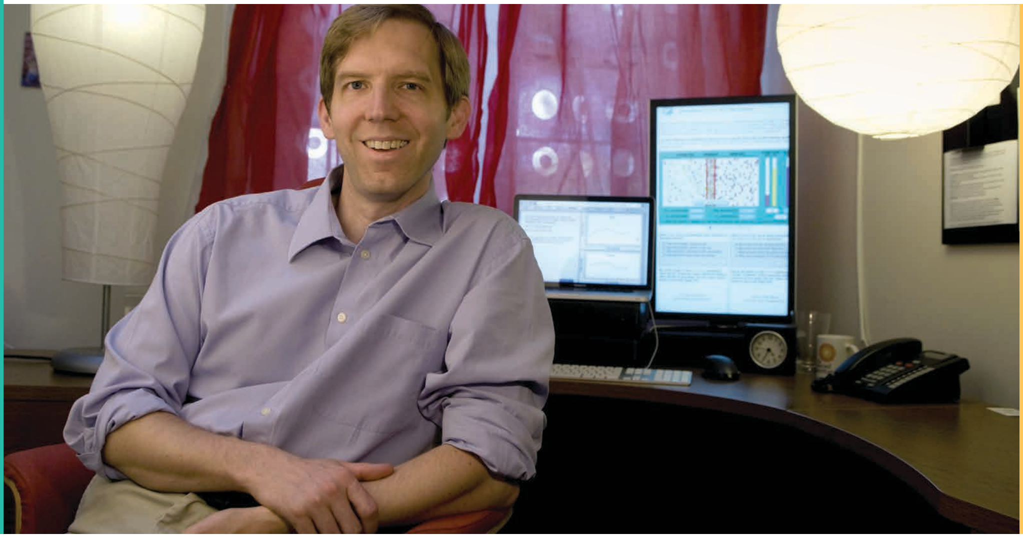
The President's Council of Advisors on Science and Technology highlighted the need to support such innovative development years ago. The administration has responded, repeatedly suggesting a solution as a tangible budget request: the creation of an independent agency for *directed development*. This agency, named ARPA-Ed, would fund game-changing technology innovation. It's an important idea with plenty of precedent: both the Defense Advanced Research Projects Agency (DARPA) and its cousin ARPA-E, founded in 2009 to support energy-related projects, have led to innovations as world-changing as the Internet itself. As a similar organization for education, operating with flexibility and independence, ARPA-Ed could create a wealth of new solutions, from core technologies to new curricula and models for teaching and learning. As a first step toward making the most of our current moment, this organization must be fully funded and supported now.

Supporting deeply digital learning

A core element of future innovation in the optimal use of educational technology is the development of high-quality examples for teaching and learning. We must use technology not simply for technology's sake, nor in shallow applications that result in glorified PDFs or surface-level interactivity and social engagement. Instead, in our second step toward tomorrow, we must develop examples that demonstrate how technology can make a difference for deep learning across time, in ways that leverage all we know about effective teaching and learning. Technology-based approaches must be *deeply digital*, employing rich models and simulations for in-depth student inquiry, facilitating data collection and investigation with probes and sensors, building in new forms of collaboration, providing feedback on student learning, enabling flexible approaches for a variety of teaching styles and much more.

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

By moving boldly to accelerate directed development, create high-quality curricular examples and bridge the results of research to widespread impact, we can turn this moment of opportunity into lasting change.



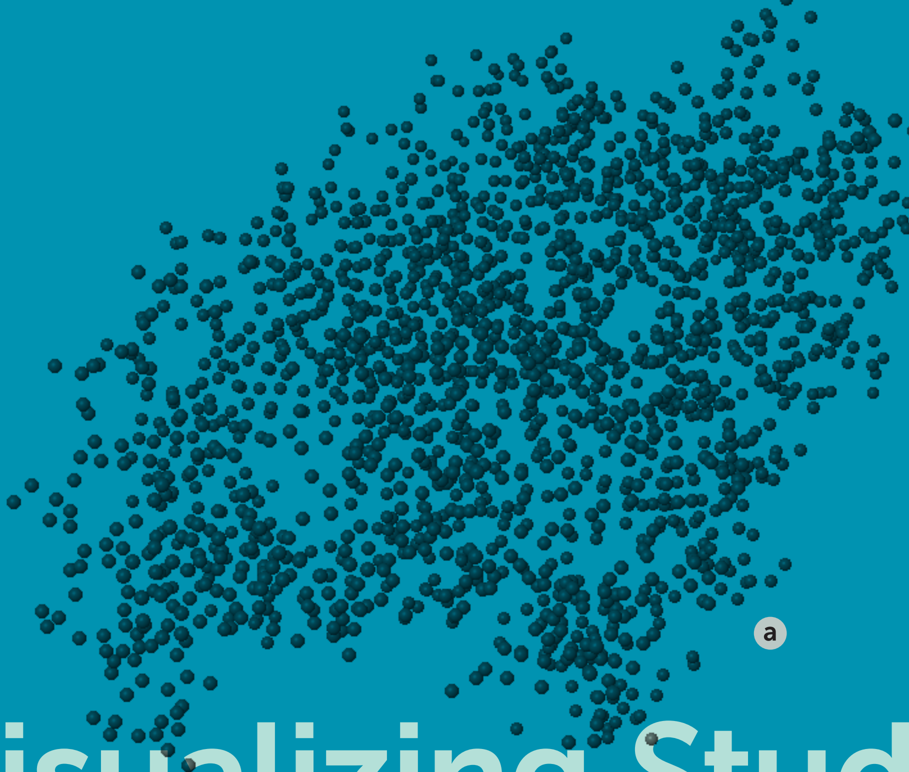
Currently, federally funded projects supply the best representations of this type of learning. However, federal funding mechanisms limit these resources to individual projects, resulting in a set of unrelated products that lack coherence and continuity. Though private companies are building more complete solutions, it is not at all clear that their development can support true innovation or sufficiently integrate research-based understanding of teaching and learning. Instead, we need to see how deeply digital learning looks in extended situations across time and topics. This will require solutions that resemble courses rather than activities, either developed as complete projects or coherently assembled from a series of independent modules. Until this is fully supported, innovation in STEM teaching and learning will continue to suffer. Identifying the means to fund these solutions must become a priority.

Sustaining research-based work by bridging the gap to industry

We are building many great innovations for teaching and learning every year. However, these examples are supported only up through their initial development. Federal dollars such as those from NSF programs do not provide funding for the sustainability of these resources, nor do they include provisions or requirements for ensuring that sustainability is factored into the creation of these projects. As a result, promising innovations are lost every year when their creators do not have the time or receive the support needed to keep them funded. From the other side, private industry groups, such as publishers with wide distribution channels, frequently have no way to discover that these resources exist, let alone benefit from the research base that created them. As a result, publishers and new media distributors go on to develop independent programs that may be less effective than research-based solutions, while the promise of millions of research dollars every year sits unrealized.

It should come as no surprise that no mechanism exists to support the translation of resources from federally supported research and development to industry use. Without one, these two fields simply continue, out of habit and necessity, within their own independent spheres. But if we are to generate the true impact our taxpayer dollars and research efforts demand, this pattern needs to change. As the third of our three action steps, we need to create an intermediary that can correct this situation. A new organization, overlapping both spheres, would work with the research community early in their projects' life cycles to help identify goals that foster sustainability or large-scale use. It would also work with industry partners and distribution channels to identify industry needs and time frames and match them with research innovations that show promise. Such an organization would likely need an infusion of seed money to become established, but would quickly transition to become self-sustaining through service-based fees charged to the two sectors it would bridge.

The course is set, and now we must act. All of these three steps are needed. Any one of them in itself would bring important benefits. But their power is especially evident in combination—taken together at this critical juncture, they could launch us on a new trajectory entirely. By moving boldly to accelerate directed development, create high-quality curricular examples and bridge the results of research to widespread impact, we can turn this moment of opportunity into lasting change and set the nation on an upward track for generations to come.




Charles Xie (qxie@concord.org) is a senior scientist who works at the intersection between computational science and learning sciences.

Visualizing Student Learning

By Charles Xie

More than fifteen years ago, I worked as a postdoc in computational biophysics. Our dream was to uncover the secrets of life through numerical simulations based on solving foundational equations in physics. We believed that, if we could simulate the motion of every atom and every wavefunction of a protein or DNA molecule, we could eventually figure out the tricks of biology.

Computation is not the only bottleneck in attaining this goal. In fact, through over more than half a century of research on molecular modeling consecrated by three Nobel Prizes (the latest in 2013), a wealth of computer code has been developed. Meanwhile, many state-of-the-art supercomputers have been available for life scientists.

The end of a computer run is just the beginning of a daunting task: post-processing vast quantities of calculated data. Although scientists can build more powerful computers and write more efficient code, nothing can replace human intelligence for searching spatial, temporal and energetic patterns buried in data. Ultimately, it is through analyzing these patterns that we come to an understanding of the science they represent.

Human analysts rely on visualizations to find patterns and trends in an ocean of data. For example, the atomic coordinate data of a biomolecular system appear to be random dots when plotted (Figure 1a). But when they are connected using a code known to scientists, some structures emerge (Figure 1b). Many readers can recognize that this is a compound of a DNA and a protein molecule. Observing how this system evolves over time under different conditions, we can hope to identify the intermolecular forces between the protein and the DNA that are responsible for phenomena such as DNA translation and replication.

Fifteen years later, I am facing another challenge of a similar magnitude. Only this time, the data are generated not by thousands of atoms in simulations but by thousands of students in classrooms. This article explains why data visualization has, once again, become an indispensable part of my research.

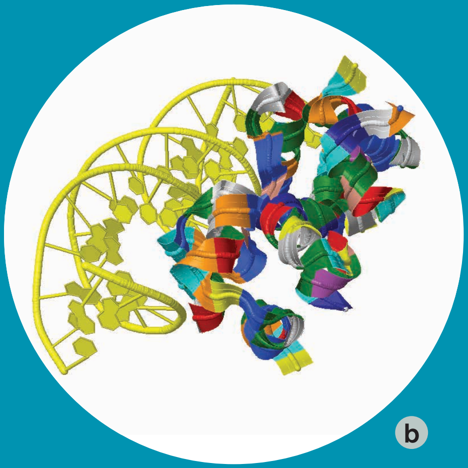


Figure 1. Visualizations help scientists see patterns in data. (a) Raw data of atomic coordinates offer no clue about the structure of this biomolecular system. (b) Structures emerge from the data after the dots are connected using some visualization schemes.

Mind recorders

One of the most important goals in the learning sciences is to understand how students learn. Traditionally, learning is assessed through tests. But tests may not be the best way to measure and monitor the development of sophisticated skills such as scientific inquiry and engineering design.

Just as atoms cannot be seen by the naked eye, the workings of the human mind are also invisible. Researchers may carefully observe students, ask them questions and assess their learning from their actions and responses, but that approach is too laborious to be scalable. To cover *all* students, a fundamentally different method is needed.

To "see" atoms, scientists invented techniques such as X-ray crystallography, which produces informative diffraction waves. What, then, is the equivalent of X-ray diffraction for reading students' minds while they are learning?

The answer lies in digital inquiry and design tools that are by now ubiquitous. These interactive tools are commonly viewed as "technology interventions" introduced to enhance learning. But with some additional work, they can also be turned into "mind recorders" (see Figure 2 for an example) because students' interactions with them invariably leave digital traces that reflect how a student reacts to problems, instruction or other stimuli with actions. Such a mind recorder can work at a high frequency that enables every mouse, key, touch or other sensor signal and every change of an artifact property to be logged. Recording these data points is thus analogous to recording the motion of every atom in a biophysics simulation.

Because these data points also represent units of interaction or events that cannot be divided further, we often refer to them as "atoms." From the data streams of these atoms, a high-resolution picture of learning can be reconstructed for in-depth analysis. In analogy to the post-processing step in computer simulation, we have a data analysis job to do.

Data clouds

At first glance, the raw data may appear to be simply points scattered in the learning space, resembling the atomic coordinate data of macromolecules. Figure 3 shows such "data clouds" of two students' actions with our Energy3D software as they were solving a solar urban design challenge. They chose the shapes, orientations and layouts of a cluster of buildings in a metropolitan area with the goal of achieving optimal solar performance in different seasons for the whole community. How can we extract any clue of learning from these seemingly random data?

Compared to answering multiple-choice questions, creative inquiry and design processes are often highly open-ended, especially when the problem space consists of many degrees of freedom. Thus, it may not be feasible to enumerate, *a priori*, all possible pathways for solving a specific problem. Given a tremendous number of possibilities, researchers can hardly find two identical instances in student data, posing a great difficulty to developing statistical modeling techniques for reliably predicting students' learning trajectories. Without such a "compass," it is all too easy to get lost in a cloud of data. This difficulty is similar to hard problems in natural science. For instance, the research on protein folding is also confronted by an astronomical number of evolutionary pathways in a gigantic phase space. As such, insights garnered from those fields may guide educational research as well.

Not long ago, educational researchers began to seek help from machine learning. *Educational data mining* and *learning analytics* are the two closely related research branches that have recently emerged as a result. However, few researchers in those fields face the challenge of analyzing the complex learning dynamics in inquiry and design activities that is ruled by the tyranny of high dimensionality described above. This puts our research in a frontier of process analytics that has rarely been

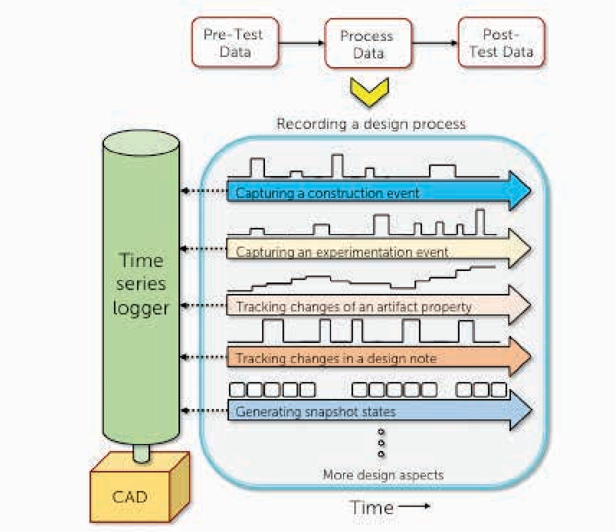


Figure 2. Educational researchers use pre/post-tests extensively to measure differences in the initial and final states of students in a study. In many cases, the in-between states are largely in a "black box." Opening this black box allows researchers to look into what happens in every student's learning process and explain the pre/post-test differences. The technology for recording and analyzing the process data is the key. This illustration shows how a computer-aided design (CAD) tool such as our Energy3D (http://energy.concord.org/energy3d) can be used as a "mind recorder" for capturing and tracking many aspects and fabrics of an engineering design process.

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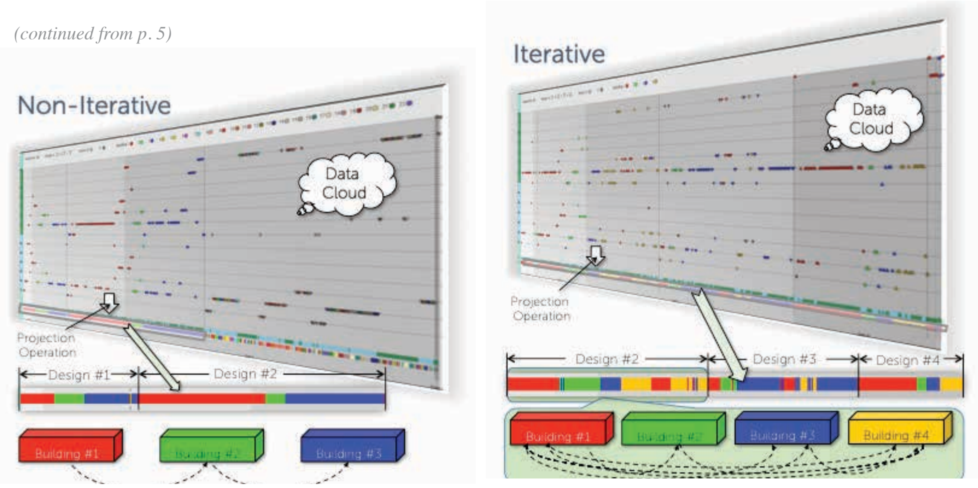


Figure 3. Non-iterative and iterative patterns are "textures" in the data clouds of students' design actions, which can be detected through a dimensionality-reduction operation that projects the attributes of artifact index of the data points to the axis of time. The degree of iteration is highly suggestive of systematic design.

explored. It was through working in this vastly unknown area that we realized the pivotal importance of *computational thinking* in educational research. This change of mindset has enabled us to frame problems in learning sciences with concepts in computational science, especially with those in signal processing, time series analysis, graph theory and pattern recognition. Across the board, visualizations are playing a central role in our research and are giving rise to new developments in learning infographics.

Holographic visualizations

As in any other scientific discipline, visualizations are invaluable tools in educational research. To see structures in data, researchers must first define the indicators for measuring student performance, proving a hypothesis or capturing a cognitive response. Using the molecular structure metaphor, these indicators constitute the "chemical bonds" that connect the dots or "secondary structures" that track learning progresses. Figure 3 illustrates how such an indicator can be used to visualize iterative patterns in data clouds. Infographics like this allow evidence of iteration, a cognitive process key to engineering design, to be visualized and evaluated.

In addition to the projection onto the axis of time for showing temporal patterns, high-dimensional data clouds can also be projected onto a Cartesian coordinate system to reveal spatial patterns or a digraph model of a concept map to reveal learning paths. Figure 4 provides an example of visualizing design optimization using a 2D plot of artifact movement. This capacity of viewing a single data cloud from different perspectives to sift different information is the result of the "holographic" nature of the data, a profound feature that allows researchers to simplify problems through *dimensionality reduction* and create reliable assessments through *triangulation*.

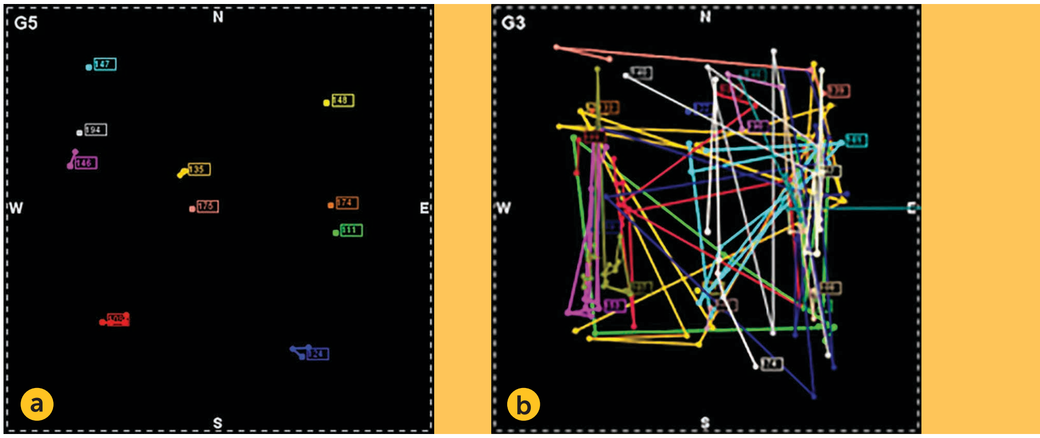


Figure 4. The states of student artifacts can be used as an indicator of design optimization. In the solar urban design project, students must constantly move buildings in order to look for optimal locations. The absence of building movement (a) signals premature design fixation, a problem commonly observed in engineering design. Dense trajectory lines (b), on the other hand, suggest intensive search for solutions.

Learning sciences as data science

The *Common Guidelines for Education Research and Development*, published in 2013 by the Institute of Education Sciences and the National Science Foundation, begins, "At its core, scientific inquiry is the same in all fields. Scientific research, whether in education, physics, anthropology, molecular biology, or economics, is a continual process of rigorous reasoning supported by a dynamic interplay among methods, theories, and findings. It builds understanding in the form of models or theories that can be tested."

Indeed, there has never been a better time to highlight the scientific nature of educational research. Today, the digital footprints left behind by millions of students who use interactive tools such as sensors, simulations or mixed-reality apps are being aggregated into a gold mine of research data. Similar to what happened in molecular biology decades ago, this flux of data is driving learning sciences into the domain of data science; one may hope that this will eventually allow useful learning informatics to be engineered.

But this vision will not be realized without extensive interdisciplinary research. The discovery of knowledge from large sets of learner data is a computational problem that can only be solved by uniting educational research and computational science.

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

Monday's Lesson:

Modeling an Agricultural System

By Amy Pallant

Everything is connected. That's the single most important lesson about human interactions with Earth systems. Unfortunately, it's not that simple to teach.

Traditionally, we learn and teach about systems using tools that focus on the parts of a system and the interactions among them. But we cannot see all of the parts—or all of the processes—so we have to imagine their interconnections. To explore the system as a whole requires a different approach because the whole typically does not act merely as a sum of its parts.

Left photo courtesy of *USDA Natural Resources Conservation Service.*

The High-Adventure Science project, funded by the National Science Foundation, is developing Earth systems models that promote different facets of system thinking, including time delays, stocks and flows, and non-linear causality. Our goal is to help students and teachers alike explore phenomena that result from changes to a system and correlate this to the causal mechanisms. Earth systems visualizations and their dynamic outputs can help students see how systems respond to human actions in both expected and unexpected ways.

Modeling land use through system dynamics challenges

The goal of this lesson is to help students experience the behavior of the whole system and think about the reasons for this behavior. Using Earth systems models students explore the interrelationships of erosion and soil depletion using system dynamics. They also explore the relationship between climate, farming practices and plant types on food production.

Time delay, which refers to a lag between the initiation of an action and the effect, is a central feature for understanding the dynamic behaviors of systems over time.

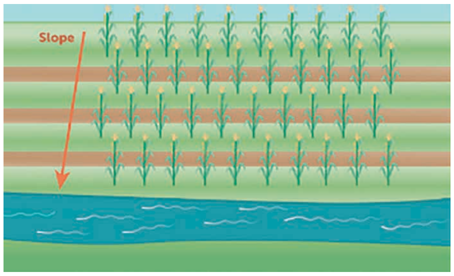
Explore time delay related to soil quality in the following model: http://activities.concord.org/activities/354 (page 1)

Set "Management Plan" for wheat (conservative tillage) in Zone 1 and wheat (intensive tillage) in Zone 2, and then run the model. You can see soil quality changing (represented by the color of the soil). How do these two different land use plans affect the soil quality? How does this experiment show that changes take time to emerge in a system?

Non-linear causality (or non-linearity) refers to cause-effect chains and loops; causes are not necessarily proportional to their effects. In the land use system, the relationships between precipitation, plant type, terrain and tillage each exhibit cause-effect chains and loops. Sometimes seemingly small changes have devastating effects on the system, and sometimes, they are undetectable.

Explore these relationships with this version of the model: http://activities.concord.org/activities/354 (page 2)

Set "Initial Landscape" to plain for each zone and "Climate" to "Use Precipitation-Slider Values." Choose different plants in the two zones under "Management Plan." Run the model and adjust the precipitation amounts. How does precipitation relate to plant growth? Erosion? Experiment with different terrain, climate and plant types.



Students consider how plowing and planting affects erosion on hilly terrain.

So far, we have explored two system dynamics concepts. You can also use these models to explore other system dynamics concepts including stocks and flow, emergence and uncertainty.

Can we feed the growing population?

In our "Can we feed the growing population?" module (http://activities.concord.org/sequences/50) students use these and other models to explore the availability of resources in an agricultural system in the context of food production. They explore how soil quality, nutrients, organic content, water and farming practices impact soil erosion and soil quality. They also consider how extended droughts or floods reverberate throughout the system.

Our goal is to maximize the potential of systems models for developing system dynamics thinking. We are optimistic that this approach has great potential.

LINKS

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

From Museum to After School:

Tracking Learning Across Boundaries

By Chad Dorsey

Museums provide distinctive STEM learning opportunities in our everyday lives, and make STEM learning possible in a way unmatched by other facets of society. Museum experiences elicit emotional and sensory responses that resonate for years, provide access to phenomena on inspirational scales and enable personalized experiences with a freedom unequalled by many other learning settings. They also offer learning opportunities to a huge diversity of learners and social groups who visit from a wide range of settings including homes, after school programs and schools.

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

Learning experiences today transcend many former boundaries, and learners are beginning to expect this. Children can now engage with many STEM experiences—Minecraft, LEGO robotics, Scratch programming and more—almost interchangeably in school, after school, at home and in museums. The wide availability of tablets and smartphones and the proliferation of bring-your-own-device policies in schools only accelerate this trend. Children can now have the same access to learning wherever they are.

However, though society has changed, museums have not adapted sufficiently. The museum experience remains fragmented, and museum visits primarily still provide solitary learning opportunities. As a result, they suffer from the "Vegas problem": what happens in the museum stays in the museum. Rarely do museum experiences connect with opportunities outside the museum walls, and when they do, they typically bridge to activities that are only tangentially related to the original museum experience. Further, gaining any rich understanding of related learning that takes place following a museum visit has been practically impossible.

Learning everywhere

Stunning advances in technology now link experiences across boundaries. Within our daily lives, we take for granted that we can read and listen to an e-book across devices without missing a beat or easily transfer a phone call to a car's audio system. Technology's wide availability can—and should—permit the same type of seamless transfer for learning experiences, bringing them smoothly out of museums into different settings.

The Concord Consortium's new Learning Everywhere initiative aims to do precisely that. The initiative combines multiple institutions in a transatlantic collaboration with the goal of extending, tracking and closely examining learning across settings. In a collaboration with leading museums including the Tech Museum of Innovation, the New York Hall of Science, the @Bristol science center in the United Kingdom, the Exploradome in France, and after school programs including the Carver Center of Norwalk, Connecticut, our Learning Everywhere initiative will develop exhibits and mobile learning experiences that provide trackable, closely coordinated learning opportunities. Our initial development focuses on the crucial topic of energy within the context of renewable energy, energy efficiency and the use of natural resources. Activities and exhibits will also involve design challenges, enabling extended experiences that adapt flexibly to different learning settings.

We are currently prototyping and testing a wide variety of hands-on and virtual activities using our powerful open source software. For example, learners will use our Energy2D simulation software to examine the principles of heat transfer and build energy-efficient houses with our simple but powerful computer-aided design environment, Energy3D. In one challenge, learners construct and power virtual villages, testing the energy efficiency of different configurations while striving to develop a "zero-energy village," which generates as much energy as it consumes.

We are also exploring additional ways to enhance both the museum experience and virtual experiences to maximize engagement. Interactions between real-world constructions and virtual simulations allow museumgoers to get a hands-on feel for how different building features affect the flow of heat energy within them, or project enhanced information about a model village as a visitor constructs it on a table. Multi-player features permit learners to create virtual villages that provide power to their friends' villages or form part of a virtual power grid they are challenged to help manage. Importing and sharing features allow learners to design houses using Energy3D and bring them into a virtual village or enable them to share their designs for other museumgoers to modify or optimize.

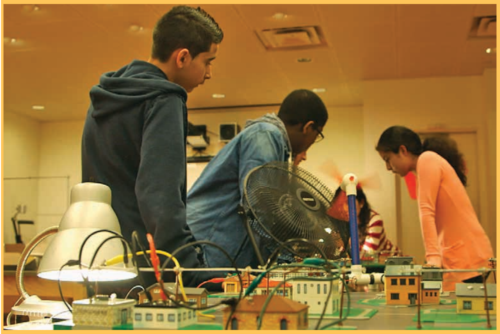
Tracking and logging

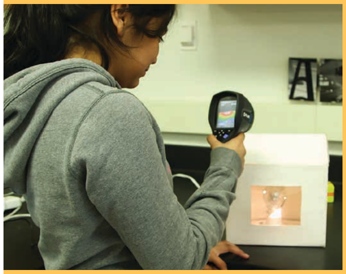
Two technological advances redefine our ability to understand museum experiences and their related learning. First, new technologies increasingly deployed in museums around the country can track learners within a museum, providing detailed views into a visitor's activities as she interacts with museum exhibits. In the Tech Museum of Innovation in San Jose, California, a museum-wide system of Tech Tags allows visitors to scan in at exhibits and afterwards access personalized content online from their visit. The next generation of this system, currently in development, will follow users throughout the museum, dynamically modifying exhibits to tailor them to a visitor's history and preferences and suggesting new activities on future visits.

The second advance concerns our ability to track and log a learner's interactions with technology-based activities and analyze these interactions through educational analytics and data mining techniques. These techniques, which continue to advance, provide new, highly detailed information about interaction patterns that can be powerful proxies for engagement and processes such as inquiry or design. (See "Visualizing Student Learning" on page 4.)

With this combination of in-museum tracking and technology-based activities that can move with learners outside the museum, we now have the ability to develop an unprecedented, full-spectrum picture of learning as it occurs across boundaries. Our understanding of this learning today is extremely limited, so answering even basic questions such as how and when activities are used in different settings—from the museum to the home, after school and school settings—could add significantly to understanding how learning unfolds following museum visits. Answering more detailed questions such as how activity use and learning in these settings correlate with different visitor variables (age or gender), museum engagement (time spent at exhibits, depth of interaction, number of return visits), or type of visit (school field trip, family visit) and especially how these are associated with logged interactions outside the museum could provide new perspectives on learning that have previously been hidden to even the best research on informal science learning.

Attaining this goal will take time and ingenuity. Activities, software, data collection and research techniques must be developed and integrated in an iterative fashion if we are to enhance museum experiences meaningfully and understand learning in a nuanced manner. Thanks to a generous matching grant from the William K. Bowes, Jr. Foundation, we are embarking on this important, international initiative to explore these questions. Rather than being limited to single experiences within museum walls or fragmented across diverse settings, we believe these experiences should be seamless and ubiquitous, and should contribute to learning that is coordinated, cohesive and continuous. As we create examples of these seamless experiences across a variety of topics, we gain new insights into educational connections that pave the way for true anytime, anywhere learning.





LINKS

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

Sensing Science:

Temperature and Heat Readiness for Early Elementary Students

By Carolyn Staudt and George Forman

Carolyn Staudt
(cstaudt@concord.org) directs the Sensing Science project.

George Forman
(geforman@aol.com) co-directs the Sensing Science project.

Young children learn through everyday activity. They invent strategies for exploring the world and develop intuitive understandings of phenomena that surround them. Mixing hot and cold water in the bathtub, putting on a winter coat, and feeling the warmth of a fire or a chill climbing out of a swimming pool are personal experiences that instill concepts of temperature and heat. Children generalize data from these experiences to construct theories of temperature and heat well before they enter formal education. We have found that children as young as four years old have definite ideas about the source of heat and how heat moves through air and objects. These early scientific conceptions are often incorrect, but once established, are tenaciously held.

Research

Our Sensing Science project, funded by the National Science Foundation, is researching "temperature and heat readiness" for K-2 students. During our research, students in kindergarten through second grade performed facilitated explorations or watched interviewers conduct experiments with temperature probes and other physical objects. For example, students mixed hot and cold water, saw a metal pipe being heated and decided which material would best insulate chocolate from a hot light bulb.

When external data conflict with personal theories, children's naïve conceptions can be reconstructed. These explorations provided students with experiences that confirmed or countered their predictions, and ultimately generated new theories about temperature and heat.

During these explorations we interviewed students to elicit and document their conceptions of temperature and heat rather than to teach. In the first phase of project research, we examined children's free exploration of temperature and heat concepts using fast-response temperature sensors and infrared (IR) cameras. During the second phase, we piloted and refined an interview process involving verbal prompts and additional tools such as infrared thermometers, thermal clay, and pre-recorded videos and simulations. In the final phase, which is currently under way, we have standardized the explorations and verbal prompts into an interview protocol.

New digital tools

Since heat and temperature are invisible, the Sensing Science team designed new digital tools to help make the invisible visible and link the visualizations directly to children's tangible perceptions of hot and cold.

IR cameras and IR thermometers.

Infrared (IR) cameras and their companion technology, IR thermometers, represent a revolution in the ability to access and understand the invisible world of thermal energy. Once costing tens of thousands of dollars, these cameras are now affordable and contain digital screens, permitting interactive exploration of temperature and heat concepts in new ways.

Graduated-color representations.

Children can express their theories about temperature and heat verbally or by referring to pictures or by drawing. They drew temperature using a set of red and blue pencils. For example, they drew gradients of temperature down the length of a heated object. This gives children the opportunity to represent their ideas about temperature explicitly.

Thermoscope. Since heat is generated from the movement of particles, we wanted to provide a simplified visualization of particle movement. (Our goal was not to teach about the particulate nature of matter per se, but to make visible in a schematic manner temperature differences between two materials.) We created a new thermometric representation, called the thermoscope, by connecting a fast-response temperature sensor to a computer model that displayed moving dots inside a circle (Figure 1). Rather than using the display of a conventional thermometer with a rising red line, the computer shows a five-inch circle populated with moving dots. Probing hotter materials causes the dots to move more quickly and collide more frequently. We did our best to explain this display as tiny parts of the material itself in motion and not as little bits of stuff floating inside the material like dirt in water.


Figure 1. Children using the thermoscope connected to two fast-response temperature sensors.


Figure 2. A child views a hot metal key with an IR camera. Inset: A thermal image of the key remains visible after the key is removed.

By working with this metaphor, could children begin to treat heat not as a hot or cold substance, but as particles that move and bump at different speeds? That is, could they treat temperature as relative speed as opposed to the amount of hotness? Although we were concerned that children would find it improbable that a piece of soapstone had moving parts, students from kindergarten to second grade quickly adopted a new way to refer to hot and cold: hot became "fast-moving particles" and cold became "slow-moving particles."

We also wanted to know if these action words carried any implication for why temperature changes or for how heat works. In one exploration, the children looked through an IR camera at a metal key that had been heated. The IR camera clearly showed a red (hot) key in the display. When the key was removed from the tray on which it was resting, the red key shape could still be seen in the IR camera (Figure 2). Children invented a number of explanations based on the macroscopic world of one object affecting another, such as "the key made a mark" or "the key made a dent." A few of the older children said "the heat from the key went into the tray." Children also used the terms "fast" and "faster" for variations in heat. But we have not heard anything such as "the fast-moving particles in the key make the particles in the tray move faster."

Results

We have interviewed over 150 children and have begun to characterize their ideas as proposed conceptual levels. (See the project website for current research results.) We have found some well-known preconceptions*, such as thinking that the insulating material in a glove was itself hot without considering its ability to keep the body's warmth from escaping the glove. Other discoveries are new candidates for where children go wrong and how to help them.

At first, children simply know what is hot (the sun, the stove), but they do not consider that things might warm slowly or warm an adjacent object. Gradually, they understand that heat requires a process that goes from warm to hot, and takes time. They then understand that it is best to treat heat as something other than the hot object itself, something that requires a source such as "turn on the grill" or "set the wood on fire." At about the same time they understand that heat can move through space (e.g., "it comes from the fireplace through the air"). By eight years old, children know that heat can come from mechanical energy (e.g., "the tires on my bike get hot when I ride fast" or "I can warm my hands by rubbing them together").

Although temperature and heat are topics usually postponed in school curricula until third grade, it is our belief that basic concepts of thermodynamics can be understood by children much younger. By providing young students with a representation of heat as movement and allowing them to think about invisible particles, we believe students can form critical building blocks for a much later understanding of ideas as foundational as energy and molecular motion.

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* Albert, E. (1978). Development of the concept of heat in children. *Science Education, 62*, 389-399.

LINKS

Sensing Science
http://concord.org/sensing-science

Trudi Lord
(tlord@concord.org) is the Geniverse project manager.

Frieda Reichsman
(freichsman@concord.org) directs the Geniverse project.

Dragons Go Wild

By Trudi Lord and Frieda Reichsman

"This software program fully supports my inquiry-based style of teaching and the students have benefited tremendously from the experience. As they are playing, they are making discoveries that they can then connect to the unit's concepts and skills."

"We started today and the kids were glued to the screen trying to work through it. It was awesome! I love how it allows students to work at their own pace and receive feedback throughout. Geniverse is the definition of differentiated learning."

Traditional genetics experiments are difficult to do in schools. To demonstrate real-world genetics in action, teachers must have the time and space to maintain or grow stocks of model organisms (e.g., fruit flies or Fast Plants). Breeding experiments with these specimens can take weeks or more and may not result in usable data. Due to time and resource limitations, multi-generational experiments, which are the hallmark of genetic science, are nearly impossible to complete.

Compare that to a computer simulation, based on real genes, that immerses students in a narrative adventure. Last year, 23 teachers in 18 New England schools used Geniverse, our genetics software that models inheritance patterns of dragons, and their model species drakes, to teach genetics to their high school biology students. By programming the mechanisms that govern real-world genetics into a virtual environment, we circumvent traditional classroom obstacles of time and space and provide a means for experimentation that closely mimics real-world genetics.

Students begin their adventure by choosing an avatar and befriending a sick dragon. Over time, as they explore Mendelian and non-Mendelian traits, meiosis and events at the molecular level, students uncover clues about an underlying genetic disease. Using interactive models to do experiments, students generate realistic data and win star ratings for efficient experimentation. Geniverse provides an engaging environment where students can develop and refine their skills in multiple scientific practices highlighted in the Next Generation Science Standards: using models, conducting investigations, analyzing data, constructing explanations and arguing from evidence.

Students can progress through four levels of the "Drake Breeder's Guild" with 32 unique challenges, each with a specific objective that supports experimentation. There are multiple pathways for students to achieve each objective; all involve manipulating alleles, breeding strategies or learning different patterns of inheritance. When students have reached the Master level, they have learned all they need to know to solve the mystery of the dragon's disease and find a cure.

Opening the Geniverse gates

Now that our National Science Foundation-funded research is coming to an end (we are currently crunching numbers and will report results soon—stay tuned), we have released our dragons and set Geniverse loose in the world for all to use. At first, we worried if our servers could handle the large demand, or maybe they would just go entirely unused. But in the eight months since we opened up Geniverse to use by anyone, hundreds of teachers and over 10,000 students across the globe have begun their journey with drake genetics.

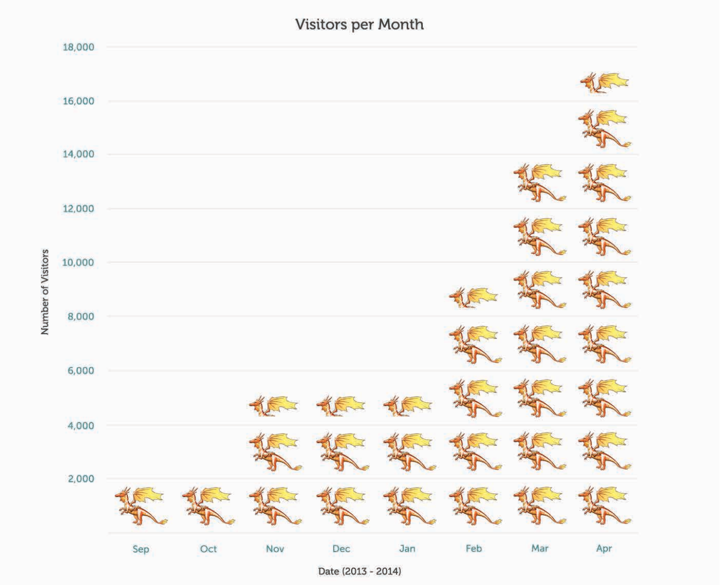
How did we reach so many users? Aside from the obvious answer that dragons with wings roam far and wide (the genotypes

WW or wW produce wings!), we also got the word out through our email newsletter, social media, conferences, website and, of course, our *@Concord* magazine. The initial message went out to high school biology teachers, but we found that middle school teachers were also interested in using Geniverse. We're hoping to make modifications specific to this grade band in future versions of the software.

Get started with Geniversity

Teacher professional development was an important piece of our research study. Using feedback from teachers and students over the past four years, we have refined our teacher support materials, including teacher guides and lesson plans as well as student organizers. These resources are all available on Geniversity, our teacher support website. In addition, Geniversity offers video screencasts to help teachers at every phase of their Geniverse experience, from beginning the registration process to breeding their first drake to viewing the results of the final assessment. Geniversity also contains frequently asked questions and discussion forums designed to foster collaboration between teachers, a first attempt to build a larger community of Geniverse teachers.

Try the three-lesson Geniverse Primer to learn the software and story—and some dragon genetics, too, including connections between genotype, phenotype, meiosis and fertilization. Or go on the full journey to solve the mystery of the ailing dragon, complete all the challenges and move from the Training level to Apprentice, Journeyman and ultimately Master. You'll be a dragon's best friend.



Visits to Geniverse have increased steadily since our public launch in September 2013. The majority are from the U.S., but we have also had visitors from New Zealand, Italy, Brazil and Norway.

Want to try Geniverse?

Register now for a free online summer Geniverse course!

https://www.surveymonkey.com/s/GVSummerCourse

Beautifully designed graphics by the Fablevision Media and Interactive Development Studio illustrate the world of Geniverse.

Top: Scarlett, the Geniverse female avatar, visits the village elder and learns that dragon genetics are studied at the remote Drake Breeder's Guild.

Middle: Scarlett and Arrow the dragon depart from home on the long and arduous journey to the Guild.

Bottom: Students track their own progress through the Guild and navigate to each Geniverse Lab activity through the Case Log.

LINKS

Geniverse
http://concord.org/geniverse

Geniversity
http://geniverse.concord.org/geniversity/

Under the Hood:

Interactive API

By Scott Cytacki

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

To truly tap the potential of deeply digital learning, curriculum authors need a common API for interactives. Currently authors can embed iframes in most content authoring tools. Our new interactive API allows the iframe and surrounding system to communicate with each other, enabling an even richer learning experience.

We've been building deeply digital learning activities for years, and we want to make it possible for more curriculum authors and teachers to create them, too. An activity consists of two parts: an activity authoring and delivery system (think simple LMS) and the interactives that are embedded into the system. Creating interactives often requires programming, so it's not feasible for most authors, who instead look for existing interactives and build activities around them. If these pre-built interactives implement an API, then authors can customize, control and monitor them. However, if each interactive has a different API, such rich integration becomes cumbersome, requiring custom work.

We have started to build a common API for interactives to share. The first need we had for this common API was the ability for learners to take a snapshot of any interactive in an activity. All of our interactives now use Shutterbug (see "Under the Hood" in Fall 2013 *@Concord*) to implement this part of the interactive API.

The second need came from the Innovative Technology in Science Inquiry (ITSI) project. There are often several interactives on a single page of an ITSI activity. If all the interactives are running at the same time, the page slows to a crawl. To avoid this, ITSI uses the interactive API to ensure that only one interactive is running on the page at a time. Each interactive sends a message to the page when it starts playing, and each interactive listens for a stop command. With those two pieces the page can coordinate the interactives (see Figure 1 for the code).

In both cases the activity author just provides a URL for an interactive. The API is the same for all of our interactives, so the activity system takes care of the rest.

This is just the beginning of an interactive API. In addition to snapshots and coordinating the running interactives, the API should also include requesting and setting the state, event logging, property setting and getting, and data export. These enable other organizations to use the interactives in new ways. Our Common Online Data Analysis Platform (see page 16), for instance, will be able to use the API so any interactive can be integrated without customized work.

The idea of a common API is supported by PhET, which is creating HTML5 versions of their simulations. We are planning to work together to make this API a reality. We hope to make add-ons or plug-ins that support this API for other LMS systems and to attract other organizations to support a common API, too. Join our mailing list at groups.google.com/group/cc-developers to learn more.

```
 interactives.forEach(function(me){
  me.addEventListener(‘play’, function (){
    stopInteractivesThatAreNot(me);
  });
})
function stopInteractivesThatAreNot(me) {
  interactives.forEach(function (interactive){
    if (interactive !== me) interactive.stop();
  });
}
```

Figure 1. Coordinating interactives on a page.

Definitions

API: a defined way of communicating with another program, library or service

iframe: an HTML tag for embedding one page in another

interactive: a simulation or visualization that allows the user to interact with it (e.g., change variables, add or remove features, etc.)

LINKS

Running Example of Interactive Coordination
http://concord-consortium.github.io/under-the-hood-2014-spring/

Under the Hood: In-browser Image Capture with Shutterbug
http://concord.org/publications/newsletter/2013-fall/under-the-hood

Innovator Interview:

Amy Pallant

apallant@concord.org

Q. What were you interested in when you were little?

A. I have been dancing since I was five—first ballet and jazz, and later, contemporary. I love to move and can pick up dance movement quickly. I continue to take yoga and dance classes and perform when I can.

Q. What took you to Oberlin?

A. I was looking for a liberal arts college where you didn't have to be anything but yourself. When I visited, I knew it was the place for me. The same thing happened to my daughter (who is now a sophomore).

Q. How did you get into Earth science?

A. I thought I was going to study biology or pre-med. During my sophomore year I took organic chemistry and an Intro to Geology course. I fell in love with the subject immediately. I liked thinking about space and time, which is what geology is all about. Geology and dance are both about 3D!

Q. Tell us about your time at Woods Hole.

A. While at Oberlin, I did a month-long internship at Woods Hole Oceanographic Institution. After graduation, I worked at USGS, where I discovered an extinct microfossil. These fossils are so tiny, they used to be washed through the sieves. I moved to Woods Hole and continued to collect microfossils from the sea floor and do mass spectrometry—studying carbon and oxygen isotopes related to changing global temperatures.

Q. What education projects have you worked on?

A. I was project manager of the *Insights in Biology* curriculum at EDC, then moved to Turnstone Publishing, Inc., where I developed curriculum that connected student activities in oceanography and astronomy with the work of scientists. We created sixteen units for upper elementary and middle school students. This was the inspiration for including videos in Concord Consortium's High-Adventure Science curriculum units: expose students to what research scientists are currently doing. Science is not stagnant!

Q. What are you currently working on?

A. I direct the High-Adventure Science project, which is developing Earth science modules with the National Geographic Society and the University of California, Santa Cruz. The goal is to help middle and high school students become Earth systems thinkers and to have students explore uncertainty as part of scientific argumentation.

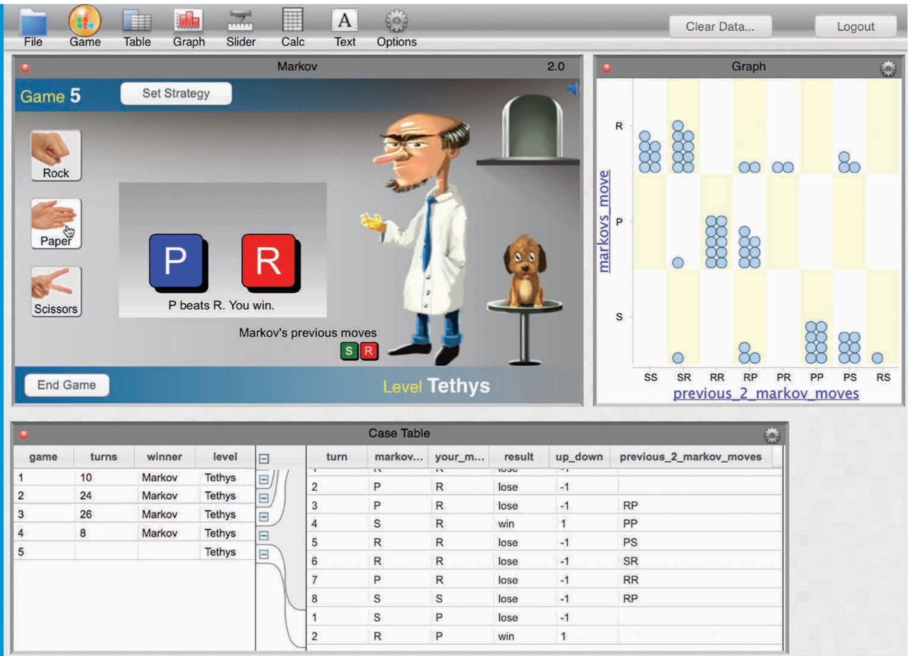
I've also been pulled back to Woods Hole with the TREET [Transforming Remotely Conducted Research] project. Since you can't get a lot of people aboard a boat, we're investigating new ways of doing fieldwork in ocean science. The goal is to use telepresence to enable undergraduates to guide remote vehicles from shore. An ethnographer on the project is investigating the cultures of education, scientists and ocean research.

And I'm overseeing research on the InquirySpace project, which is helping high school physical science students do their own research projects. The tools available to students to help visualize the data are amazing.

Q. What's distinct about the Concord Consortium?

A. I like learning, and I haven't been on any project where I haven't had to learn both content and technology. The family-friendly atmosphere is important to me, and the people and culture here are just brilliant. Everyone offers something unique.

The Concord Consortium
25 Love Lane, Concord, MA 01742



P beats R. You win.

game	turns	winner	level
1	10	Markov	Tethys
2	24	Markov	Tethys
3	26	Markov	Tethys
4	8	Markov	Tethys
5			Tethys

turn	markov...	your_m...	result	up_down	previous_2_markov_moves
2	P	R	lose	-1	
3	P	R	lose	-1	RP
4	S	R	win	1	PP
5	R	R	lose	-1	PS
6	R	R	lose	-1	SR
7	P	R	lose	-1	RR
8	S	S	lose	-1	RP
1	S	P	lose	-1	
2	R	P	win	1	

In Data Games you learn to read the conditional probability graph to beat Dr. Markov and save Madeline the dog.

Common Online Data Analysis Platform

Think of problems confronting the world: hunger, violence, disease, inequality and more. Now think of questions to be answered about the brain, the origin of the universe, how children learn and human behavior. What do they have in common?

It has become impossible to solve any of these problems and questions without people who are really good at working with data, people who can get data to show its patterns, reveal its buried treasure, and suggest answers and solutions. The gap between the number of people who can do this work and the number needed is large, and growing. Where will they all come from?

Part of the answer lies in doing a much better job getting kids accustomed to working with data. Data are truly everywhere! Students could have exposure to data at every grade level and in every course from science to math, and history to physical education.

Technology has powered the data revolution by making it possible to gather, store, access, visualize, analyze and archive vast quantities of data. And kids will only learn to harness data if they are facile with such technology.

Thanks to funding from the National Science Foundation, the Common Online Data Analysis Platform (CODAP) project is creating software that can be used by curriculum developers to get students working with data—in any subject area. CODAP is free and runs in a web browser. It's also open source, which means that any developer can modify it.

CODAP is building on the NSF-funded Data Games project (play.ccssgames.com), directed by Bill Finzer, creator of Fathom. Play the "Rock, Paper, Scissors" game to rescue Madeline the dog from the evil Dr. Markov. Once you learn to read the graph with all the dots, you'll be able to beat Markov; in fact, you'll be able to set up a strategy that beats him quickly.

One of CODAP's keys to success is working with other successful projects. Collaborators include the Ocean Tracks project at EDC, Terra Populus at the University of Minnesota and the InquirySpace project here at the Concord Consortium. By building data analysis capabilities for disparate projects, CODAP will develop more flexibility and become a more powerful data analysis environment.

The ultimate goal of CODAP is to create a community of educators and developers who are actively working on bringing data into classrooms, so today's students become tomorrow's data scientists.

Editor: Chad Dorsey | Managing Editor: Cynthia McIntyre | Design: Jan Streitburger | concord.org
The Concord Consortium | 25 Love Lane, Concord, MA 01742 | 978-405-3200 | fax: 978-405-2076
@Concord is published two times a year by The Concord Consortium, a nonprofit educational research and development organization dedicated to educational innovation through creative technologies. This material is based upon worked supported by the William K. Bowes, Jr. Foundation and the National Science Foundation under several grants (DRL-1348547, IIS-1124821, DRL-1220756, IIS-1147621, OCE-1344250, DRL-1222892, DRL-0918642, DRL-0929540, DRL-1316874 and DRL-1435470).