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The Concord Consortium

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Perspective:

New Initiatives Open Doors for STEM Learning

By Chad Dorsey

A number of important trends have evolved that will shape the future of learning through technology. These paint an exciting picture for the coming years. The Concord Consortium is pursuing significant research and development opportunities at the forefront of these trends.

Opportunities for discovery

One of the central aspects of science learning is the importance of discovery. Scientists can toil their whole lives toward seemingly intractable problems, fueled solely by the excitement and intrigue of discovering something new that adds to or changes our understanding of nature. Learners are no different, motivated by the next "aha!" moment. Every chance to interact with phenomena is an opportunity for personal scientific discovery. However, these opportunities are all too often unidentified or unavailable, so moments of inspiration are lost. Technology can change that, turning everyday moments into exceptional flights of inspiration and opening doors to learning far sooner than traditional approaches.

Much of the potential for discovery in science depends upon the ability to notice something new or different in the first place. Any new "way of seeing"—think telescope, microscope, or MRI—has ushered in its own groundbreaking era of insight. In science education, another new era is upon us with the advent of the affordable infrared (IR) camera. These devices, which cost tens of thousands of dollars only years ago, now transform an iPhone into a sophisticated discovery device for less than $200. For years we've been using their compelling images to provide new perspectives on the natural thermal energy differences of everyday phenomena. Now, new funding will expose the hidden world of chemistry, shedding new light on chemical processes and creating powerful new techniques that enable discovery in the undergraduate chemistry laboratory.

Students don't need to be in an undergraduate lab to reach new understandings about the world around them—they can just as well be in kindergarten. We're developing innovations to enable young students to discover aspects of the particulate nature of matter. A new project unites probeware and model-based inquiry to help young learners investigate connections between heat and phases of matter. Experiences linking temperature sensors and particle-based simulations make the relationships among these topics visible and explorable. As students combine hands-on observations with representations of particles they see on the computer, they build and refine a model that explains their discoveries. Our curricular approach will help young learners gain a powerful, explanatory appreciation for the unseen world and leverage discovery into foundational understanding of a topic essential to all future science learning.

Fostering inquiry

While tools and approaches for discovery are essential to uncovering intriguing phenomena, the next step for both scientists and students is to explore these phenomena systematically. Although research makes it clear that students should conduct independent, open-ended investigations, the process of generating, managing, and understanding scientific experiments can often be overwhelming. Learners must juggle measurement tools and lab equipment, understand the process of data collection, and then format and wrangle data sets into meaningful representations. As learners navigate these complexities, hiccups and complications abound. As a result, most laboratory experiences end up far more reminiscent of recipes than independent inquiry.

Though the cognitive journey leading toward open-ended inquiry is complex, it is crucial to developing a deep understanding of science and to cultivating skills necessary for both citizenship and future STEM careers. Using innovative technologies, we are transforming this otherwise ungainly experience into a seamless progression with opportunities for analysis, sense making, and further investigation. By combining a software environment that integrates probeware, video analysis tools, and data exploration capabilities with instructional guidance, we aid students in moving from fundamental data analysis and scaffolded experiments to open experiments of their own design.

In addition to facilitating measurement and analysis, we will engage students in thinking about the control of experiments and the computing skills involved in managing data flow and feedback loops that monitor and respond to an ongoing experiment. In the process, students will engage with inquiry experiences that replicate essential aspects of modern laboratory experiments, using computational thinking skills and gaining experience with the actuators and sensors that comprise the "Internet of Things."

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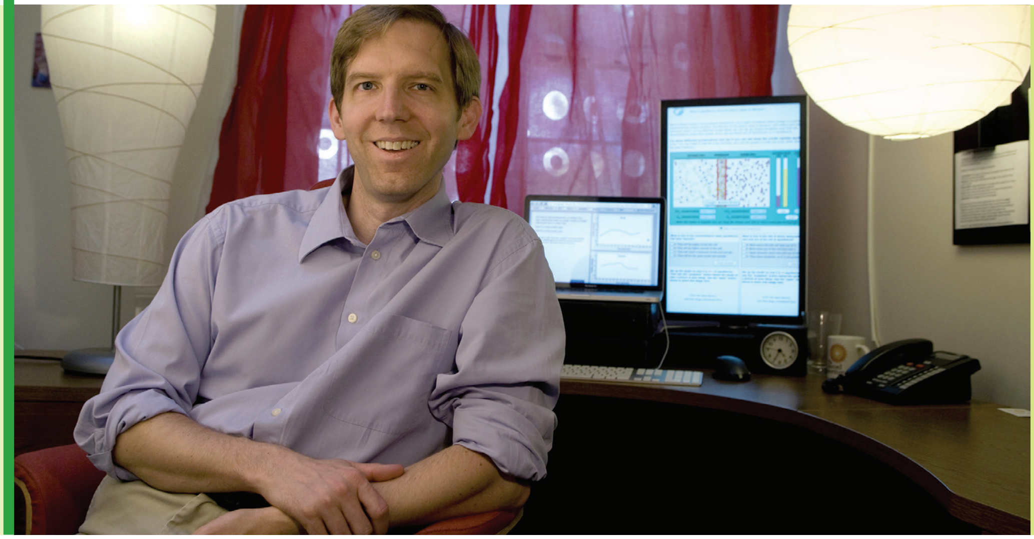
Technology can turn everyday moments into exceptional flights of inspiration and open doors to learning far sooner than traditional approaches.



Expanding the boundaries of modeling and simulation

Our work in modeling and simulation has demonstrated technology's power to make the invisible visible and explorable for years. Whether providing "hands-on" access to the molecular world or enabling inquiry in genetics, our models and simulations open doors to understanding many otherwise inaccessible topics. In the process, we have developed a flexible set of open-source simulation engines and strong research-based approaches for their development and application. The next generation of work in this area is expanding the horizons of modeling.

One way in which these horizons can expand is through stronger connections across interrelated topics. Natural phenomena abound with complex interconnections, but educational constraints often force them into containers that render the connections all but unrecognizable. Biology is perhaps the key offender—in genetics, activity at the cellular, molecular, and whole-organism biological layers is inextricably intertwined, yet the three are typically addressed as discrete topics. Further, the central evolutionary concepts that bind them together are often taught in isolation from all three. We are addressing this problem directly, developing models and simulations that combine the richness of evolution and ecosystems with all aspects of genetics into a single interconnected whole.

We are stretching the notion of models and simulations in other innovative ways. In our new GEODE project, we are bringing static visualizations of most Earth science classes to life with dynamic modeling environments that students can use to create and test scenarios and explore concepts of geological systems and deep time. We're also expanding models in a literal sense—our Precipitating Change project will place students directly inside models of severe weather events, allowing them to monitor live radar screens and place virtual rain and wind gauges on the floor to collect data as virtual thunderstorms pass through the classroom. Students will also design models themselves, applying computational thinking skills as they create, evaluate, and combine forecast models and issue evacuation orders to nearby "towns."

In other cases, combining technologies can extend the possibilities of models far beyond the ordinary. Our work with electronics models focuses on understanding and fostering collaboration, linking multiple students together in collaborative groups, each designing a part of a full virtual circuit. As students work together to troubleshoot the circuit, they exhibit and hone their collaboration skills. Behind the scenes, we are able to analyze their interactions with the simulation and each other, using data analytics to develop new approaches for characterizing, assessing, and supporting student collaboration. And in yet another new project, we are creating an entirely new technology genre, permitting learners to grapple with "wicked problems" involving multiple interlinked complex systems. Combining our easy-to-use SageModeler tool for diagramming and modeling complex systems with MIT's StarLogo agent-based modeling environment, we will enable learners to model complex systems at multiple levels, providing an unprecedented path to understanding the complicated world of system dynamics.

We are thrilled to stand at the forefront of so much exciting new work, and are eager to develop and share the resources, findings, and tools we generate. We invite you to read the back cover of this issue where we outline additional projects that will move our research forward in innovative new directions.

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LEARNING TO BUILD **a sustainable world**

By Charles Xie

On September 3, 2016, the United States ratified the Paris Agreement, which sets the goal to confine the global average temperature within 2°C above pre-industrial levels. Unlike many other treaties, the Paris Agreement took a bottom-up approach—exactly how the goal is to be accomplished is left for countries to pursue. As such, its fulfillment will require epic efforts from the grassroots in each country. As Bill Gates said to *The Atlantic*, "We need an energy miracle."

The Concord Consortium has responded to the call with an education-industry partnership to engage millions of students in co-building a sustainable world with cleantech companies. This partnership is creating pathways from science learning in the classroom to problem solving in the real world with the goal of fostering science education and cleantech growth simultaneously. In collaboration with Borrego Solar, Boston Solar, and FLIR Systems, the project focuses on residential energy efficiency and solar energy exploitation. Such a project is compelling to schools because integrating real-world challenges in the curriculum can motivate students to learn.

> "It felt as if I was getting some amazing experience that professionals do and I am only in high school."
>
> *– A student who used an infrared camera to inspect his home, 2016*

Research and development concentrate on supporting students to learn science and engineering concepts and skills necessary for performing meaningful tasks to identify energy waste and solar potential in their homes, schools, and towns. While it is not appropriate to expect students to do a professional job, it is feasible to design a curriculum that guides them to gather scientific evidence that is sufficiently strong to influence decision makers, thereby generating valuable leads for cleantech companies. Industry contributions include co-developing the curriculum, ensuring the authenticity of tasks, incentivizing students to attain goals, and following up with practical solutions when leads emerge. The participation of cleantech companies is essential. After all, a problem is not solved until a solution is applied. By meeting the needs of all the stakeholders, this project can achieve a triple win: Students learn STEM knowledge and skills, families save money on energy costs, and companies create more cleantech jobs. This triple win is vital for the project to eventually find a way to fund itself.

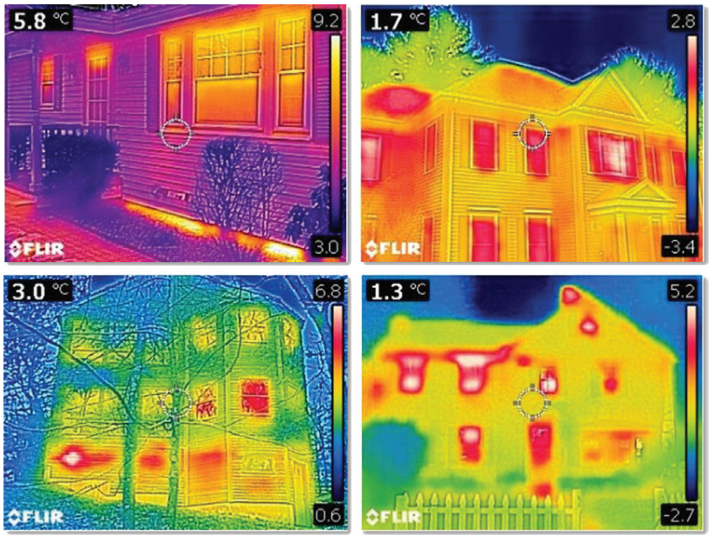
Two innovative technologies

Our project would have little chance to succeed without tools that can support students in learning science and engineering and solving complicated real-world problems. Education is a priority as the project must first address this need.

Our work on infrared (IR) thermography and computer-aided design (CAD) over the past six years illuminates how engineering technologies can be transformed into educational technologies. These technologies used to be clumsy and expensive, but their latest generations have become much more friendly and affordable. The price of IR cameras (special cameras that show otherwise invisible heat transfer) has plummeted from thousands of dollars to about $200 in recent years, removing the last hurdle for them to become scientific inquiry tools in classrooms. As educational technology vendors such as Vernier and Pasco have started selling them to schools, more students will have access to their incredible power. In the meantime, CAD programs have evolved far beyond their original drafting versions of the 1990s and incorporated many physics engines that allow users to test ideas with simulations while conceiving designs. Sophisticated CAD software with this level of agility provides students with an engineering design environment for rapidly exploring clean energy solutions without any cost or risk. Free CAD tools of this type can propel the much needed K-12 engineering education to a large scale.

Two pathways from learning classroom subjects to solving real-world problems are made possible by these technologies.

Figure 1. Students in our pilot tests took IR images of their own houses from the street.



Pathway I: From thermal science to energy efficiency

Many people are unaware of energy waste in their homes as heat transfer across the building envelope is often unnoticeable—until it is revealed by an IR camera. Unfortunately, an IR scan of a building works only seasonally, works best at night, and occasionally raises privacy concerns. These downsides limit its field applications and drive up business costs. But students are not subject to any of these limitations—they have no problem inspecting their own homes at night for free. The question is how we can teach them to get the job done right.

The ability to visualize heat makes IR cameras unrivaled for teaching thermal science—a subject area that most students spend weeks learning. A solid understanding of thermal science is also a prerequisite to thermographic diagnostics. This lays the groundwork for the following pathway: Students learn thermal science through hands-on experiments with an IR camera in schools and then, equipped with knowledge and skills and guided by an inspection protocol, study the energy efficiency of their own houses with the camera as homework (Figure 1).

Professionals may question the accuracy of student work. Indeed, when students are examining their homes independently, they can make mistakes. Part of our solution to this problem is a smartphone app called SmartIR, being developed in partnership with FLIR based on their FLIR ONE plug-in camera and the built-in sensors of a smartphone. SmartIR can walk students through an inspection process in real time and help them avoid common mistakes. For example, IR inspection requires the indoor-outdoor temperature difference to be at least 10°C. When viewing a building from the outside, nighttime is preferred as there will not be any false positives caused by solar heating. By using the temperature data from a weather service or the IR camera itself, the app can determine whether the temperature difference is large enough to do an inspection. By using the clock or ambient light sensor of the phone, it can tell whether students are conducting a task during the day or at night. And by using the location tracker, the accelerometer, and the digital compass, it can acquire the location and orientation of the camera. If an ideal condition is not detected, the app will suggest that students wait until nightfall eliminates the side effect of solar heating and lowers the outside temperature. SmartIR also allows students to easily collect IR images or videos, tagged with contextual data from sensors. Students can use a voice recorder to narrate an image or video. To accelerate the reporting process, the app automatically assembles the inputs from students, sensors, and cameras into reports that students can submit for grading.

Pathway II: From engineering design to solar power

There is no better time than now to inspire and prepare students for the solar challenge. Many teachers already cover solar power in their curriculum. But in most cases, students are not deeply involved in the solarization of their own homes, schools, and towns. It is true that students are not professionals and adults may not trust them when making serious investments in solar energy. But there is a safe way to let them try: computer simulation.

Unfortunately, CAD programs for solar simulation typically cost $1,000 per license and most hardly support student learning.

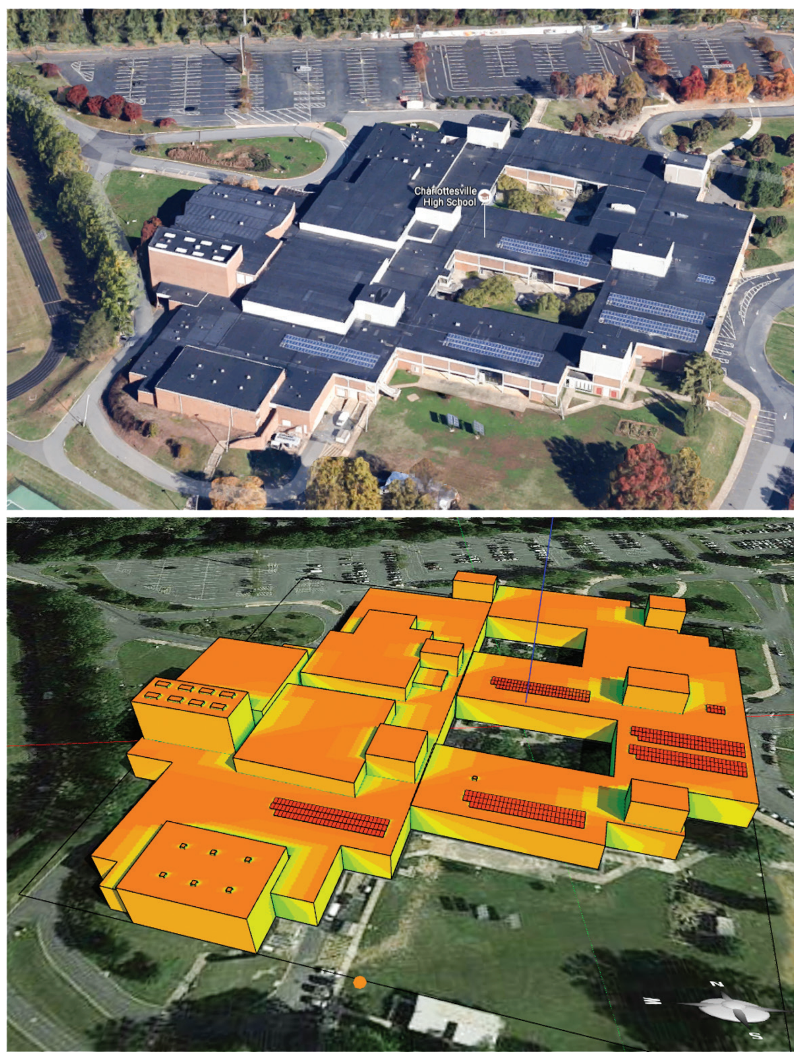


Figure 2. Upper image: The 3D model of a school in Google Maps. Lower image: Energy3D's shading visualization shows the distribution of solar radiation on the roof.

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To address these problems, we have developed a free alternative—Energy3D. With a simulation accuracy that rivals its pricey counterparts, this versatile tool can be used to design rooftop solar systems for residential and commercial buildings, ground-mounted photovoltaic solar farms with or without trackers, and concentrated solar power stations. Importantly, Energy3D is full of visual effects and graphing tools essential to teaching and learning.

We have developed three engineering projects based on Energy3D for students:

- **Solarize Your School.** Students design solar solutions that turn the roof and parking area of their school into small power plants. If their school has already installed solar panels, students can model the existing design as a baseline and investigate whether it can be revised to produce more electricity (Figure 2).
- **Solarize Your Home.** Students design solar panel arrays for the roofs of their own houses. They sketch Energy3D models of their houses, add solar panels, and use simulations to decide whether it is viable for their families to "go solar" (Figure 3).
- **Solarize Your Town.** Students explore all sorts of solar solutions for their towns. This open-ended project aims to unleash creativity. Students have flexibility in choosing solar technologies, sites, and scales.

In all three projects, students must perform feasibility analyses to evaluate the costs and benefits of their designs. Borrego Solar and Boston Solar will provide their expertise in commercial and residential solar systems, respectively, to support the implementations of these student projects.

From students to change makers

Our pilot studies have shown promising outcomes. In a study of 18 students in the energy efficiency pathway, all 12 respondents to the exit survey indicated that the heat transfer concepts they learned in the classroom helped them understand how energy flows in their homes.

To ignite changes beyond the school walls, we will create a virtual network based on Google Maps for students to inform the community about their work. Through this network, students will be able to share their thermal images and solar designs—along with their scientific analyses, feasibility studies, and presentation slides—with friends, parents, schools, governments, and companies. An extension of SmartIR will empower students to create the Infrared Street View, an IR version of the Google Street View that renders a virtual thermal reality of neighborhoods. Together, students can collect and produce useful information about the energy efficiency and solar potential of their areas. Cities and towns can use this information to assess the current state of their energy issues. Companies can use it to identify potential customers. And future students will be able to compare their results with past results to see if any progress has been made.

Ultimately, as envisioned by the National Science Foundation, which invests in the future of our nation, millions of "change makers" cultivated by our education systems will jointly catalyze an energy miracle.

Figure 3. Middle school students solarized their houses and presented their designs to parents.

> "Learners can be Change Makers, identifying and working to solve problems that matter deeply to them, while simultaneously advancing their own understanding and expertise. Research shows that engaging in real world problem solving enhances learning, understanding, and persistence in STEM."
>
> – *National Science Foundation, 2016*

LINKS

Energy, Engineering, & Education
http://energy.concord.org

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Monday's Lesson:

Students Making Models

By Dan Damelin

One of the key practices of the Next Generation Science Standards (NGSS) is "developing and using models," which should be done in the context of exploring disciplinary core ideas and crosscutting concepts. This definition of modeling is broad, encompassing both using and evaluating simulations made by others as well as defining models through drawings, diagrams, and descriptions. The NGSS practice also includes students building their own simulations based on underlying models of phenomena.

While scientists and engineers commonly build models, existing tools for building and testing models are not typically accessible for students, especially younger students. The Building Models project, a collaboration between the Concord Consortium and the CREATE for STEM Institute at Michigan State University, is designing a new web-based systems modeling tool called SageModeler to address this need. SageModeler is easy to use and accessible to students as young as middle school.

Build a model of ocean acidification

The HS-ESS3-6 performance expectation reads, "Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity." With SageModeler, we can model ocean acidification as one example.

1 Open SageModeler

http://concord.org/building-models

SageModeler is embedded in Concord Consortium's Common Online Data Analysis Platform (CODAP), which allows you to analyze model outputs with tables and graphs.

2 Add variables to the canvas

First, brainstorm factors that affect ocean acidification. What contributes to it and what is affected by it? Since ocean acidification is caused by increased levels of carbon dioxide in the water and affects the viability of shellfish and other calcifying organisms, we need at least three variables to model the system: CO_2 in the water, acidity level of the water, and shellfish health. Now, add images for each variable to the canvas.

3 Link variables and set relationships

Draw links from one variable to another and select from a menu to set the relationships between those variables. By using words and pictures of graphs (Figure 1), students can define the underlying equations that will be used to run the model without advanced math knowledge.

4 Run the model

Open the simulation controls and run the model to collect data. Adjust the model settings to see how changing the variables affects the outcome. Does the model output data make sense? Does it match real-world data? Are the relationships between variables set up appropriately?

5 Revise and expand your model

Revise your model to better match the phenomenon you are modeling. The model doesn't tell the whole story of ocean acidification, so you may want to add more variables. For example, how does carbon dioxide get in the water? What are the sources of CO_2? What other factors moderate the production of CO_2? What else might be affected by changes in the health of shellfish? As you continue to ask new questions, you can revise your model and deepen your understanding of the system.

We are currently adding functionality to SageModeler, including the ability for older students to define relationships with algebraic definitions. We are also developing curriculum units with multiple opportunities for students to build and revise models of real-world phenomena.

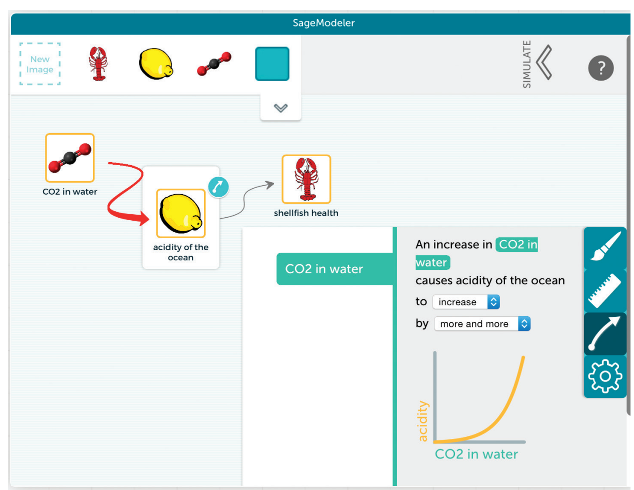

Figure 1. Create links between variables and set relationships with words and graphs.

LINKS

Building Models
http://concord.org/building-models

CODAP
http://codap.concord.org

Dragons Rule After School:

Helping Students Prepare for Biotech Careers

By Kiley McElroy-Brown and Trudi Lord

Geniverse is a digital game where high school biology students put genetics knowledge into action as they breed virtual dragons. Now we're sending our dragons into afterschool programs, specifically those that support underserved middle school youth, with the goal of connecting the students with local biotechnology professionals to strengthen their awareness of STEM careers.

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The GeniConnect project, funded by the National Science Foundation, will couple a "next-generation" version of the Geniverse game with coaching from biotechnology industry professionals, hands-on activities and experiments, and visits to local labs to introduce participants to careers in the burgeoning field of biotechnology. Since the research and treatment of human disease is at the core of much of the biotechnology industry, students will encounter dragons with disorders in Geniverse and learn about their real-world parallels and research leading to treatments. Helping students better understand how issues they encounter in their daily lives—for example, the current prevalence of genetic diseases such as diabetes—are being addressed through science is at the core of making science relevant and helping students envision themselves as future scientists.

Classical genetics focuses on the correlation between genes and specific traits, skipping over the means or mechanisms by which genes exert their influence over traits. The next generation of Geniverse reveals the key role that proteins play in the manifestation of genetic traits. Students will zoom into a cell to help the proteins that link genes to traits do their jobs. New game mechanics are being designed in partnership with the award-winning FableVision Studios to bring proteins to the fore, while engaging a younger audience. We will also include Next Generation Science Standards (NGSS) disciplinary core ideas, crosscutting concepts (especially scale, structure and function, and cause and effect), and science and engineering practices (such as asking questions, using models, conducting investigations, and analyzing data) for middle school students. Although the focus is on afterschool and informal learning, Geniverse activities will help students build understanding toward the MS-LS1-1 and MS-LS3-1 performance expectations.

Evidence-centered Design

To weave the varied elements of the GeniConnect project into a unified program, we are employing Evidence-centered Design (ECD) as a guiding framework to develop each key project area. While ECD was originally conceptualized for assessment design, it can also be applied effectively to program design and evaluation.[1] ECD provides a structure for the clear identification and unpacking of targeted outcomes, specifies the experiences needed to achieve those outcomes, and identifies what constitutes evidence for evaluating students' knowledge, skills, and abilities (KSAs). An ECD-based design has two essential models at its core, a student model and an evidence model. The student model defines the variables related to students' knowledge, skills, and abilities that we hope to elicit with GeniConnect. The evidence model consists of a selection of specific tasks that can elicit behaviors providing evidence of students' KSAs, and includes detailed instructions for measuring the KSAs targeted by the student model.

Our student model defines targeted levels of KSAs using a genetics learning progression defined by an expert team of genetics education researchers.[2,3] We prioritized three concepts (transmission genetics, genes as instructions, and the relationship between a protein's structure and its function) that students will encounter through Geniverse game play and hands-on activities. Through discussion and guided activities, students will relate these concepts to real-world diseases and make connections between the laboratory research their game coaches are conducting and the research and experiments they are doing with dragons within the Geniverse virtual labs (Figure 1).

Using ECD, we have also outlined specific items to measure students' motivation towards studying genetics and future careers in science. These items include how students see genetics as relevant to the real world, their confidence in their ability to understand and apply genetics knowledge, and their intent to pursue additional learning opportunities in science (Table 1).

Our evidence model focuses on detecting support for varying levels of understanding and motivation. We are developing pre- and post-assessments to measure student content understanding and motivation before and after the eight-week program of activities. In the spring of 2016, we piloted the pre-assessment protocol with a representative sample of six students from our inner-city afterschool partner, interviewing them about their prior knowledge of genetics terms and their interest in science-related careers. For example, while the term "genetics" was unfamiliar, students recognized "genes" and "DNA" and knew that they are involved in the inheritance

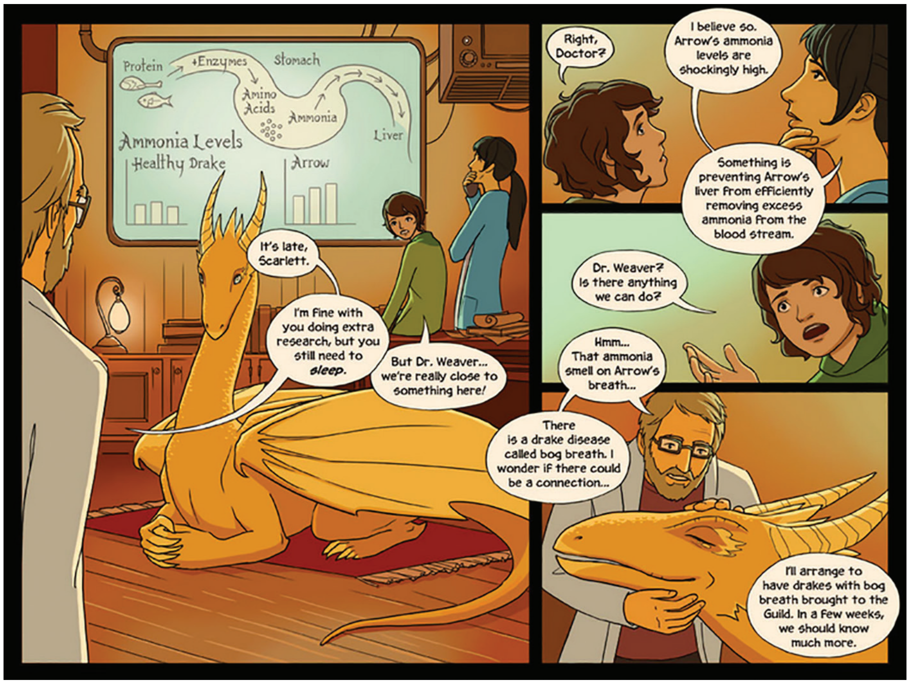

Figure 1. Students enter a virtual lab in Geniverse to solve genetics problems and visit real scientists in their laboratories.

of traits from biological parents. When they were probed about their interest and motivation in science and genetics, most students had difficulty recognizing value in learning about genetics for themselves, but were better able to talk about the value to others, suggesting that we should prioritize the value of genetics to society. We tested a set of 16 content understanding items and 15 motivation items, and have identified the six most appropriate items in each category for further development.

Breeding engagement and STEM career awareness

Through exciting game-like activities, relevant hands-on science, coaching from industry professionals, and field trips to local labs, we hope to interest more youth in studying science and, eventually, successful careers in the growing arena of biotechnology. We are counting on our Geniverse dragons to breed more interest in science and STEM career awareness in middle school students.

STUDENT MODEL		EVIDENCE MODEL		
KSAs developed as a result of student participation in GeniConnect	**Irrelevant KSAs** (KSAs necessary to succeed, but not targeted as content knowledge. Need to support, but not assess.)	**Experiences we will provide**	**Expected student thinking**	**Type of evidence to be collected**
Genes as information Genes are instructions for building physical, functional structures found in cells called proteins.	Students have the ability to: • Interpret and interact with representations of genes and proteins in Geniverse • Interpret scientific terms • Navigate through game environment • Read and interpret text prompts • Use working memory effectively	Students manipulate genes while being able to view how each protein associated with those genes affects dragon appearance and health. Students manipulate proteins to level up in the game. Students identify and manipulate DNA instructions for proteins and observe the connections to molecular machines.	Based on learning progression of Duncan et al. (2009) and Todd (2013) • Level 1: Genes are non-informational in nature; they are passive particles associated with traits • Level 2: Genes are non-informational in nature; they are active particles associated with traits • Level 3: Genes are active instructions that "tell" proteins, cells, or the body to carry out specific functions • Level 4: Genes have information about biological entities and function at multiple levels • Level 5: Genes are instructions for proteins that carry out functions within the organism	**Proximal measures** (actions or artifacts from Geniverse): Students manipulate genes on chromosomes to affect protein structure and function. Proficient students successfully manipulate genes to alter protein structure in order to carry out proper function in the cell and cells of future progeny; they suggest introducing proper functioning proteins to treat dragon disease. Non-proficient students only focus on repairing a single protein to remediate effects. **Distal measures** (pre/post items; tasks embedded in pre/post interviews): Students draw, describe in words, or select a model in a new context (e.g., family contexts involving a disease like diabetes or Alzheimer's). Students are asked to relate concepts such as gene, protein, and cell. Proficient students include proteins or link genes and proteins in models and articulate a molecular model to account for a disease. Non-proficient students do not link genes and proteins or fail to include proteins in models; they may also include non-canonical ideas.
Value (Real-world connections) Students see genetics as relevant and/or useful in the real world.	Ability to interpret survey and prompts by interviewers about value to society.	Opportunities to learn about how genetics can be used to find cures or treatments for diseases. Targeted interactions with coaches. Activities and discussions in afterschool sessions that make explicit connections between GeniConnect program features and value.	Students perceive learning about genes, patterns of inheritance, and/or proteins as… **High value:** useful to society and can point to specific examples. **Intermediate value:** useful to society, but without specific reasons. **Low value:** not useful or relevant to anyone's life.	**Survey items** **High, intermediate, and low value:** Using a Likert scale, students select level of agreement with statements about finding genetics relevant or useful. **Interviews** **High value:** Verbal responses that connect features of Geniverse that have import to the real world, such as "my brother has sickle cell anemia and is wondering if his child will get it, too." **Intermediate value:** Verbal responses such as "It's useful to know more about genes. They seem important since I hear about genes in TV shows and movies." **Low value:** Verbal responses such as "I can't think of any reason we should learn about genes."

Table 1. A small section of our Evidence-centered Design table illustrating one content area and one motivation outcome.

1 Mislevy, R. J., Almond, R. G., & Lukas, J. F. (2003). A brief introduction to Evidence-centered Design. *ETS Research Report Series, 2003*(1), 1-29.

2 Duncan, R. G., Rogat, A. D., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th–10th grades. *Journal of Research in Science Teaching, 46*, 655–674.

3 Todd, A. N. (2013). The molecular genetics learning progressions: Revisions and refinements based on empirical testing in three 10th grade classrooms (Doctoral dissertation). Retrieved from Wright State University CORE Scholar.

LINKS

GeniConnect
http://concord.org/geniconnect

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Data Science Games

By Natalya St. Clair

The emerging discipline of data science combines computational thinking, mathematics, statistics, and content knowledge, paving the way for a new genre of educational technology: data science games. Funded by the National Science Foundation, our Data Science Games project is developing games and curriculum materials for middle and high school students to use data while learning science. The goal is to research the potential of this new genre of educational technology.

Data science games

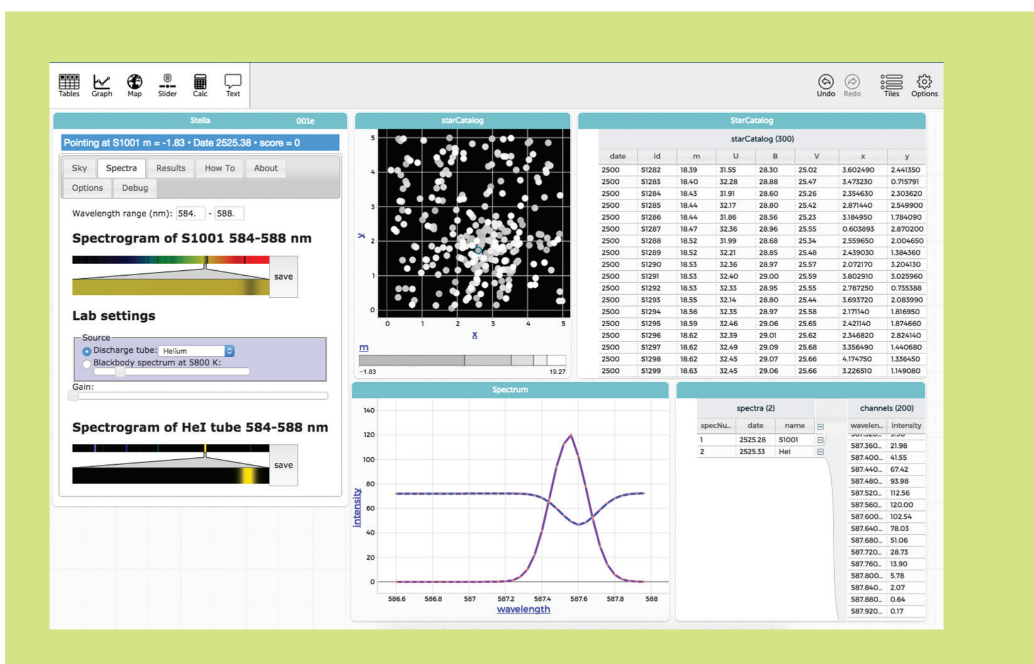
The more experience students have working with data, the better prepared they are to contribute to the data-driven society they are entering. Students practice data gathering and interpretation best in the context of learning subject-specific material. But middle and high school students currently do not get much experience working with data. Our Data Science Games project is exploring how games about science that include data at their core can be integrated into classroom learning in schools that have adopted Next Generation Science Standards (NGSS).

All data science games are embedded in our Common Online Data Analysis Platform (CODAP), so students can analyze the data generated in each game. The games follow a similar design: students generate data through their actions and make sense of that data as essential moves for game play. CODAP allows students to store, organize, analyze, and visualize their data. By combining, filtering, and transforming the data, students better understand the game, improve their game strategy, and level up—plus experience data science at the same time.

Games for physics, chemistry, and biology

In the game *Stella* the goal is to find information about a star, such as the speed with which it's receding from the Earth (Figure 1). In this simulation, students compare the color spectrum of a star with elemental spectra to detect the pattern of its chemical composition. The score depends on the ability to use data about spectral lines to find the star's "red shift." *Stella* helps students build an

Figure 1. Students visualize their data in graphs and tables in CODAP to solve challenges in the game *Stella*.



understanding of the NGSS HS-PS3-3 performance expectation, so they learn science content in the context of a game.

We are also exploring additional games for physics, chemistry, and biology (Figure 2). For example, another physics data science game might involve building or altering a structure within certain constraints; the data include the forces on all the structural elements. A chemistry game might incorporate the custom design of chemical reactions to achieve specific goals, such as buffering a chemical system so it doesn't explode. Each reaction could generate data about bond strength, activation energy, pressure, temperature, and concentration that students use to solve specific problems or puzzles.

And a biology game could consist of an epidemiology puzzle, in which the goal is to stop the spread of a highly contagious disease. For each move, students are allowed to examine some of the patients who come to the clinic for treatment. Students can use maps in CODAP to visualize data about the spread of disease among clinic patients in the same neighborhood or workplace. The score is determined by how quickly the student stops the spread of disease.

We are currently developing and testing beta versions of these games to ensure they are engaging and educational. Future versions of the games will be released under open content licensing and available at no cost.

Classroom testing

In August 2016, eight San Francisco Unified School District secondary science teachers tested game prototypes and lesson ideas and provided realistic perspectives on connections to classroom practice. Teachers offered feedback to improve each game and participated in a brainstorming session to design a chemistry data science game aligned to NGSS. One teacher said, "I definitely see myself using CODAP in my classroom to have students generate graphs and analyze data. I will be playing for a few hours when I get home!"

Six middle and high school teachers will teach a two-week curriculum unit focused on one or more multi-level games, in which students participate in game-playing episodes interspersed with classroom activities and discussion. Based on classroom testing and feedback, we will improve curriculum materials for each unit.

Research

Our research focuses on discovering ways this new genre can be integrated into classroom learning, and how data science games can be used to increase student encounters with data-rich situations. We expect to learn how students reason with data in ways we have not been able to before at the pre-college level. Specifically, we are interested in exploring young people's conceptions of data structures and other data science competencies. Interviewing students as they interact with data science games will help us understand the learning processes and the challenges students experience as they work with data structures. Later, we will move toward a broader exploration of student learning and behavior in workshop and classroom settings to better understand the classroom supports and scaffolds required to encourage learning.

This research will inform the design and development of future data science educational tools and serve as the framework for guidelines that other educators can use to design and develop data science games. We hope to provide models of how to integrate learning data science into established content areas.

The future of data science

We are optimistic that data science games can create a path for students to learn how to make data-driven decisions in both games and life. We are excited about the potential of data science games and invite others to consider how to include data science across the curriculum—in games or other inventive ways.

Data science games can be developed by any software or curriculum developer and embedded easily in CODAP. Contact us at dsg@concord.org for more information or check out the CODAP help videos for instructions to embed an interactive.

Figure 2. In the game *Stebbins*, students act as predators eating prey, using data to understand how protective coloration can influence evolution.

LINKS

Data Science Games
http://concord.org/data-science-games

CODAP
http://codap.concord.org

Integrating Knowledge

Across Virtual Worlds

By Janet Kolodner, Amy Pallant, and Ken Wright

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Imagine your students are visiting a virtual pond to learn about ecosystems. Their challenge is to figure out why all the large fish in the pond have died. Students examine the flora and fauna and analyze their relationships to each other and to the fish. They consider how human activity or weather might affect the environment and the health of the fish. They walk around the pond, talk to people, and dive underwater to collect data. Their complete engagement in this virtual world carries over into classroom discussions, which are lively and full of data analysis, arguing from evidence, and talking through ideas.

Later in the year, months after their visit to the virtual pond, your students are faced with a new challenge within a new virtual world. They must identify the sources of the poor air quality in this world. To do this, they need to determine the human and natural impacts on air quality, connect the flow of matter in the atmosphere with sources of pollutants, and understand how and why air quality changes over time.

Having discovered what killed the fish in the first challenge, students should have a general understanding of how systems and organisms interact. But will they remember and put that knowledge to work in the second challenge? This is the research question we are exploring.

How does understanding deepen?

The Towards Virtual Worlds that Afford Knowledge Integration Across Project Challenges and Disciplines project, funded by the National Science Foundation, is investigating under what conditions students remember something learned from an experience so that they can use it to solve a new challenge. Such remembering offers meaningful opportunities to integrate what they are learning across units and disciplines. Our goal is to learn how to design and use project challenges and their virtual worlds to support such knowledge integration.

Figure 1. While walking around the pond in EcoMUVE, the student's avatar meets a ranger, who suggests using the submarine tool to explore the microscopic world of the pond.

Case studies

Our research focuses on what students take away and remember after solving a complex and engaging problem in a virtual world. What influences their learning and memories? By comparing what they remember to what they *need to remember* to make inferences in new worlds, we hope to develop preliminary design principles for virtual worlds that will prepare students to make connections across multiple topics.

We recently observed and interviewed students who were studying ecosystems using EcoMUVE*, the virtual world introduced above (Figures 1 and 2). EcoMUVE was created by researchers at the Harvard Graduate School of Education, who allowed us to use their software for our investigation and connected us to a school where two teachers were integrating EcoMUVE into their ecosystems unit. We observed two sixth grade classes every day for two weeks. Students worked in pairs, and we used screencast software to capture what they did in the environment—ways they explored it, information about the plants and animals they observed, data they collected, and their hypotheses and explanations. We videotaped class discussions so that we knew what students were hearing from the teacher and from other students that might influence what they did and remembered. We also videotaped their final presentations.

We focused our observations on select pairs in each class to capture the discussions they had with each other and with small groups around them (Figure 3 and 4). These conversations reveal student thinking as they tried to solve the challenge. Two weeks after the unit was complete, we interviewed the students and asked what they remembered about using the software. A week after that, we interviewed them again and asked what they remembered about ecosystems and why the fish died.

We have begun to compile case studies of three student pairs in each class. Each case study will include the activities the students carried out in EcoMUVE and where they focused their attention as they addressed the challenge. We'll make hypotheses about why the students remembered certain things, and analyze the relationships between the reasoning they do in the virtual world and what they remember. We will look across the case studies to identify similarities and variations in what influences what they remember.

Figure 2. The submarine tool in EcoMUVE displays blue-green algae (green) and a single bacterium (small red speck) at a magnification of 500X. Students get a sense of the relative size of such organisms. Other tools allow students to measure temperature and the concentration of algae and bacteria in the pond.

What we are learning

Our early analysis provides some clues. First, all of the student pairs had very good memories of the explanations they came up with for the dying fish. This tells us that when they grapple with an engaging problem, they remember their explanations.

Second, the students remembered much of the data they had analyzed while exploring their hypotheses and coming up with explanations. During classes, small groups of students had rich discussions around data they had collected and spent a lot of time examining and trying to make sense of graphs of their data. Indeed, when students had a reason to use the data in charts and graphs, they were eager to collect data, use graphs to examine trends, and attempt to draw conclusions from the graphs. Additionally, students were able to use data as evidence for their explanations.

Giving students an exciting challenge in which they had to work hard to come up with explanations led to willing engagement in data collection and in data analysis. They remembered what they put a lot of effort into figuring out, and they came to understand the relationship between evidence and explanation.

What's next?

Our next step will be to draw connections between what students experienced and what they remembered, especially focusing on what influences the richness of their memories. We will then develop hypotheses about the kinds of tools that might be included in virtual worlds to increase the probability that more students will build rich memories of their experiences and the phenomena they encounter. In the future, we hope to build virtual worlds that include those tools and continue our research efforts by learning how technology can help students use what they remember to integrate what they are learning across challenges, virtual worlds, content areas, and disciplines.

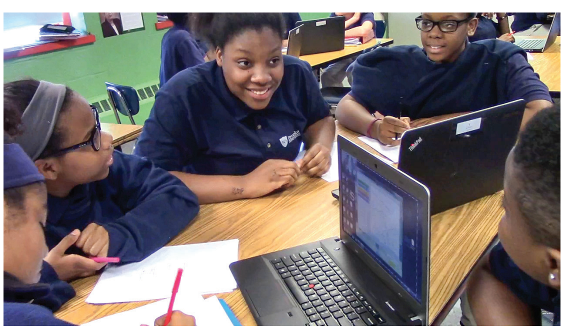

Figure 3. Students are discussing whether the fish died due to lack of dissolved oxygen in the water or the influence of bacteria.

Figure 4. A student explains to her partner how a change in one factor occurs in tandem with a change in another one as shown on the graph.

* http://ecolearn.gse.harvard.edu/ecoMUVE/overview.php

Under the Hood:

Hands-on Interactive Activities with Leap Motion

By Christine Hart

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Three years ago, Leap Motion, Inc. released a small USB device that had the potential to offer a completely new way for people to interact with computers. Using a combination of three infrared LEDs and two cameras, the device can track the position and movement of hands in three dimensions, enabling gesture-based controls for applications. A welcome change from over 30 years of clicking a mouse.

The GRASP (Gesture Augmented Simulations for Supporting Explanations) project is leveraging this capability and using the Leap Motion controller in desktop mode to capture hand movements and control web applications. (Learn more in "GRASPing Invisible Concepts" in the spring 2016 *@Concord*.)

With the Leap V2 SDK, defining gesture-based interactions for controlling a web application via JavaScript becomes quite simple. Events from the Leap are captured in the processLeapFrame function:

```
processLeapFrame(frame) {
  const hands = frame.hands;
  const data = {};
  data.numberOfHands =
    hands.length;
  …
}
```

Frames are snapshots of data sent from the Leap device to the application multiple times per second. From this frame data, we can determine the number of hands in view. We can also determine the angle of each tracked hand using `hand.roll()` and the relative velocity of each hand using `hand.palmVelocity`. Many other types of gestures can be detected, including pinch, grab, and individual finger positions.

With the Leap API, the data returned from the cameras is translated through the API, describing each of these gestures with an additional metric—the level of confidence of detection. The Leap hardware uses infrared cameras to detect movement, so bright sunshine can impair the ability to track hands. Overlapping hands are not easily identified, which can also impact the confidence level and can affect tracking performance. The design of a gesture-controlled application must take into consideration both the ease of performing a particular gesture by the user and the likelihood that the device will recognize that gesture.

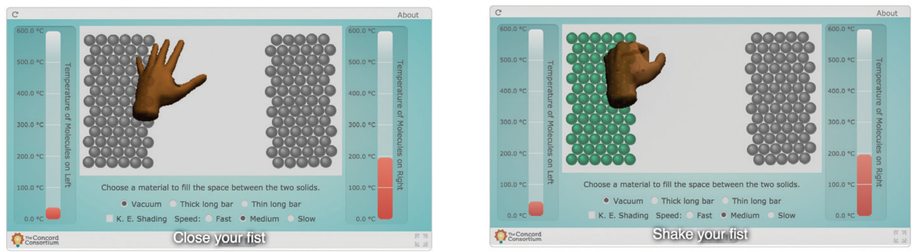

Figure 1. In the heat transfer simulation, the user is instructed to close (left) and shake (right) her fist. The Leap Motion controller senses that the block of molecules has been selected and turns green.

The gestures that have proved most successful for GRASP in terms of their ability to be recognized reliably are those that involve significant hand movement and rotation. In our Molecular Workbench heat transfer simulation, for example, the user must "grab" a molecule and shake it to initiate interaction (Figure 1). Detecting a closed fist can be configured and adjusted:

```
const hand1 = frame.hands[0];
const hand2 = frame.hands[1];
let closedHands = 0;
if (hand1 && hand1.grabStrength
> this.config.closedGrabStrength)
{
  closedHands += 1;
}
if (hand2 && hand2.grabStrength
> this.config.closedGrabStrength)
{
  closedHands += 1;
}
```

In our seasons simulation (Figure 2), the angle of the sun's rays relative to the ground is controlled by the roll of the detected hand, with some tolerance adjustments:

```
function isPointingLeft(hand) {
  return
   angleBetween(hand.palmNormal,
   PALM_POINTING_LEFT_NORMAL)
   < HAND_POINTING_LEFT_TOLERANCE;
}
```

Being able to interact with simulations via hand gestures supports GRASP research goals. The Leap Motion device with the V2 SDK makes it possible within the context of a web browser.

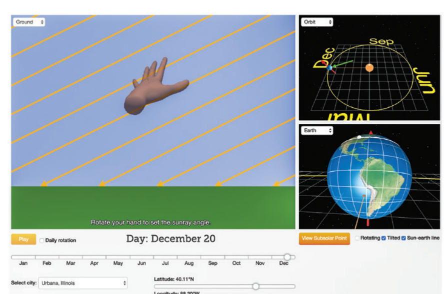

Figure 2. The student can control the sun's angle by rotating his hand.

LINKS

GRASP
http://concord.org/grasp

Innovator Interview:
Carolyn Staudt

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Q. Did you start out as a teacher?

A. I wanted to be a chemist and worked on micelle research. I also tutored graduate students and really liked it. I was certified to teach chemistry and math, and taught at an all boys school. I moved to another parochial school where I started 24-hour space simulations, which grew into something really big.

Q. What did you simulate?

A. Going to the moon! Kids designed an entire geodesic dome for a weeklong moonbase. John and Annie Glenn came to the opening ceremony. Astronaut Al Worden did the closing ceremony. We had a NASA live feed for an hour a day. Two years later we created a seabase to simulate life at the bottom of the ocean with Sylvia Earle as the keynote. The domes lasted about 20 years. Kids still write to me about what an amazing experience it was.

Q. What did you take away from that experience?

A. Those were live simulations. Simulations mean something different now. Students need both hands-on and computerized versions of simulations. Students should not be underestimated. They can do anything given the opportunity.

Q. When did you get started with sensors?

A. We needed to monitor everything from the air to the water in a tilapia tank. It was about that time I met Phil Smith, designer of the IBM Personal Science Lab, and later David Vernier, an Ohio teacher at the time, at the local AAPT meetings, and started building sensors of my own. Then in the late '90s, I worked with Logal in Israel. Yoel Givol sent me a box of sensors and said, "Tell us what to do with these for education."

Later, I met Bob [Tinker, founder of the Concord Consortium] and started full time in 1999. We were playing with handhelds and thinking about attaching temperature sensors to them. The eMate was great because it had a keyboard, touchscreen, and a clamshell. We made the eProbe, which was available with the eMate. Our TEEMSS [Technology Enhanced Elementary and Middle School Science] project got all the major sensor vendors together in one room. We showed significant learning gains with probes, and TEEMSS was included in the What Works Clearinghouse.

Q. What does that unlock for learning?

A. It's exciting to have kids ask questions and collect data instantly. Probes are an extension of their hands. Sensors and models complement one another so well.

Q. What's driven your interest in professional development?

A. Being in the classroom for 20 years was really important. We have to trust students. In Innovative Technology in Science Inquiry we help teachers customize activities to make them locally relevant and provide multiple ways for students to learn.

Q. Water is now a focus in two of your projects. Tell us about that.

A. In 1998 I was at UNESCO in Paris and was asked about the most important resource. I had just been in Sierra Leone, so I said clean water. Most of the world has clean water problems. Water is shared—there are people upstream and downstream. What you do with your local watershed impacts everyone.

Q. Tell us about your pioneering work with young kids.

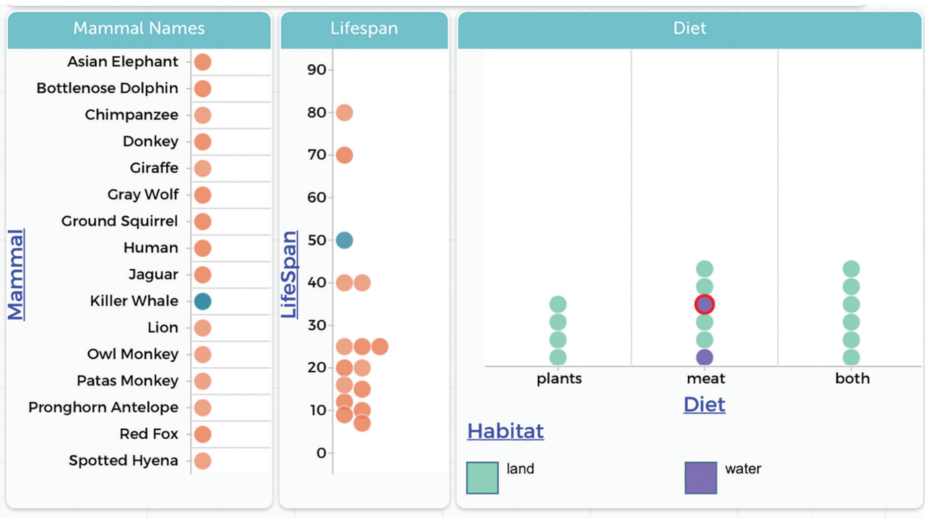
A. My work goes back to the simulations and summer camps and seeing early "aha!" moments. Kids use their only sensor—their hands—to learn about the world around them. I love being able to make something visible that's invisible through models and using sensors to drive that home.

Q. What's the best part of your job?

A. I get to play! The Concord Consortium makes tremendous open-source toolkits available to all.

The Concord Consortium

25 Love Lane, Concord, MA 01742



Data Science Education Technology Conference

You're invited to the Data Science Education Technology conference! Please join us at this groundbreaking event in the emerging field of data science education from February 15-17, 2017, at the beautiful Brower Center in Berkeley, California. The Concord Consortium's Common Online Data Analysis Platform (CODAP) project will be featured. Funding from the National Science Foundation supports this free event. Space is limited. Register online: http://codap.concord.org/dset/

- **Connect.** Join a growing community of data science educators and expand your network. There will be plenty of downtime for informal and impromptu connecting with colleagues. We'll provide innovative networking tools.
- **Innovate.** Work with programmers and educators and learn new strategies to make use of open-source software, new methods of integrating data science with content learning, and new ways to provide learners with access to data.
- **Discover Data Solutions.** Get access to CODAP and other free, open-source technologies to help as you develop online materials in which students use data.
- **Participate.** Learn, discuss, design, and create. Session leaders are experts in making use of CODAP and other data technologies for developing online materials for courses, citizen science, and public dissemination of data.

Middle Grades Students' Understanding of Big Math Ideas

Thanks to funding from the National Science Foundation, we will collaborate with Michigan State University (MSU) to develop digital capabilities associated with MSU's Connected Mathematics project. The project aims to understand how digital presentation of the curriculum and digital tools including drawing and sharing capabilities can help students collaboratively construct, manipulate, and interpret their digital drawings and representations. The project will conduct research on the effects of this digital environment and representations on learning, examining evidence of student thinking and the conceptual growth of big mathematical ideas.

Zoom In to Data Literacy

With funding from the National Science Foundation, our new Zoom In to Data Literacy project will create and evaluate six supplementary, drop-in digital curriculum modules—three in biology and three in Earth science—that enable students to learn and practice data literacy skills while answering compelling real-world science questions. We will integrate our Common Online Data Analysis Platform (CODAP) with EDC's Zoom In online instructional platform, which supports deep literacy by scaffolding and making student thinking visible and gives teachers tools to assess and respond to students' learning in real time. Project research will investigate whether engagement with data-rich digital curriculum modules improves high school students' learning of data literacy skills and concepts in the context of regular science instruction.

Enhancing Statistics Teacher Education

The Concord Consortium, in collaboration with North Carolina State University, Eastern Michigan University, and the University of Southern Indiana will develop approaches and resources for statistics preservice teacher education in a new project funded by the National Science Foundation. We will expand our Common Online Data Analysis Platform (CODAP) with functionality to support statistical content, and create and curate videos of teachers and students engaged with statistics in classrooms. These and other resources will be widely available and packaged into an open resource repository for mathematics teacher preparation programs. We will research how infusing technical and educational resources into undergraduate teacher preservice courses affects teacher statistics learning and their ability to design activities for secondary students.

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