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Perspective:

Data: A Wider View

By Chad Dorsey

As we enter an age where data seems to be everywhere, both educators and education researchers are becoming aware of its power. Yet our current view of data is highly limited. We have only begun to conceive of the possibilities that multiple forms of data can offer for teaching and learning. We will need imagination to envision all the novel ways data can empower education and fuel innovation. To fully understand how data stand ready to transform teaching and learning we must think broadly and look far ahead.

For decades the Concord Consortium has been beating the drum about the importance of data. In recent years, the rhythm has intensified. Our newest projects and our vision for the future reflect this, and they do so in some surprising ways.

Data games for learning

One intriguing view of data comes from gameplay. The use of games for education is a growing field with significant promise for STEM learning. Games provide a strong means of motivation and engagement, and align with many STEM learning goals. The data generated by players as they interact with games offers promise for researchers as they seek to better understand how learning through games takes place. We're interested in all of these, but a newly funded project, Data Science Games, is making use of the data generated as students play digital games in a novel and creative way.

When students play a data science game, their gameplay actions generate data, but the data takes on more significance than in other gaming examples because it becomes essential to the game itself. To succeed at a data science game, students must visualize, understand, and properly *apply* the data their game playing has generated in order to "level up" and progress within the game. As they visualize and analyze the data, planning and plotting new, evolving strategies, students learn the fundamentals of data science.

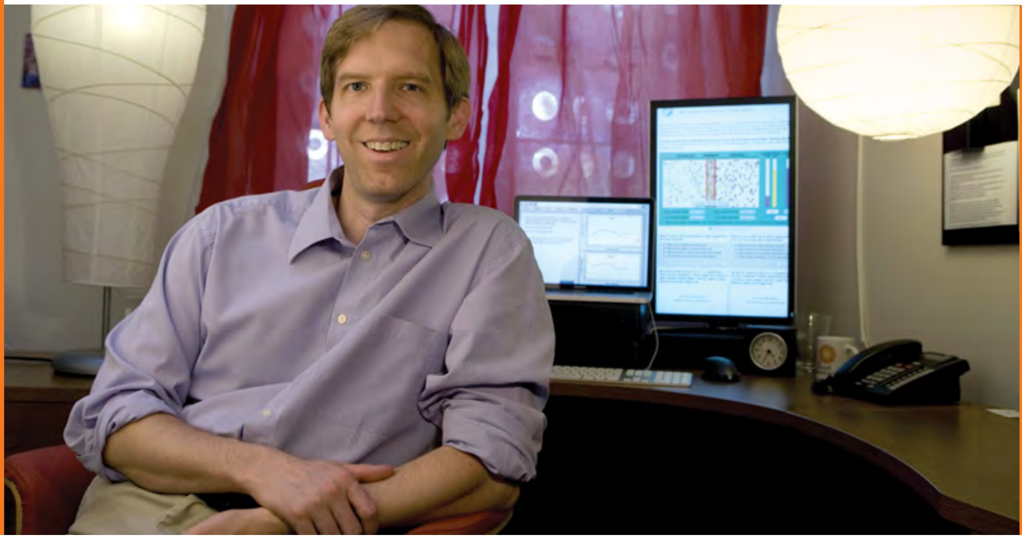
Guiding teaching and learning via data

In other Concord Consortium research, we use the data generated by students as they explore virtual environments to better understand and aid the process of learning. Our SmartCAD project expands on this important line of work by improving and advancing the data analytics behind our successful Energy3D virtual CAD software. SmartCAD will develop a full-featured environment outfitted with sophisticated metrics for monitoring and understanding the process of engineering design in real time. This is an essential step in understanding what has until now been largely a "black box." Building on highly promising past work with the same environment, we are now able to visualize process data in powerful ways. The fine-grained data will shed light on design iteration and, in particular, on how data can be leveraged to provide feedback to students during the design process.

This work is an example of our view of learning analytics. Fostering *learning* is the ultimate goal, not merely examining the analytics themselves. Another new project, GeniGUIDE—Guiding Understanding via Information from Digital Environments—is expanding this concept by integrating our game-based genetics work with robust intelligent tutoring technology. Rather than keep the tutoring system's data limited to within the software's feedback, this project explicitly acknowledges what is often a central mantra of ours: the most intelligent tutor is the one standing at the front of the classroom. By gathering the rich data streams generated as students breed dragons and attempt genetic challenges in our Geniverse environment, we can make use of such data to advise the classroom teacher and to connect individual students via direct feedback. By forging new ground for one of data's most important uses—aiding and guiding teaching and learning—we're blazing trails that we hope the field will follow in meaningful ways.

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

We will need imagination to envision all the novel ways data can empower education and fuel innovation.



Discovering data amid the fabric of learning

With so much data streaming in from existing technologies and with new examples emerging every day, it's easy to think that we have more than enough information about learning to go around. However, capturing the most critical and substantive interactions during the teaching and learning process—the discourse and conversation among students, teachers, and mentors—remains elusive. Data related to spoken language is the center of an incredible amount of effort within educational research, but these efforts are enormously time-consuming and subjective—as anyone who has ever coded video clips or performed detailed classroom observations is painfully aware. And even the most careful efforts in this direction miss huge parts of the teaching and learning picture.

The potential for capturing, processing, and gathering meaning from spoken language data via technology is increasing at an exponential rate, but its current development is missing a vital part of the picture—its use in education. Often-finicky interactions with Siri or Google products form most people's image of modern spoken language technology. But these represent only the faintest view of the potential of today's cutting-edge speech technology and its capabilities for automatic speech recognition and natural language processing. Many lesser-known technologies allow the extraction of highly accurate measures such as word counts or meaning-filled data from prosody (variations in tonality of speech, which can indicate emotion or stress). Spoken language technology stands at a powerful tipping point, and the central goal of one of our new projects is to rally attention to its potential for the education research community. We are at the forefront of a sweeping new era in educational research, in which spoken language technology will open up grand new horizons. In doing so, we hope to spark a revolution that can make wide use of the spoken interactions that have been at the core of educational exchanges for millennia.

Taking the long view of learning data

Through these and other initiatives, we are embarking on new directions and widening our current view of what data is and how it can be used for education. Our future vision, of course, far exceeds even our current work. In the spirit of forward thinking, we are thrilled to welcome another visionary, Janet Kolodner, to our team as Chief Learning Scientist. Her vision for the future is well known to many. She will bring our work into yet-uncharted territory in the area of learning science and technology. This will include work with project-driven learning, in which teachers and learners grapple with challenges that can extend for months, placing new demands upon software tools and platforms that must be able to make the related data discoverable and relevant for learning over time.

The future is exciting and by nature unpredictable. We know for certain, however, that it will be filled with data, whose expanding definitions we may have yet to understand. As we enter that future, we challenge others—as we're challenging ourselves—to consider a new view of data, its definitions, and its significance across all STEM education.

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

Visual Process ANALYTICS

By Charles Xie

Analytics has never been more important to our economy than it is today. According to a 2014 article in Forbes, "Business analytics is now nearly a $16 billion business for IBM, on track to reach $20 billion in 2015." Business analytics research has produced technologies for transforming large quantities of data into meaningful information used for making business decisions or developing business strategies with an unprecedented speed and accuracy.

As learning software that can stealthily log everything students do becomes more popular, education will also become more data-driven. Just as instantaneous business data helps people stay in business, dynamic, fine-grained learning data may help teachers respond to students' needs more quickly and precisely. But this will not happen without investing in building the cyberinfrastructures, in particular the core engines of analytics that glean learning from data. While IBM's commitment to business analytics illuminates the possible future of education powered by learning analytics, the sheer scale of IBM's investment also suggests that such a vision requires tremendous efforts. To this end, the National Science Foundation has funded several projects at the Concord Consortium to conduct basic research in this field. This article introduces Visual Process Analytics (VPA), a data mining platform developed by some of those projects to support educational research and assessment based on analyzing and visualizing process data collected by sophisticated learning software.

> "New technologies thus bring the potential of transforming education from a data-poor to a data-rich enterprise. Yet while an abundance of data is an advantage, it is not a solution. Data do not interpret themselves and are often confusing—but data can provide evidence for making sound decisions when thoughtfully analyzed."
>
> —*Expanding Evidence Approaches for Learning in a Digital World, Office of Educational Technology,* U.S. Department of Education, 2013

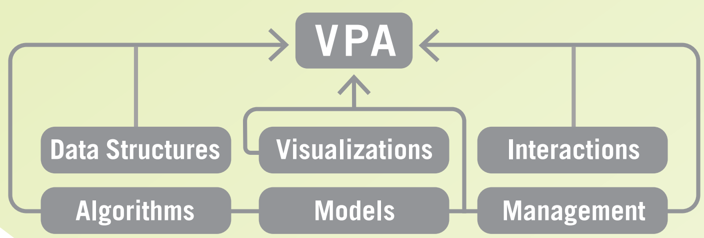


Figure 1. The six pillars of the VPA platform.

The DRIP Problem

One goal of VPA is to create a platform for tackling the DRIP ("data rich, information poor") problem, a central challenge in leveraging large amounts of computer-generated student data to improve education. The DRIP problem worsens when learning becomes more open-ended because: 1) the supporting software can generate more types of data as students explore more variables, 2) wider and deeper exploration can take more time and, therefore, produce more process data, and 3) indicators of unbounded learning are more complex to define and more difficult to find.

Open-ended inquiry and design activities are key to learning the science and engineering practices promoted by the Next Generation Science Standards. Students' "microscopic" action data logged by the supporting software during these activities, however, often appear to be so noisy that finding any order in them becomes a daunting task. Without tools that can reveal patterns in the data, researchers and teachers get nothing but a DRIP problem.

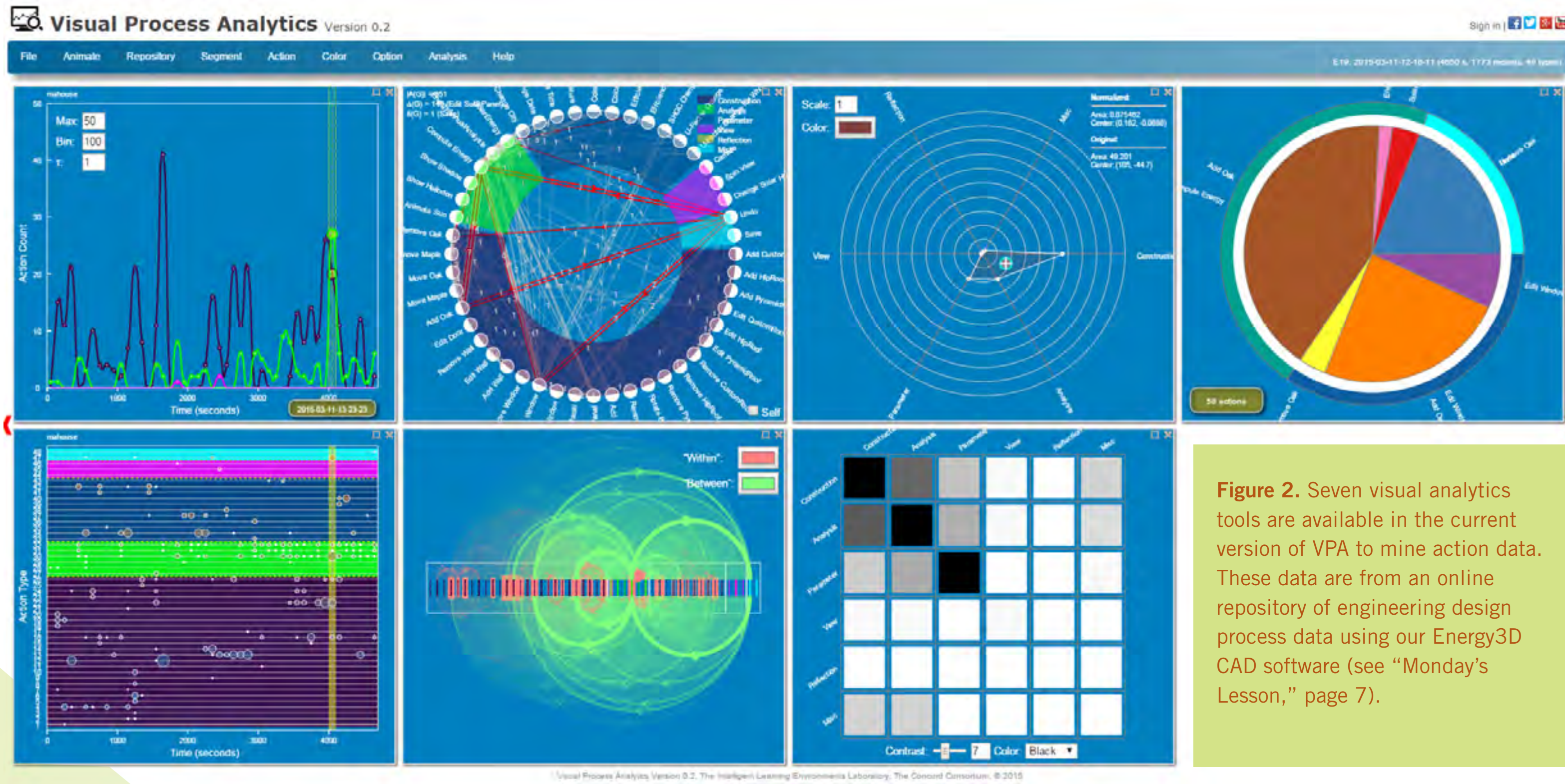


Figure 2. Seven visual analytics tools are available in the current version of VPA to mine action data. These data are from an online repository of engineering design process data using our Energy3D CAD software (see "Monday's Lesson," page 7).

The Visual Process Analytics Platform

Our ultimate goal is to equip teachers with informatics and infographics for monitoring student progress and assessing their learning anywhere, anytime. For this purpose, we created VPA as a Web app that teachers can access from any device. VPA can load a data set from an online repository or from a hard drive. Although it currently serves only our own data repositories with student data from engineering design and mixed-reality activities, VPA is intended to be a generic platform for process mining and visualization. VPA is able to recognize a JSON data set that encodes student activities, provided that the data set is formatted as a stream of timestamped JSON objects and a schema that defines the tags and attributes of the objects is given to configure it.

Like business analysts who use online analytical processing (OLAP) tools to analyze multidimensional data interactively from multiple perspectives, educators can use VPA in similar ways: 1) *roll-up* allows users to aggregate and analyze learner data in different dimensions, 2) *drill-down* allows users to zoom into and navigate through the details, and 3) *slicing* and *dicing* allows users to extract a subset of data and visualize it differently.

In addition to the OLAP features, the VPA platform is supported by six pillars (Figure 1)—software modules that perform various kinds of visualization, analysis, and management of data. Interactive visualizations are fundamentally important to VPA because: 1) a picture is worth a thousand words, 2) humans are often more capable than computers of recognizing complex patterns in pictures, and 3) interactive graphics provide more dimensions for exploring data than static graphics.

Under the Hood

Data Structures

Since real learner data are often multi-faceted, data fed to VPA are first sifted into different types of data structures, each representing a different mathematical view of the data. For instance, a sequence of action data can be stored and treated as a time series (an array of numeric data collected over time) that describes when different types of actions occurred with what results on which objects, or as a directed graph (a network of nodes linked by arrows) that describes the transitions among different actions and tasks. Each type leads to a different way to think about the data, enabling various visualization and analysis methods to be developed.

Visualizations

Scientific visualizations are powerful because they help people make sense of data by rendering salient, intuitive pictures of the data being examined. The multi-faceted nature of data suggests that a single type of visualization may not suffice to represent a data set. This is why VPA provides multiple visualizations to create a more holistic view. Seven types of visualizations—time series, directed graph, radar chart, pie chart, scatter plot, linkograph, and heat map (Figure 2)—are currently available, each depicting a unique aspect of a data set. Interactive and customizable, they allow users to examine data more flexibly. Each type also provides several options. For example, a time series can display as a histogram, a curve, a correlogram, a periodogram, a recurrence plot, and more (Figure 3).

Interactions

Like other visual analytics software, VPA provides a rich, interactive user interface for analyzing and viewing data. The graphical user interface for each visualization tool is dynamically generated based on the chosen settings. For example, to capture overall patterns in a time series, users can increase the width of the time bin to smooth the time series curve as necessary. Throughout VPA, tool tips with more information about the data pop up when users mouse over hot spots of the visualizations. Users can even take advantage of the temporal nature of the data to animate a visualization to further enhance the visual effects.

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(continued from p. 5)

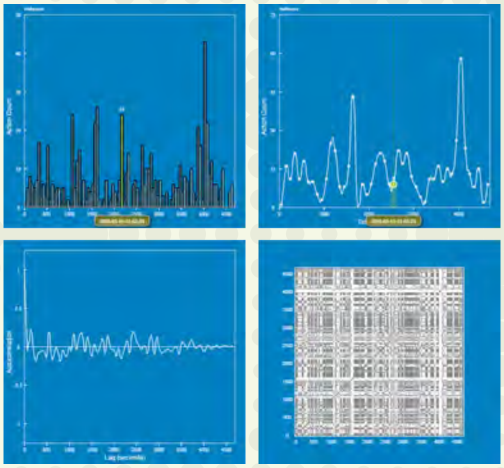
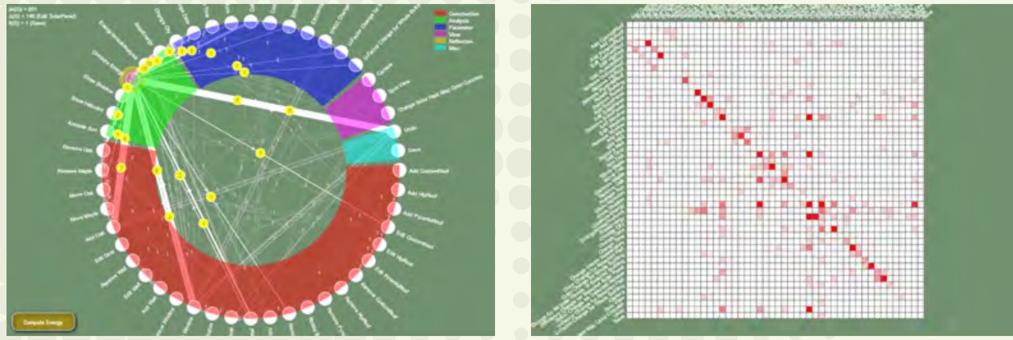


Figure 3. Four different visualizations of a time series in VPA. Clockwise from the top left: histogram, curve, recurrent plot, and correlogram.



(a) (b)

Figure 4. (a) With the built-in interactivity in VPA for directed graphs, users can look at the transitions among actions within a selected time interval or the actions linked to a selected type over the whole period. (b) VPA shows the adjacency matrix of a directed graph as a heat map that visualizes the distribution of transitions in the action space. The more intense colors of the diagonal elements indicate that this student tended to take some types of action continuously during this time period.

Algorithms

By manipulating the visualizations, users develop basic ideas about the data. But they need deeper analyses to reveal hidden patterns. VPA provides a growing set of algorithms for in-depth analyses. For instance, VPA employs time series analysis when the data are viewed as time series and graph theory when the data are viewed as graphs. Autocorrelation and cross-correlation functions in time series analysis can be used to search for patterns of iteration, correlation, or causality. These algorithms work as if we print two time series on transparency films, overlay them, and then manually slide them horizontally to search for similarities or correlations. Within the framework of graph theory, on the other hand, any process of interacting with software can be viewed as a directed graph that connects all actions with arrows that represent transitions (Figure 4a). Once the process data are coded in this way, VPA computes its properties and visualizes its adjacency matrix with a heat map that makes the high-frequency transitions clear (Figure 4b).

Models

One of our research goals is to model complex cognitive and learning processes so that we can describe, classify, or even predict student behaviors. For this purpose, we include tools for fitting the data with statistical models. For example, the autoregressive integrated moving average (ARIMA) model in time series analysis may be used as a general model to probe the degree to which a student's action was influenced by previous actions. The results can be used to gauge how autoregressive or iterative the process was.

Management

VPA includes many features designed to facilitate data mining, including:

- **Browsing.** VPA is a data browser—users can browse a data repository using arrow buttons or jump to a data set using drop-down menus for selecting classes, students, and segments. Every time a new data set is loaded, VPA automatically updates all the visualizations on the screen.
- **Persistence.** A state of data mining in VPA is called a perspective. Users can save perspectives as files to keep track of their work, compare multiple views, document a finding, or continue the analysis later. In addition, VPA remembers the last perspective—when users return, VPA comes back to the exact point of analysis where they left.
- **Output.** VPA results can be exported as data or image files that can be further analyzed or displayed using other programs.

The Future

Launched only a few months ago, VPA is in its infancy. Its current form is more suited for researchers than for teachers. But we hope to develop a recommendation engine that digests low-level data and outputs high-level information to teachers through a series of dimensionality reduction. We envision a future in which every classroom is powered by more advanced VPA-like informatics and infographics systems that support day-to-day teaching and learning using a highly responsive evidence-based approach. At a time when business runs on analytics rather than opinions, it is not fair that teachers have to rely on simple hunches or scarce information about their students' learning processes to teach. The research that we are undertaking is paving the way to a future in which teachers are empowered with tools on par with business analytics.

LINKS

Visual Process Analytics
http://vpa.concord.org

Monday's Lesson:

Designing an Energy-Plus Home


Charles Xie
(qxie@concord.org)
co-developed Energy3D.


Saeid Nourian
(snourian@concord.org)
co-developed Energy3D.

By Charles Xie and Saeid Nourian

Are you looking for high school engineering design projects that meet the requirements of the Next Generation Science Standards (NGSS)? Do you need free, high-quality software and curricula that engage students in solving complex real-world problems like scientists and engineers and yet can be easily implemented? Do you want students to be more technically prepared to tackle energy and environmental issues in the future? If you answered "yes" to these questions, this lesson is for you.

Energy3D is a simplified CAD program for designing buildings and communities that take advantage of renewable energy sources such as solar and geothermal energy to reduce fossil fuel use. Based on weather data of more than 200 worldwide locations, Energy3D allows students around the world to design sustainable architectural and solar solutions for their climates.

Unlike other CAD tools, Energy3D aims to engage students in science and engineering practices required by NGSS. The integrated capability of concurrent design, simulation, and analysis within Energy3D enables students to test and evaluate multiple design ideas through rapid virtual experimentation.

The Energy-Plus Home Design Challenge

Challenge your students to use Energy3D to design an energy-efficient house that, over the course of a year, produces more renewable energy than the energy needed for heating and cooling. In addition to this goal, students must also meet a set of design criteria and constraints. For example, the house should have one of three specified architectural styles, the size cannot be too big or too small, and the cost must not exceed the budget.

Energy3D's easy-to-use interface allows students to quickly sketch up realistic-looking houses using a basic set of design elements, including walls, roofs, windows, solar panels, and trees (Figure 1). Students can adjust the properties of each element such as size, location, orientation, U-value, solar heat gain coefficient, heat capacity, color, and more. Whenever they want to evaluate the effect of a change on the energy performance of the house under design, they can run the built-in thermal and solar simulators to generate a graph that itemizes and summarizes daily or annual energy use (Figure 2).

This design project meets the NGSS engineering standards in several ways: 1) it is a direct response to HS-ETS1-4 that requires students to use a computer simulation to model and solve real-world problems, 2) it promotes systems thinking as students can explore how individual elements collectively contribute to the overall performance of a house, and 3) it creates many opportunities for learning about trade-offs and optimizations as the built-in simulators greatly accelerate the feedback loop necessary for iterations.

Although the engineering projects based on Energy3D are limited to virtual design, they have distinct advantages:
1) students have the opportunity to learn CAD, as nearly every engineer does today,
2) software can simulate situations that are not possible to create in a school lab (e.g., waiting for a year to determine the annual energy use of a real house), and
3) the cost of implementing these projects is minimal—you only need computers that can run the free Energy3D software.

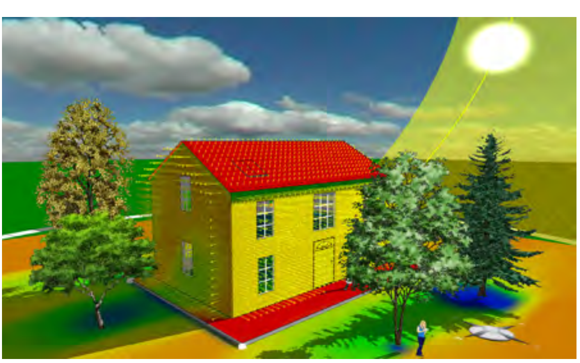


Figure 1. Solar analysis: The total solar radiation on a house in Boston on May 1 is visualized as a 3D heat map that reveals complex interplays among individual elements of a house and its surroundings.

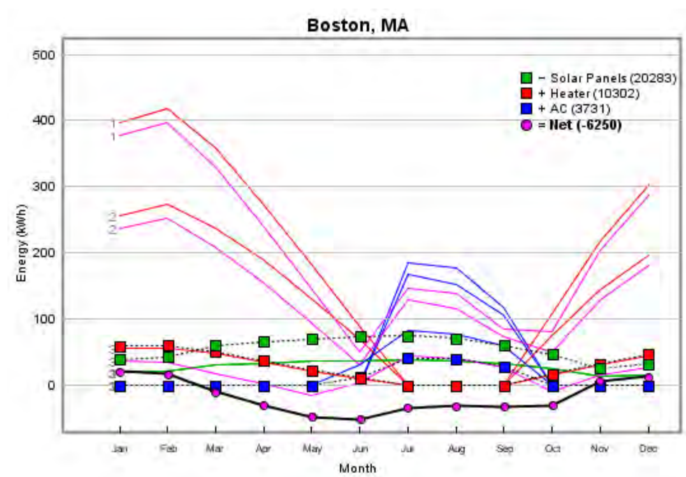


Figure 2. The graph of monthly energy use (heating in red, cooling in blue) shows gradual energy savings through four improvements. At the end, the solar panel arrays generate more energy than the house consumes throughout a year.

LINKS

Energy3D
http://concord.org/energy3d

Energy-Plus Home Design Challenge
http://energy.concord.org/energy3d/projects.html

Building
the CODAP Community

By William Finzer and Dan Damelin

Over the past several decades our society has come to rely on data for nearly every aspect of its functioning. Not only is the amount of data generated each day beyond comprehension, no significant problem facing us—from traffic gridlock to climate change—can be solved without the help of people who understand how to work with data. However, "data scientists" are in short supply. Our goal is to create a community of curriculum and software developers committed to ensuring that students from middle school through college have the knowledge and skills to learn with data across disciplines.

William Finzer
(wfinzer@concord.org)
directs the CODAP project.

Dan Damelin
(ddamelin@concord.org)
is a technology and curriculum developer.

Our Common Online Data Analysis Platform (CODAP) offers easy-to-use web-based software that makes it possible for students in grades 6 through college to visualize, analyze, and ultimately learn from data. Whether the source of data is a game, a map, an experiment, or a simulation, CODAP provides an immersive, exploratory experience with dynamically linked data representations, including graphs, maps, and tables. CODAP is not dependent on specific content, so data analysis can be integrated into math, science, history, or economics classrooms.

Open invitation to curriculum developers

Are you developing curricula that engage students with data or doing research into how students understand data and/or data visualizations? Would you like to have an online tool for working with data sets you've collected, making it easier to engage colleagues and the public? We'd love to work with you.

CODAP offers many flexible integration options for your curricula. "Data interactives" (games, simulations, database front ends, probe interfaces, and data entry forms) may be embedded in CODAP to serve as a source of data or data can be imported by simply dragging and dropping CSV or tab-delimited text files. You can use CODAP as a standalone environment or include links to CODAP documents within online curriculum materials. For example, a complete CODAP document or individual CODAP graphs, maps, or tables can be embedded in Web pages as an iFrame. Finally, CODAP can be used "behind the scenes" such that the data interactive takes over virtually the entire screen while communicating with CODAP to generate graphs through a custom interface designed into the data interactive.

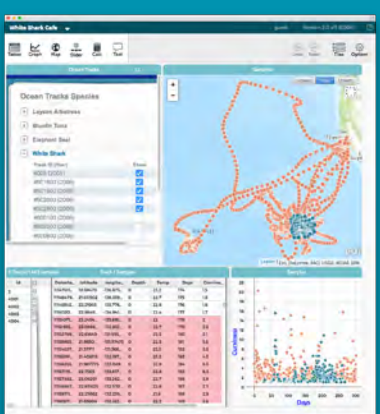


Figure 1. The EDC Ocean Tracks project gives students access to data from tracking large marine animals. Data from five sharks tagged in Monterey, California, show that four of the sharks spend a lot of time in an area east of Hawaii known as the White Shark Café (the blue points in the map). The same data points in the graph occur in a three-month period, but no one is sure what the sharks are doing there.

Figure 2. The Building Models project is creating an easy-to-use tool for students to build their own dynamically calculated models. CODAP has been integrated so that it behaves like a data analysis and visualization library, allowing the Building Models developers to focus on modeling tool features. In this model there is a tipping point where the amount of fossil fuels burned starts to cause runaway temperature increases in the Earth's atmosphere.

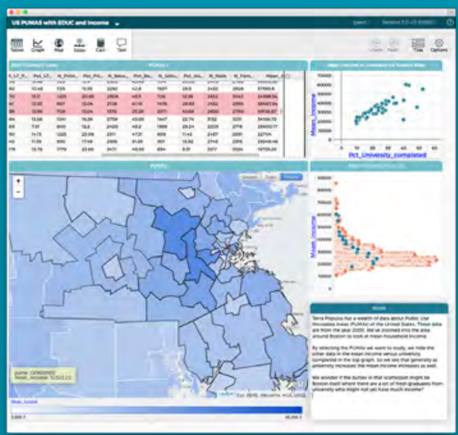


Figure 3. The Terra Populus project aims to integrate microdata about individual anonymized people from around the world, area data, and raster data. Their primary audience consists of research scientists, but with CODAP they will also be able to get their data into schools. The area around Boston is colored by mean household income. It's easy to pick out Boston's wealthier suburbs and see that income and education are strongly correlated.

Thanks to the growing CODAP community, we've been adding new features to CODAP. We are currently collaborating with a number of exciting partners and projects.

Ocean Tracks. This EDC project offers online software and a curriculum that immerses high school students in an interdisciplinary study of marine biology using GPS data from large sea animals (Figure 1). Based on EDC's needs, CODAP has incorporated map and measurement capabilities.

InquirySpace. This Concord Consortium project develops digital software and curricula that lead to scaffolded science inquiry. InquirySpace interactives and sensor collectors are embedded in CODAP, so students can analyze data from experiments and simulations. This collaboration led to extensive support for integration of CODAP with an online activity authoring system, extending the ability for teachers to collect collated reports of student work both on CODAP and via embedded assessments in the activity authoring system.

Building Models. The Concord Consortium is developing a systems dynamics modeling tool designed to make it possible for students as young as middle school age to create and experiment with their own computational models (Figure 2). Students validate and refine their models within CODAP by comparing outputs from their own models with data from one or more other sources, including experimental data from probes and data generated by simulations. To accommodate these needs CODAP is developing the ability to analyze two or more data sources and plotting data from multiple sources on a single graph.

Terra Populus. This project at the Minnesota Population Center facilitates research that depends on integration of demographic and environmental data. These data include information about individuals drawn from censuses, area data that summarize demographic and environmental measures at the state level, and raster data (measurements taken over a wide geographic area using satellite imagery and/or sensors, or a network of local measuring stations or sensors) (Figure 3). The collaboration with CODAP will lead to a website aimed at introducing students to this vast source of rich data, and make it possible to download data as a CODAP document with embedded data sets.

Open invitation to software developers

If you're creating software for learning about or engaging with data, we invite you to leverage current work and add capabilities to the open source CODAP codebase. CODAP is HTML5, making use of JavaScript, HTML, and CSS3. Various open source libraries are part of CODAP, including SproutCore, JQuery, Raphaël, Leaflet, and several other smaller libraries. CODAP uses SproutCore as an application framework. You can deploy CODAP as a static website with no server interaction. CODAP can be configured to store documents on a user's local device, or integrated with an online server for cloud-based document management. It can also log user actions to a server specified in a configuration file.

Consider becoming part of the community:

- Clone CODAP from GitHub (github.com/concord-consortium/codap) and make modifications. Submit pull requests so your improvements become part of the master repository.
- Use CODAP as is from our server, taking advantage of continuing improvements as they occur.
- Work together with our team of programmers on software development to integrate CODAP functionality, or to add functionality needed by your project.
- Join our mailing list (groups.google.com/group/cc-developers).

(Read "Under the Hood: Embedding a Simulation in CODAP" in the spring 2015 issue of *@Concord* to see how you can get started with the code.)

Open invitation to teachers

Teachers, you're welcome to use CODAP with data of your own or start with several existing curricula that make use of its data exploration capabilities, including Data Games and InquirySpace materials. They're free and ready to use in your classroom. Explore more activities at the CODAP portal, and let us know if you have ideas for other features you'd like to see. We're excited about the growing uses of CODAP and anxious to have more students learn with data.

LINKS

CODAP
http://codap.concord.org

Data Games
http://play.ccssgames.com

InquirySpace
http://learn.concord.org/inquiryspace

CODAP portal
http://codap.portal.concord.org

Contact us
codap@concord.org


Nathan Kimball (nkimball@concord.org) is a curriculum developer at the Concord Consortium.


Jamie M. Broadhead (jamie.broadhead@yahoo.com) is Head of Product Development at Videatives, Inc.

The Land of Bump:

How an Animated Story Helps Young Students Develop Heat and Temperature Concepts

By Nathan Kimball and Jamie M. Broadhead

Over the past two years we have conducted dozens of interviews with groups of children in kindergarten through second grade to find out if new visualization technologies could help young students explain phenomena of temperature and heat scientifically. We discovered that these children readily accept the idea that the world is composed of tiny particles that are always in motion—a concept that is the fundamental building block for the kinetic heat model.

What does this discovery mean for science education? Can these technologies be used practically in early elementary classrooms? To find out, the Sensing Science project worked with six adventurous K-2 teachers who took their students on a journey of inquiry into temperature and heat. We introduced the teachers to these new tools and technologies, discussed the science of molecular heat, and considered different classroom approaches to teaching the subject.

Their students worked with three technologies: an infrared camera, a "thermoscope," and an online story called "The Land of Bump" in three classroom lessons. The infrared (IR) camera helps children visualize changes in temperature, but it does not present heat as particles in motion. So we focus here on the thermoscope and the Land of Bump, technologies that address heat transfer through particle motion.

Heat and temperature technologies

The Sensing Science project invented a new tool—the thermoscope—to visualize temperature as kinetic motion. The thermoscope uses temperature probes attached to a computer to control the speed of randomly moving particles of a molecular model (see cover). The dots on the screen move faster as temperature increases (by placing the probe in hot water, for example) and slower as the probe touches something cooler. Students experimented with the speed of particles by placing the temperature probes in hot or cold water, and were asked to predict events such as mixing cold and hot water.

Using the thermoscope, students tested different temperatures and carefully observed the screen of moving particles. They noticed that the *overall* speed of the particles is governed by temperature, but that even at the same temperature, particles move at different speeds. When particles randomly bump into each other, the students noticed how the speed changes—when a fast particle bumps a slow one, the fast particle slows down and the slow one speeds up.

Students also read an online animated story called The Land of Bump (Figure 1) that we co-developed with FableVision. The main characters—round dots called "Cool Blues" and "Red Hots"—*like* to dance. The Cool Blues like to dance slowly while the Red Hots like to dance fast. While this dimension of choice ran the risk of confusing the students, who sometimes explain the characters' changes by saying "because they wanted to," the children were, nonetheless, able to relate the story to the particle motions they had observed with the thermoscope.

The problem confronted by the story's characters is how dots in adjacent areas can dance without changing their speed. Students must use their understanding of how fast- and slow-moving dots interact—how bumping transfers heat—to find a creative solution to avoid bumping. We found that their previous use of the thermoscope was critical to their solving the problem.

Young students relating concepts

With a single barrier between them, the Red Hots and Cool Blues eventually all dance at the same speed because the bumping is transferred through the barrier. But when a double insulating barrier separates them, they dance at their original speeds—fast and slow (Figure 2). A good insulator prevents the interaction of hot and cold particles. The barrier that contains the hot particles cannot bump the barrier that contains the cold particles even though both are moved by the particles on their side. How do students explain this solution?

We discovered a range of concepts in the answers students gave to the narrator in the Land of Bump (Table 1). They displayed a great deal of high-level thinking related to particle motion in the imaginary context of Red Hots and Cool Blues, offering explanations for how the barrier between the hot and cold particles prevented a transfer of energy. While not all students could articulate the more complex concepts, we expect that children have the initial tools to begin to explain the causes of heat transfer, conduction, and insulation, the building blocks for later understanding of the kinetic heat model.

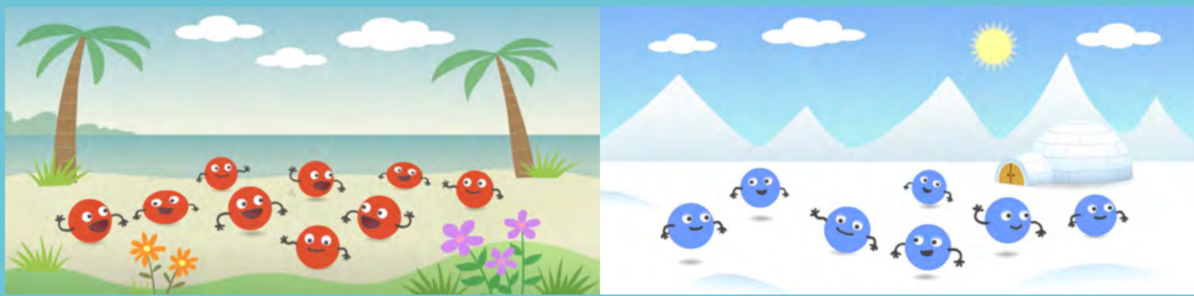


Figure 1. The Land of Bump interactive online story, starring the Red Hots (left) and Cool Blues (right). In the Land of Bump (http://lob.concord.org), timed pauses allow students to discuss concepts out loud with their partners. Click or tap (on an iPad) the green arrows to change pages. Click or tap the flashing speaker to hear the text.

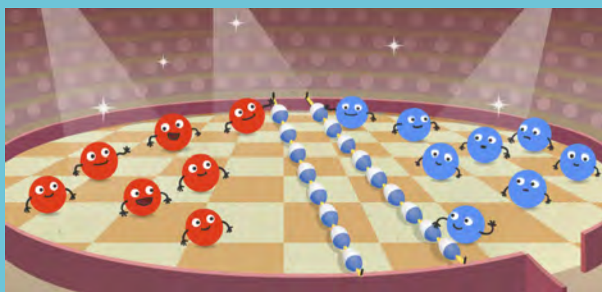


Figure 2a. With a double row of barriers sufficiently distant not to pass the dancers' bumps from one side to the other (i.e., insulation), the Red Hots and Cool Blues can dance their routines.

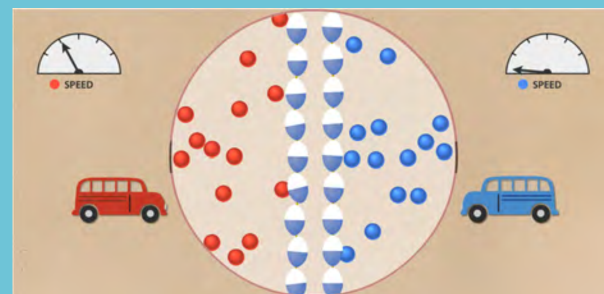


Figure 2b. A molecular view of the dancers and the insulation.

Table 1. Student concepts about the Land of Bump. (K indicates kindergarten, G1 first grade, and G2 second grade.)

Heat and temperature concept	Student responses to the Land of Bump narrator
Some particles move slowly, some move quickly.	Student 1 (G2): "Um, I noticed that the red, like, they were moving a lot faster 'cause they had a lot more energy than the blue and, like, they, they were like moving faster." Student 2 (G1): "They are not hardly moving at all. They are going slow."
Particles sometimes bump into each other.	Student 3 (K): "Oh, and they're gonna bump into each other."
Particles that get bumped can then bump other particles.	Student 4 (K): "It's going toward one. It bumped into one. It bumped into another."
Particles that move quickly can bump into particles that move slowly.	Student 5 (G2): "They [the Red Hots] have more energy and they're stronger, they have stronger power, so they kind of, like, just bumped into the blue."
Fast particles that bump slow particles make the slow particles speed up.	Student 6 (K): "'Cause the Cool Blues are getting, are getting hit by the Red Hots, so they're going really fast."
When a fast particle and slow particle collide they both change speeds.	Student 7 (G2): "Because they're touching each other so that makes the Reds slow down and the Blues faster than before."
A particle that moves when hit may not move far enough to hit another particle.	Student 8 (G2): "Yeah, ah-hum, they changed. Because they, um, kept bumping into each other and then the Blues bump so slowly that they didn't bump them very fast so they went only a couple of inches, and they're, like, going very slow." Student 9 (K): "Mine, mine is very slow [Cool Blue], and he's right there, and he's apart from all of the others."
If particles cannot reach other particles, there will be no change of speed due to bumping.	Student 10 (G2): "Because when the Reds bumped into their separator, they had their own separator so they didn't have to share their separator with the Blues. And the Blues had their own separator so they didn't have to share with the Reds. ...So, like, the Reds bump into their separator, they give speed to it, but the Blues never bump into it, so they don't speed up."

LINKS

Sensing Science
http://concord.org/sensingscience

Land of Bump
http://lob.concord.org

Dan Damelin
(ddamelin@concord.org) is a technology and curriculum developer at the Concord Consortium.

Joe Krajcik
(krajcik@msu.edu) directs the CREATE for STEM Institute at Michigan State University.

Interactions and Energy:

Big Ideas That Link Science Concepts

By Dan Damelin and Joe Krajcik

Everything in the universe is made from atoms. Virtually all phenomena we observe around us are the result of interactions between atoms and energy changes associated with those interactions: static cling is the result of attractions at the atomic level; a hurricane's energy comes from interactions between water molecules; colds caused by viruses and bacteria are disabled when molecules made by your immune system stick to them. Much of physics, chemistry, and biology can be traced to atomic-level interactions.

The Interactions project, funded by the National Science Foundation, is developing a semester-long interdisciplinary science course based on this fundamental idea. The goal of Interactions—a collaborative partnership between the Concord Consortium, Michigan State University's CREATE for STEM Institute, and the University of Michigan—is to support high school students in developing a deep understanding of forces and energetics involved in interactions between atoms and molecules, which can be applied to a variety of phenomena across disciplines.

Alignment to NGSS

The *Framework for K-12 Science Education* and the *Next Generation Science Standards* (NGSS) call for students to make sense of phenomena or design solutions to problems by engaging in three-dimensional learning—using scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. They identify atomic-level forces and energetics as physical science disciplinary core ideas. Despite the foundational importance of these ideas, most students do not develop an understanding of them. The Interactions curriculum helps students work toward achieving many NGSS performance expectations in physical science and life science.

The curriculum especially focuses on two science and engineering practices—modeling and constructing explanations—though these practices overlap significantly with other practices, such as analyzing data and planning investigations. To facilitate these key practices, the curriculum emphasizes:

- student experience of phenomena through teacher-led demonstrations and student-run experiments
- integrating simulations that help students explore related phenomena
- conducting discourse driven by student questions and student-illustrated models that predict and explain the phenomena being studied

For example, students explore the particulate nature of matter in a paired set of activities. First, they experiment with a syringe: pulling the plunger out and pushing it in, sealing it and compressing the gas inside, and measuring the mass of the syringe under different conditions (Figure 1). Students then draw a model that would explain their experiences and participate in a class discussion based on their models. Next, they use a simulation of a syringe in which they can perform many of the same experiments, this time in a context in which the particulate model of matter can be tested and observed (Figure 2). Students revise their models and engage in another discussion using their work with the simulation to drive the discussion. (Examples of classroom discourse can be seen in a series of videos created by the National Science Teachers Association—http://ngss.nsta.org/ngss-videos.aspx—that highlight a classroom implementation of the Interactions curriculum.)

Curriculum overview

The disciplinary core ideas developed in the Interactions curriculum are critical for explaining many phenomena important to physics, chemistry, biology, and Earth science. Because much of what we can see at the macroscopic level is due to underlying atomic-level interactions, linking the macroscopic and microscopic worlds connects the sciences rather than putting them into narrow disciplinary boxes.

To provide motivation and context, each of the four units is guided by a driving question. Students make sense of phenomena by constructing models or writing explanations about how they occur. Physical models and computer-based simulations are used to visualize and develop an understanding of the principles that govern interactions at very small scales, so they can be used to explain phenomena at the macroscopic scale.

Unit 1 – Why do some clothes stick together when they come out of the dryer?
The unit focuses on understanding electrostatic attraction patterns at the macroscopic level, and uses the fact that neutral objects are attracted to both positively and negatively charged objects to prompt a dive into the nature of matter and the source of static charge at the atomic level.

Unit 2 – How can a small spark start a huge explosion?
Students start exploring phenomena that are best modeled using the concept of energy conservation. They are introduced to different manifestations of energy, including potential energy. As with Unit 1, the initial exploration is at the macroscopic level, and it ultimately ends in an exploration of energy at the atomic level and a basic understanding of chemical reactions.

Unit 3 – What powers a hurricane?
Students explore energy and conversion of various forms of energy that are related to intermolecular attractions and changes in state. They explore how bonds with varying polarity result in various emergent properties of substances and associated changes in energy when these molecules interact with each other.

Unit 4 – Why is a temperature of 107°F deadly?
The topic of intermolecular attractions is extended to a biological context where the structure and function of molecules are strongly linked to their shapes. Understanding why complex molecules like proteins form stable structures is approached through both intermolecular attractions (polar and non-polar) and potential energy minimization. The unit brings together models students have developed over the previous units to explain phenomena and ties together the entire curriculum.

Research

Several districts are currently field-testing the curriculum. We are researching to what depth high school students learn ideas related to interactions at the molecular level and energy changes during interactions, what types of representations and illustrative phenomena help students connect macroscopic and submicroscopic phenomena to the underlying scientific ideas that explain them, and what instructional tasks and teacher scaffolds effectively promote three-dimensional learning.

We believe that students completing this curriculum will have a solid basis for understanding and explaining much of the world around them. They'll gain a foundation of usable knowledge that will give them a jump-start for future subject-specific courses later in high school and beyond.

Figure 1. Students explore the particle nature of gases using a syringe.

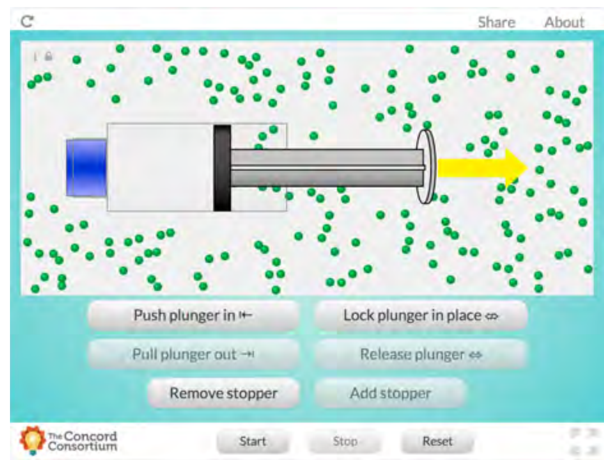


Figure 2. Students also explore the particle nature of gases using a simulation of a syringe.

LINKS

Interactions
http://concord.org/interactions

Interactions Curriculum
http://interactions.portal.concord.org

Dragons Fly Higher

with New Projects

By Chad Dorsey and Frieda Reichsman

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

Frieda Reichsman
(freichsman@concord.org)
is a senior research scientist.

Dragons have been breeding on servers and in classrooms worldwide for many years at the hands of students using our Geniverse software to learn about genetics. Now they're multiplying—and migrating to new topics and grade levels—thanks to two new projects funded by the National Science Foundation.

Geniverse is free, web-based software for high school biology that engages students in exploring heredity and genetics by breeding and studying virtual dragons. By programming the mechanisms that govern real-world genetics into a virtual environment, this game-like software circumvents traditional classroom obstacles of time and space and provides a means for experimentation that closely mimics real-world genetics. Two new projects will build upon this strong foundation, bringing it to new learning settings and enhancing its use within technology-rich classrooms.

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

GeniConnect: Afterschool biotechnology learning and mentoring

The three-year GeniConnect project will use Geniverse to help connect underserved students with local biotechnology professionals. By deepening its gaming aspects and revising content to more fully target middle school biology, we plan to extend Geniverse into the afterschool environment at East End House, a community center in East Cambridge, Massachusetts. Local professionals will mentor students, playing Geniverse with them and exploring biotechnology and its impacts on everyday life while also helping to broaden students' views of future career options to include science. With researchers from Purdue University, we'll explore how an immersive game and a connection to a real scientist can increase student interest in and learning of science. In addition to creating connections between students and mentors, we will build and characterize robust networks between biotech firms and the community center to produce a toolkit for STEM industries to foster successful partnerships with community centers and afterschool programs nationwide.

GeniGUIDE: Providing intelligent guidance for teachers and students

As students engage with next-generation digital curricula on individual laptops, teachers often find themselves in the position of knowing less about their students' learning or struggles on a daily basis. A four-year collaboration with North Carolina State University will pair Geniverse with robust intelligent tutoring systems (ITS) to provide real-time classroom support.

GeniGUIDE—Guiding Understanding via Information from Digital Environments—will offer automatic support for students' common problems and stumbling blocks, leveraging the strengths of ITS to relieve teachers of the burden of answering commonly repeated questions and problems. At the classroom level, it will continually monitor student learning and progress, and make use of this capability to connect learners. When it identifies a student in need of assistance that transcends basic feedback, the system will connect the student with other peers in the classroom who have recently completed similar challenges, thus cultivating a supportive environment.

At the highest level, the software will leverage the rich data being collected about student actions and the system's evolving models of student learning to become a valuable real-time resource for teachers. GeniGUIDE will identify students most in need of help at any given time and provide alerts to the teacher. The alerts will include contextual guidance about students' past difficulties and most recent attempts as well as suggestions for pedagogical strategies most likely to aid individual students as they move forward. Project research will contribute to understanding how data streams from deeply digital learning tools can be useful in furthering student content understanding.

We're excited to welcome veteran teachers who have followed dragon genetics tales (and tails) for many years in BioLogica or GenScope, as well as our newest Geniverse teachers and students. Studying dragons is a great way to teach genetics!

LINKS

Geniverse
http://concord.org/geniverse

GeniConnect
http://concord.org/geniconnect

GeniGUIDE
http://concord.org/geniguide

Innovator Interview:

Janet Kolodner

jkolodner@concord.org

Q. You began in AI and pioneered case-based reasoning. What is that?

A. Rule-based expert systems were becoming more capable in 1980, but they broke unless you told them exactly what to do, and they didn't get better with time and experience. My advisor, Roger Schank, and I thought we could realize expertise better by building systems that could have experiences and remember them, reason about those experiences to create new knowledge, and organize those experiences so the new knowledge could be refined with new experiences.

Q. So case-based reasoning (CBR) led to your interest in education?

A. My kids were telling me that elementary and middle school science was boring. At the same time, I was running the EduTech Institute at Georgia Tech with the idea that what we know about how people learn should guide what we do with technology. The advisory board consisted of people from around campus who were interested in educating better, including K-12. With its engineering and architecture colleges, design education was the sweet spot at Georgia Tech. Designing things gets people excited about learning. And design requires iterating towards better solutions, matching CBR's focus.

We began by working closely with engineers, architects, and middle school teachers, plus Howard Barrows and Paul Feltovich, experts in Problem-Based Learning (PBL). Together, we figured out ways of using the tenets of PBL to guide learning from design in middle school classrooms. *Learning by Design*, the Georgia Tech approach to middle school science, came from that. It turned out to be a beautiful amalgam of what CBR says about reasoning processes involved in learning from experience and what PBL says about how to manage classroom facilitation and sequencing.

Q. You founded the *Journal of Learning Sciences*. How did that get started?

A. I started the journal in '89. We didn't know what it would become, we only knew there were a lot of people in a lot of different disciplines who wanted to learn about learning. I talked to people in computer science, education, cognitive science, and so on. I learned almost everything I know about education from my experience as a journal editor.

Q. Tell us about your time at the National Science Foundation with the Cyberlearning program.

A. I had a great time at NSF. I had several beliefs that made their way into the Cyberlearning solicitations. First, you can't be successful at making a difference if what you're funding is just a little out from the current time. You have to give researchers a chance to design the future they are envisioning. Second, the best insights come from teams with different expertise and a variety of perspectives. Third, the best designs for learning technologies are informed by what is known about how people learn. Research funding for learning technologies should not simply be about designing new products, but should combine designing and building a product with learning from the design and development. My legacy will lie in the way these core tenets are taken up.

Q. What are the next challenges you want to pursue in education and technology?

A. I've learned how important integration across projects and approaches is to having impact. I also realized that technology can play two huge game-changing roles. The future of the computer in education is in helping people experience phenomena, processes, and situations they could not otherwise experience and in fostering the kinds of expression that help people refine their understanding. I'd like to be chief architect on several integrative projects that show what's possible when technology is used well in education.

Read more of Janet's interview at **http://concord.org/innovator-interview-janet-kolodner**

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.

Next Step Learning

The Concord Consortium, Next Step Living, and the Virtual High School are collaborating to create a technology-enhanced learning pathway from school to home and then to clean tech careers. The goal of the new three-year Next Step Learning project is to develop and test an education model that fuses science learning in school and energy efficiency at home. Students will use infrared cameras, sensors, simulations, and mixed-reality technologies to visualize, investigate, and design invisible heat and mass flows in real and virtual worlds. Over 2,000 students in diverse secondary schools across Massachusetts will participate in this research.

Towards Virtual Worlds

A new one-year project is exploring how to foster knowledge integration across disciplines. Middle school students will learn about ecosystems in the context of an ecosystems challenge, and later will be asked to address an air quality challenge. Researchers will examine (i) conditions under which learners form memories of their ecosystems experiences that allow them to address the air quality challenge and (ii) conditions under which learners want to improve their solutions to the ecosystem challenge after the air quality challenge. Lessons learned will inform the design of project challenges and virtual worlds with affordances for supporting knowledge integration across projects and disciplines.

Building Partnerships for Education and Speech Research

The sophistication of technologies for processing and understanding spoken language—such as speech recognition, detection of individual speakers, and natural language processing—have radically improved in recent years. These technologies can now automatically detect many features of speech—including questions, emotion and stress, and spoken keywords—with high accuracy. However, educational research has barely begun exploring their potential to provide insight into, and eventually revolutionize, research areas as diverse as collaboration, argumentation, discourse analysis, emotion, and engagement. This project—a partnership of the Concord Consortium, SRI International's Center for Technology in Learning, the Speech Technology and Research Laboratory at SRI, and the Center for Robust Speech Systems at the University of Texas at Dallas—will help launch a new interdisciplinary field of study in spoken language technology for education.

Data Science Games

No significant problem facing society can be solved without the participation of people who have a deep understanding of how to work with data, but there are too few such people. Data Science Games will develop and test new data science games for high school biology, chemistry, and physics, and research how learners conceive of and learn with data. The data science games will be embedded in our Common Online Data Analysis Platform (CODAP). Data from the game will flow seamlessly into the CODAP environment, and high scores in the game can only be achieved through data modeling, thus increasing learners' fluency with data science skills and concepts.

SmartCAD

The Concord Consortium, Purdue University, and the University of Virginia will conduct design-based research on SmartCAD, a computer-aided design (CAD) system that supports secondary science and engineering with three embedded computational engines capable of simulating the mechanical, thermal, and solar performance of the built environment. These engines will allow SmartCAD to analyze student design artifacts on a scientific basis and provide automatic formative feedback to guide student design processes. The project will develop three curriculum modules based on the Learning by Design framework to support three design challenges: Solar Farms, Green Homes, and Quake-Proof Bridges. Research will investigate what types of feedback are effective in helping students attain the learning outcomes and under what conditions these types of feedback help students attain the outcomes.

Editor: Chad Dorsey | **Managing Editor:** Cynthia McIntyre | **Design:** Jan Streitburger | **concord.org**
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