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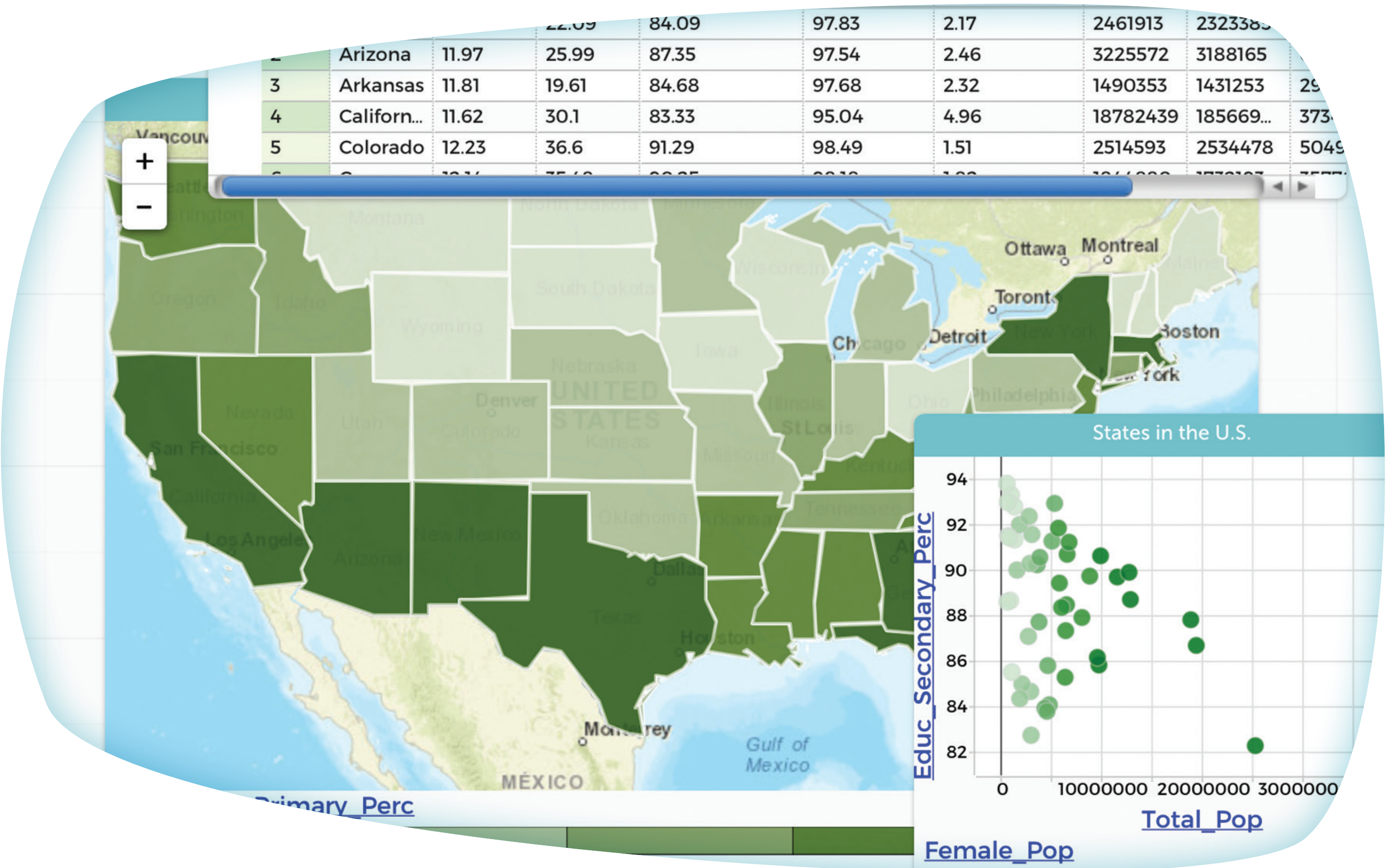

The Concord Consortium
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Perspective:
Honoring the Legacy of Bob Tinker

By Chad Dorsey

There are many ways of viewing our path in the world. Some people focus on the road ahead, considering each step one at a time. Some look slightly farther, to the upcoming bend, hoping a flicker of light will appear to illuminate their way. But a rare few have the ability to glimpse the distant horizon. It is these remarkable individuals who make the real strides, enlightened by a perception of the future that eludes the rest of us. Bob Tinker could see to the horizon—and beyond. He plunged toward it gleefully and without hesitation. On the way, he inspired and motivated us all as he blazed the trail to a transformative era in education.

The dawning of technology's presence in my own life crops up as flickering bursts of memory, each one a dusty page in the history of educational technology.

A printer head in a dusty community college lab screeches. Jagged black dots form words on broad white paper. The magic message—`DEER HIT!`—marks another step along the Oregon Trail.

My friend and I crouch over an Apple II, lugged home from school by my father for the weekend. We watch in silent awe as the blinking cursor paints pixelated swaths of random color. Then we regroup and debate: which snippet of BASIC to copy in next?

Crimped copper tubes on my father's workbench sprout bouquets of colored wire. Each hints at a tiny thermistor buried deep inside. The shining stalks stand together, at the ready, anxious to make their intended transition—from mere idea in a teacher-conference DIY session to the reality that beckons: hands-on, real-life voltages and temperature graphs in a bustling physics classroom.

Many years later—in a classroom of my own—a simple but compelling thought: could computer models, like the ones that formed the toolkit of my years of physics research, be equally powerful as tools for my students' learning?

Of course, Bob was ahead of me at every point. He was ahead of most of us.

Long before most people even had a clear understanding of what computers were, Bob had recognized their potential to transform the way we teach and learn science. And from the earliest days when he'd corner someone at an AAPT meeting to show them his wired-together contraption—a naphthalene-like substance in a test tube, a portable heater, and a thermistor, all fastened to a large piece of plywood and connected to a KIM-1 single-board computer—Bob was an evangelist for technology's power to bring the joy of science exploration to learners everywhere.

Even though the Concord Consortium has lost its founder—and an amazing friend, colleague, mentor, and collaborator—our memories of him and his work resonate in an enduring way. Because of Bob's consistency of vision, depth of foresight, and broad legacy, we recall and honor his spirit every day through the work we do. Bob played a significant role in two of the major NSF-funded projects we're currently working on. What's more, they both share core notions about STEM teaching and learning that speak to Bob's longstanding vision about technology and learning, and address our central mission as an organization.

Of course, Bob was ahead of me at every point. He was ahead of most of us.

"*[Microcomputers] offer flexible tools for communication, data acquisition, instrumentation, computation, analysis, and visualization. These tools empower students to do science, to undertake investigations of immediate interest and to build a durable understanding of the underlying science.*"

These words, written by Bob nearly 30 years ago, outline the important role he saw for technology, even then, as a means of opening up the process of science for learners. As Bob saw it, technology is a ticket to freedom, an invitation to jettison the rigid, formulaic trappings of traditional school teaching and go investigate. The nature of such undertakings was clear to Bob as

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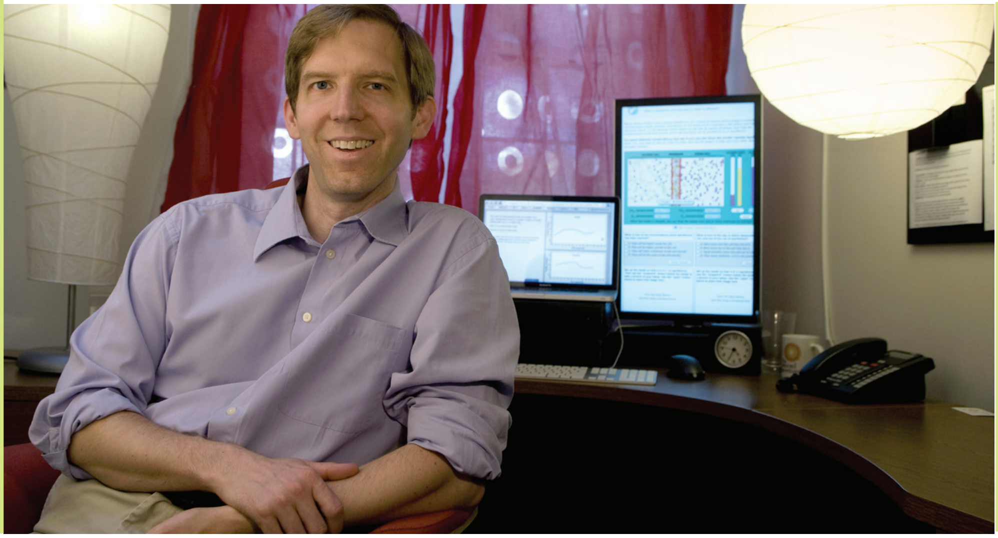

well—technology could enable youth to engage with problems of their own choosing and investigate them in open-ended ways.

Bob drew a contrast between these open-ended investigations and what he called the "storehouse model" of education, in which "we ask kids to store away facts, formulas, and definitions against some day in the future when they will need to draw from their hoard." Sadly, this contrast remains relevant in education still. It also remains central to our work.

The formula for successful science education, Bob noted, is right in front of us—science itself. "Science," he wrote, "provides the ingredients missing in science education: the joy of discovery, the excitement that comes from deeper understanding, and the satisfaction of solving an important problem."

Bob's vision of learning and how it progresses is the antithesis of the storehouse of knowledge. It casts learning as an adventure, an exploration, a series of discoveries. It is also highly empowering. Engaging in this process—identifying, defining, exploring, and *solving* a problem of one's own choosing—launches a powerful cycle. This cycle grows over time, reinforced by additional encounters, until it begins to unlock enormous personal potential. Engaging repeatedly with the true process of science provides both the practice and the pathway to identifying, understanding, and tackling problems of all types and topics, throughout all walks of life.

This process, captured by the broad term "STEM inquiry," encompasses the important practices of science and engineering and puts them to use in meaningful ways. It notably does not imply adherence to any kind of cookie cutter recipe, most certainly not the so-called "Scientific Method." Bob supplied frequent, adamant reminders that actual science proceeds in anything but a straight and methodical path; it moves instead through a mishmash of mistakes and false starts. He encouraged curricular formats and patterns that could help move students toward extended experiences of meaningful, non-formulaic inquiry learning. When successful, this type of learning is truly three-dimensional, providing powerful, long-lasting take-aways for learners. It is the type of learning that technology can render flexible, insightful, and powerful. And it is the type of learning Bob sought to promote from his earliest days in considering technology's role.

These notions—uncovering, demonstrating, and spreading the ways that technology can expand and deepen STEM inquiry—form the core of all our work. They weave through all our projects. And they excite us. They are also a constant reminder that there is still a great deal of work to do. Far too few examples of technology's important role in STEM inquiry reach learners today, especially those who remain traditionally underserved. Far too few teachers are well versed in selecting STEM inquiry resources that pivot on technology's presence. Even fewer have had the opportunity to become skilled at using them to facilitate deep learning. And, more broadly, too few of those who control the gates to STEM learning—from policymakers to parents—have had the chance to appreciate the importance and power STEM inquiry practices hold for students' learning and futures. These are big problems, for our children and our society. With Bob's legacy in mind, our work aims to confront them head on.

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The Data Science Education Revolution

By Chad Dorsey and William Finzer

Life is particularly interesting these days, if you have an eye for data. While predictions about entering the "data deluge" began only a decade ago, the current situation makes those warnings seem almost quaint. Today, data does much more than help us interpret complicated scientific or engineering problems and define basic choices we make every day, it dictates decisions *made for us* by the myriad machines, software, and algorithms that pulse just behind the curtain of modern life. Living and working in a world with data at its core lends a new urgency to teaching and learning about the skills and concepts of data science.

Two years ago, we noted in these pages that educators had only begun to conceive of the possibilities increasingly easy access to data offer for teaching and learning. Those ideas continue to ring true now. Society has a pressing need to envision the novel ways data can empower education. Moreover, there is an urgent need for action. Virtually every significant problem—from combating global warming to feeding the growing population, reducing violence, and increasing equity—will need to be tackled by people with data science skills and understanding. Unfortunately, there are far too few such people.

At the Concord Consortium, we have begun the challenging work of helping to launch the new field of data science education. As we do, we advance the goal of determining how best to bring about effective learning with and about data. We have made notable progress defining the boundaries and essential elements of data science education and drafting the first sketches of pedagogical and technological roadmaps. More important and exciting work lies ahead.

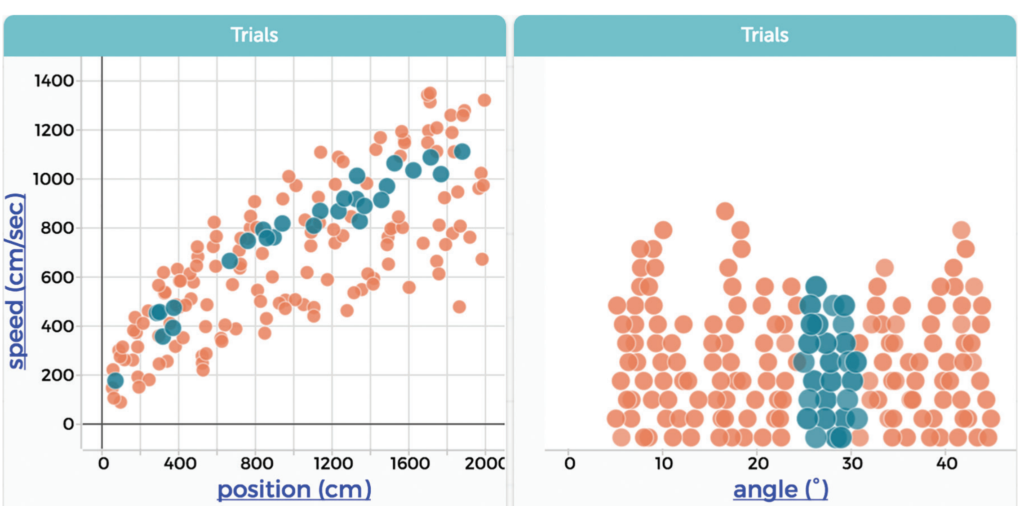

Figure 1. Data from a data-rich physics activity in which each point represents rolling a ball a given distance down a ramp, positioned at the given angle, with its speed measured at the ramp's bottom.

Preparing the next generation of data scientists

It is increasingly clear that data science is a critical area of focus for the future. And if you're a data scientist—or a company that needs one—that fact is evidenced by the competition (and pay) across industry. Data science has taken hold at the undergraduate and graduate levels, with data science institutes, departments, and courses materializing everywhere.

However, K-12 education is another matter entirely. Despite the fact that tomorrow's data scientist is today's fourth-grader, experiences with data are rare in today's K-12 classrooms. The situation is not entirely bleak—an increased emphasis on data in both the Common Core Mathematics Standards (CCMS) and the Next Generation Science Standards (NGSS) has helped usher in a recognition that this situation should change.

To launch K-12 classrooms along the data-rich path we desperately need we must provide more opportunities for K-12 students to work with data in ways that will better prepare them for learning and doing data science in college and the workforce. We must focus on early experiences to ensure that children develop core ways of thinking about data: the *habit* of looking for the data in any given situation; the *intuition* that visualizing data lends important insight; and the instinct to reach for appropriate technological tools to aid analysis and visualization. Such *habits of mind* are essential to providing the foundation our future citizens need to live and work fluently in a data-filled world. However, they can't just be tacked on after the fact—habits of mind become most potent when begun early in life and cultivated over time. If today's students are to be the ones who discover the data-driven solutions to important, complex problems of tomorrow, we must ensure that they have rich, immersive experiences with data throughout their pre-college learning, building up data habits of mind through frequent opportunities. Fortunately, there are useful points of entry into this important endeavor. The CCMS and NGSS provide good starting places for integrating data science skills and concepts into math and science learning, and the social sciences as well.

Extending K-12 data science curricula

What can we do now to foster data habits of mind in today's youth? The answer begins with learning experiences that engage students in high-quality, data-rich experiences rooted in existing standards and curricula. It continues beyond the basic standards, incorporating opportunities for data exploration, visualization, and analysis.

Tim Erickson gives a simple example familiar to every physics student: a ball rolling down a ramp. (See his blog post "Smelling Like Data Science.") In current classrooms, students might work in groups to roll a cue ball down a ramp and analyze its motion, with all groups following precisely the same steps. How, he asks, could this same experiment incorporate data science? What if the students each did something different? If your answer is that the result would be a mess, you're correct. The data set would require students to examine data from the motion of *many* different balls rolling down *many* ramps, of *many* different inclinations (Figure 1).

Consider the larger picture, however. What data is generated and analyzed in the two contrasting approaches? The standard lab activity yields a straightforward two-variable data set. The other yields a much larger data set with more than two variables. While both examples produce data that can lead to the lab's targeted understanding, the second invites inquiry. Its messy data pose a puzzle, one which requires students to experiment. Students must try different ways of organizing the data and produce different visualizations in order to uncover the relationships within. In our job of preparing students to swim in the data deluge they are certain to encounter later in life, we must purposely prepare learners for roles where dealing with messy data will be not only necessary, but routine.

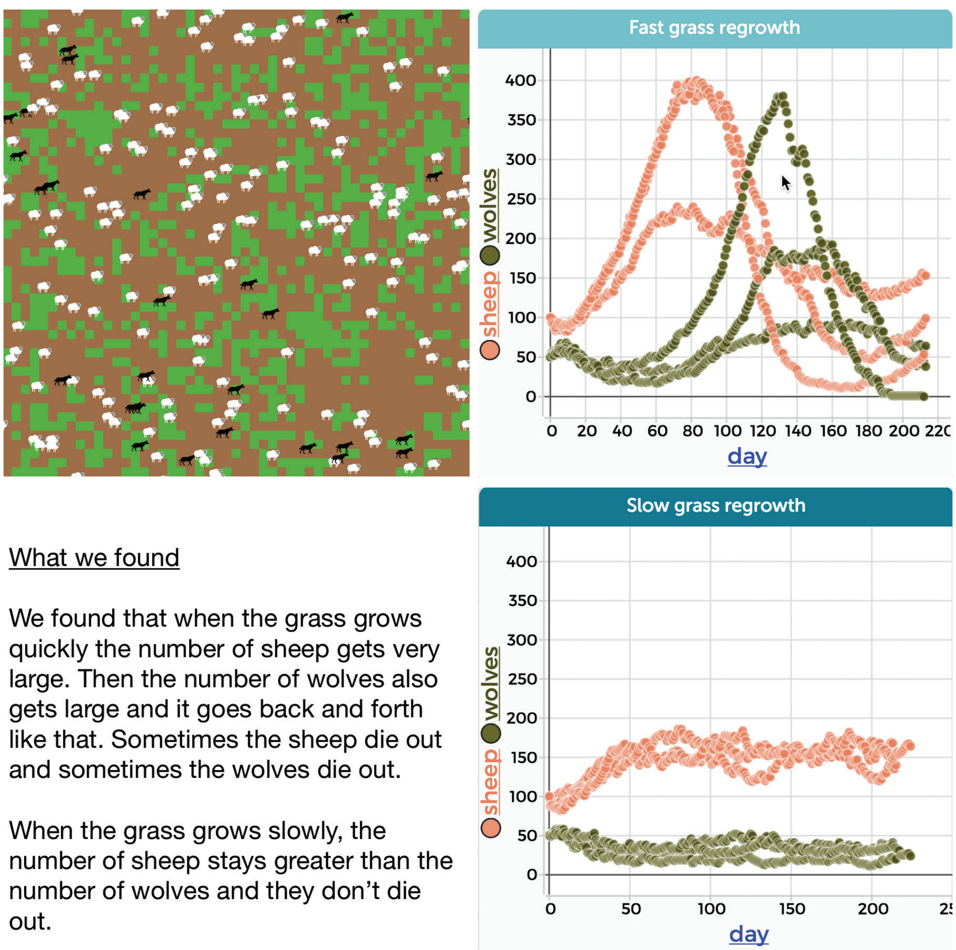

Figure 2. Students make sense of a very messy data set involving predation.

(continued on p. 6)

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Let's look at another example from a middle school science class. Using an agent-based simulation, students explore an ecosystem containing wolves, sheep, and grass. The simulation generates a lot of data for each run, and there are seven initial parameters to adjust, including how fast the grass grows. Even with identical parameters, two runs can differ greatly because of built-in randomness. After playing around for 20 minutes, students discuss their observations and questions, deciding to investigate "How can you set things up so that the wolves and sheep live happily together?"

One group focuses on the rate of grass growth (Figure 2). As they run the simulation multiple times, the students generate a large, varied, and naturally messy data set. They interact with the data by hiding some runs, reorganizing the data, and creating new groupings. Rather than see it as a barrier, they view the messiness as an invitation to dive in and poke around, coaxing out the stories hidden deep within the data.

These are the actions of future data scientists. As they work with the data, viewing and organizing it in evolving ways, students are performing the essential actions we call *data moves*. Building students' experience, breadth, and fluency with such data moves is critical, because they are the raw material of data practices. Much of the data science done in the field involves these moves, wrangling, cleaning, and restructuring data sets so they can be further investigated. To prepare students for the future, we need curricula that evoke and encourage these data moves—at all levels and across all topics—in order to ensure that students develop coherent data practices and enduring data habits of mind.

If today's students are to be the ones who discover the data-driven solutions to important, complex problems of tomorrow, we must ensure that they have rich, immersive experiences with data throughout their pre-college learning, building up data habits of mind through frequent opportunities.

Developing supporting technology

While curricula are essential to developing children's habits of mind and fluency with data analysis, another necessary ingredient is technology designed for learning with data. Indeed, the tool students use to engage in rich data inquiry is the second make-or-break factor in the development of data science skills and understanding. Of course, such tools must be easy to use, but they must also draw learners into data experiences that are immersive and encourage exploration, experiences they will look forward to repeating with new data sets and new challenges.

Such data tools exist. The technology used in the two examples above is our Common Online Data Analysis Platform (CODAP). Designed specifically as a robust data exploration environment for education, CODAP is also easy to use—a 60-second demonstration launches students into hours of exploration. CODAP is highly interactive—students make their own choices and perform their own data moves, dragging and dropping data sets and variables in ways that illuminate and engage. CODAP works easily with web-based tools in ways that render it relevant to a wide variety of disciplines. And it's free and open source.

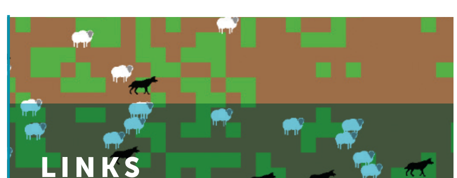
Research

Curricula and data tools are essential for spurring the data science education revolution. But in order to build and design them effectively, we need significant research into how learners acquire data science skills, concepts, and habits of mind. Research findings can inform crucial design decisions in surprising ways. For example, the decision to use nested data structures in CODAP—a more useful way of structuring data than the flat, two-column approach encouraged by tools such as spreadsheets—is reinforced by our findings that younger students generated similar structures spontaneously. Research in a variety of areas will illuminate additional design principles and point to new curricular directions.

Defining future directions

To reach our goal of fostering data science education at all levels, we must answer important questions. What do lessons and curricula that effectively integrate learning data science into various disciplines look like? What do educators who wish to develop such materials need to know? How do K-12 learners visualize data? What kinds of experiences improve their understanding of data? How can we coordinate across disciplines to maximize learning and leverage what students have learned in previous encounters with data?

Answering these questions will require dedication, resolve, and commitment among a wide variety of partners. Curriculum developers, technology developers, researchers, policymakers, industry leaders, and more must coordinate their activity to bring about the needed changes. And the partnership doesn't stop there—we invite you to join us as well! Visit https://concord.org/meetup to learn about upcoming data science education webinars and meetups, and to see how you can help bring about the data science education revolution.



CODAP
https://codap.concord.org

Experimenting with Extended Reality in our Innovation Lab

At the Concord Consortium, we're always experimenting with new ideas, using new technologies to support classroom inquiry in STEM, and researching the effects on learning. We're a group of thinkers and tinkerers. As we invent new tools for tomorrow's learners, our Innovation Lab draws from the future.

We're currently fascinated by the potential of extended reality (XR)—a general term that includes technologies such as augmented reality (AR), mixed reality (MR), and virtual reality (VR)—to improve learning in schools, homes, and informal learning spaces like museums. From the practical to the fantastical—Google cardboard to the HTC VIVE—we're exploring approaches and technologies that blend the real world with the virtual or immerse users in an imagined space to help students understand the world around them.

GRASP (Gesture Augmented Simulations for Supporting Explanations), a project funded by the National Science Foundation, is studying the role that motions of the body play in forming explanations of scientific phenomena. We're designing web-based gesture-controlled simulations for students to investigate molecular heat transfer, the pressure-volume gas law relationship, and the causes of the Earth's seasons. Using the Leap Motion controller, GRASP can track the position and movement of a user's hands in three dimensions. For example, students can explore the changing seasons by controlling the tilt of the Earth with the angle of their hands.

Our Infrared Street View program is a counterpart to Google's Street View. IR cameras are capable of visualizing otherwise invisible heat flow and distribution, so we designed the IR Street View using the low-cost FLIR ONE thermal camera that can be plugged into a smartphone (iOS or Android) to collect heat flow data from buildings (Figure 1). We envision a time when a massive crowdsourcing project could engage students to collect data that demonstrates the current state of energy efficiency of their neighborhoods, towns, and states. Infrared Street View won the 2016 JUMP competition, sponsored jointly by CLEAResult, the largest provider of energy efficiency programs and services in North America, and the National Renewable Energy Laboratory, a research division of the U.S. Department of Energy.

The William K. Bowes, Jr. Foundation provided funding for our Learning Everywhere project, which is experimenting with attaching the Leap Motion to the headset of an HTC VIVE fully immersive room-scale VR system, so students can become part of the microscopic world and use their hands to control simulations. (Think Ms. Frizzle on a Magic School Bus field trip.) With typical VIVE controls, we can provide haptic feedback; however, we're making the experience controller-free, so we're using audio feedback (e.g., changing volume and pitch) to help students understand their movements—for instance, when they pull two molecules apart to explore ionic and covalent bonds. We also prototyped a simple room-scale solar system simulation where a learner can walk around the surface of a model Earth, observe shadows on a distant moon, or teleport and see the system from an alternative perspective.

We've just started to explore Microsoft's HoloLens to bring the physical and digital worlds together in augmented reality. The HoloLens is a wireless headset that is transparent, but it allows a user to see a hologram on top of the real world. We're experimenting with teaching complex subjects using gesture-based interactions with virtual holograms, which provide the freedom to move around and explore a simulation from different perspectives.

At the 2017 Augmented World Expo, we gathered with like-minded geeks and technology futurists ready to discuss the innovative uses of AR and VR. Enthusiasm and inventiveness were in the air everywhere. We don't know where the future of AR and VR will lead us, but we're optimistic about the possibilities for STEM teaching and learning.

Figure 1. We imagine an immersive thermal vision. Based on the orientation and GPS sensors of a smartphone, SmartIR can create a thermogram sphere and then knit images together to render a seamless IR view. Virtual Infrared Reality can be uploaded to Google Maps so the public can experience it using a VR viewer, such as Google's Cardboard Viewer.

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Monday's Lesson:

The STEM Resource Finder

By Evangeline Ireland and Jason Simpson

Our updated STEM Resource Finder includes hundreds of resources to engage your students with scientifically accurate virtual labs and hands-on digital tools. Make the invisible visible and explorable in a way that brings out the inner scientist in everyone. While registration is not required, your free registration includes access to several key features, like creating classes for your students, assigning activities, saving work, tracking student progress, and more.

Follow these simple steps to get started.

Register for a teacher account

1. Go to **https://learn.concord.org** and click the REGISTER button in the upper right-hand corner.

2. Use your Google or Schoology account to register OR enter your name and create a password to complete the registration form. Click REGISTER!

3. Select the radio button for TEACHER, create a username, and provide an email address.
   - Enter your location and school. Click REGISTER!
   - If you don't find your school listed, or you are a homeschool, click "I can't find my school in the list" to enter the name of your school.

4. After registering, you'll receive an email from STEM Resource Finder (help@concord.org). Click the "Confirm Account" button in the body of the email to activate your account. *(Note: Google and Schoology users will not receive a confirmation email.)*
   - If you do not receive the activation email in your inbox, check your junk or spam mailboxes, or any quarantine used by your email provider.
   - Contact help@concord.org for assistance.

5. After clicking the link in the activation email, you'll be logged into the STEM Resource Finder homepage.

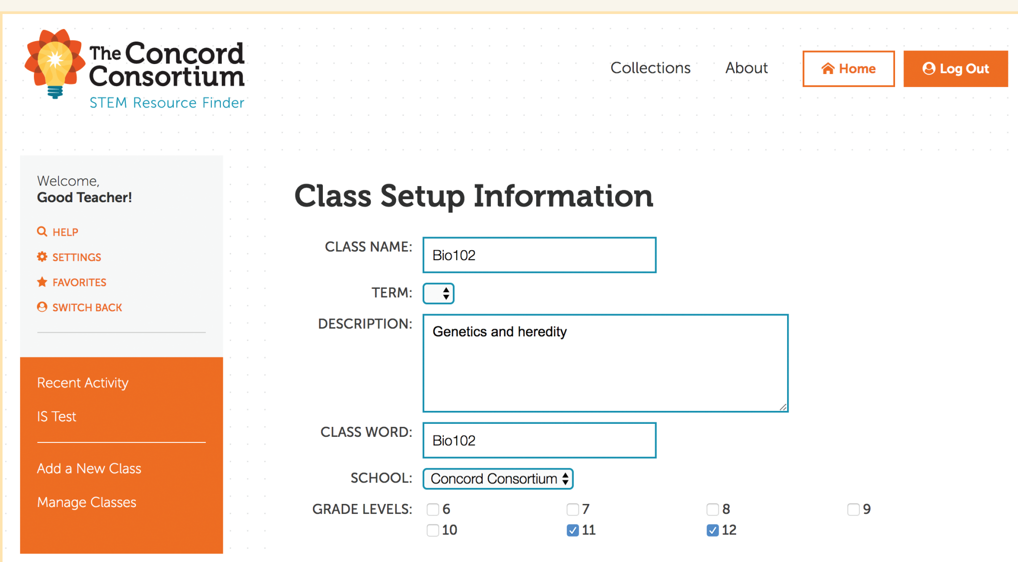

Figure 1. Enter Class Setup Information. Provide a class name, description, class word, and applicable grade level(s). Save your class information.

Add a new class

1. Once you are logged in, click the HOME button in the upper right—that's your personal homepage, where you create and manage your classes, and track student progress.
2. Click the ADD A NEW CLASS link in the orange navigation box on the left. Enter your CLASS SETUP INFORMATION. Provide a class name, description, and applicable grade level(s).
3. Create a unique CLASS WORD that students use to enroll in your class. A class word can be more than one word and is not case sensitive, but it cannot include any special characters (such as *, @, and %). Click SAVE (Figure 1).

Find and assign resources for your students

1. Return to the STEM Resource Finder main page by clicking the Concord Consortium logo in the upper left. Use the filters to search by subject area, type, grade level, or keyword. You can also click COLLECTIONS at the top of the page to search for resource sets. Each collection has specific learning goals within the context of a larger subject area.
2. *Note: If you find a resource that you're interested in, but aren't ready to assign it to your class, click the star icon on the resource card to save it to your* FAVORITES *(Figure 2), which is accessed from your homepage.*
3. After filtering, click the resource you want to assign to your class. This displays more detail about the resource. Click the ASSIGN TO A CLASS button (Figure 3). If you've created more than one class, select the class(es) to which you want to assign the resource.

Student registration

Students can register themselves or you can manually register them from the STEM Resource Finder homepage. (Teachers can also register students from the Student Roster.) *Note: If your students have a Google or Schoology account, they can register with either of those accounts.*

1. Go to **https://learn.concord.org** and click the REGISTER button.
2. Enter a student name, choose a password, and click REGISTER! again. On the next screen, select the STUDENT radio button.
3. Enter the unique CLASS WORD that identifies the class (the one assigned by the teacher).
4. Click SIGN UP!
5. A success message appears with the student's username (first initial followed by last name). (*Note: A number is appended if there is more than one student with the same first initial and last name in the system.*) Write down the username and password. (*Note to teachers: If a student forgets his or her username and/or password, use the Student Roster to see the username and reset the password.*)
6. Students can now log in to the STEM Resource Finder from here by entering their username and password and clicking LOG IN!
7. Students log out of a class using the LOG OUT button in the upper right.
8. To log in later, students use the LOG IN button on the STEM Resource Finder homepage.

Student reports

When your students begin to work through models and activities you have assigned to them, you can see reports of their progress.

1. Log in to the STEM Resource Finder.
2. In the left-hand column of your homepage, click the name of your class, then ASSIGNMENTS.
3. Click on the drop-down list of assigned activities to access a specific one. Each student's progress in that activity is displayed in the orange progress bars.
4. Click the REPORT button for a detailed summary report. (Reports are not available for some activities.)
5. Provide written feedback and/or scores electronically by clicking the PROVIDE FEEDBACK button to the right of a question. Your students see your comments the next time they log in or refresh their Report page.

Use models in your class

Sequences and activities include embedded questions while models do not. Use these standalone models for student inquiry by projecting a model for the whole class to explore and make predictions together or challenge students to analyze model data and construct explanations in small group work. Preview the model and click Share to get the URL link, then embed that link in a class website or shared Google Doc along with a question or two for review, enrichment, or homework.

For more information, see the User Guide:
https://concord.org/srf-user-guide

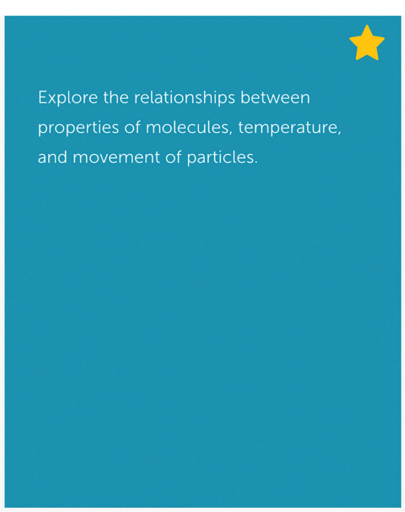

Figure 2. Hover over a resource card for a short description. Click the star icon to add it to your Favorites.

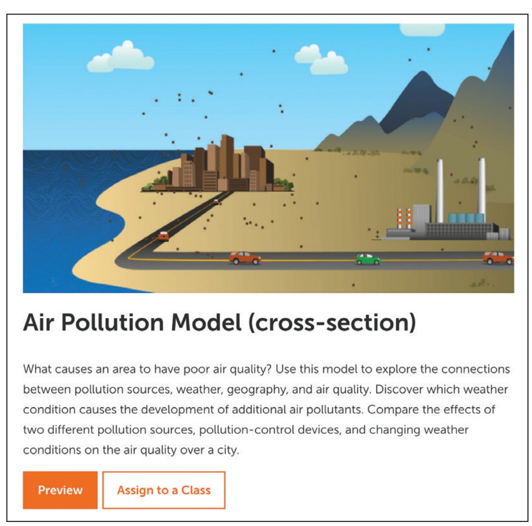

Figure 3. Assign resources to your class by clicking the "Assign to a Class" button

Science Thinking
for Tomorrow Today

By Sherry Hsi, Lisa Hardy, and Tom Farmer


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Tucked away all over the world are seed banks, places that store seeds to preserve and protect them: Colorado, Norway, Syria, even Framingham, Massachusetts, where a standard chest freezer stores a million rare seeds. These so-called "seed arks" are saving their contents for use in an uncertain future in which everything from war to climate change may determine whether a seed can germinate. How can we best prepare today's students to engage the complex, precarious scientific and engineering problems of tomorrow, when even germinating a seed may test the limits of knowledge?

We live in an era in which connectivity reigns supreme, and the "Internet of Things," from self-driving cars to "smart homes," has become part of our increasingly technological world. Solving big problems like growing sufficient food and developing complex medical treatments requires more than memorizing facts. Knowing how to leverage technology and program computers, formulate and solve problems, generate and interpret various kinds of data, as well as carry out hands-on experiments have become part of an essential skill set. Yet these skills—necessary for solving today's dynamic, multidisciplinary problems—are rarely taught in a collaborative and integrated way in current K-12 classrooms.

We're investigating ways to teach students how to learn science by doing science, like real scientists—by undertaking authentically complex experiments that rely heavily on digital technology, and often have unexpected outcomes.

Doing familiar biology experiments a new way

InSPECT (Integrated Science Practices Enhanced by Computational Thinking), a project in its second year of development and supported by the National Science Foundation, is researching a new model for science learning that aligns with NGSS science and engineering practices. Using inexpensive DIY lab instruments, InSPECT is developing a series of sequenced, open-ended, technology-enhanced high school biology experiments that facilitate inquiry and integrate computational thinking into core science content and practices.

More than a half dozen biology units are under development. Activities include a focus on cellular respiration and plant photosynthesis using traditional leaf, soil, and plant growth labs. An example is seed germination, a familiar biology topic that technology can enhance by supporting independent investigation and inquiry. Using electronics that measure and control temperature, light, and moisture, students use a growth chamber with sensor inputs to record data on changing conditions. Do seeds need specific temperature, moisture, and/or light conditions to trigger germination? How do plants successfully transition from germination to seedlings? Laboratory experiments, using these same basic components, are under way in academic institutions worldwide, assessing the effects of climate change on global food sources.

InSPECT is currently piloting a setup familiar to many teachers, an eco-column—a three-tiered mini-biome using clear two-liter soda bottles. The activity reaches a new level of sophistication by inserting electronic sensors into the eco-column's terrestrial, aquatic, and composting chambers. The self-identifying sensors are plugged into a low-cost Raspberry Pi computer less than an inch high and the size of a credit card that sends a bounty of sensor data wirelessly to a server (Figure 1). By recording air and water temperatures, and light, humidity, oxygen, and CO_2 levels, students can investigate the flow of energy and matter between the chambers.

We are preparing to add another innovation: actuators (a component that moves or controls a mechanism). The actuators are triggered by pioneering software called Dataflow, a simple visual interface that students can program to do things such as turn lights on if it's too dark or turn on a water sprinkler pump if the soil is too dry (Figure 2). Dataflow was co-designed in collaboration with Manylabs, an open science lab in San Francisco for scientists, researchers, and "makers." They also helped develop the eco-column sensors. InSPECT utilizes another Concord Consortium innovation to help students and teachers visualize and interpret their data: CODAP (Common Online Data Analysis Platform), a user-friendly, open-source software platform available free for any curriculum development project.

Figure 1. Growth chambers made by PASCO connect to a credit card sized Raspberry Pi computer wirelessly connecting virtual Dataflow programs with physical sensors and actuators in experiments.

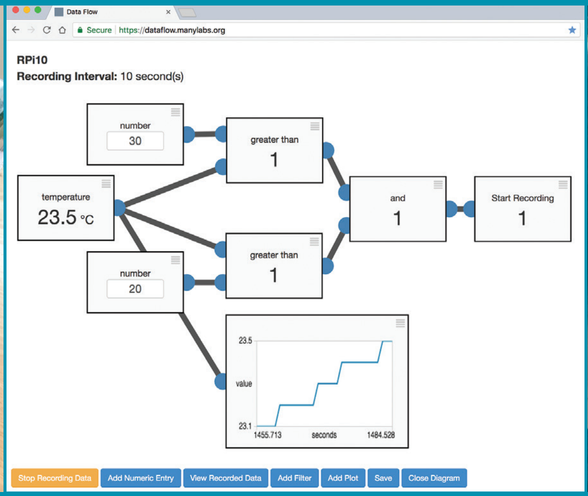

Figure 2. Dataflow is a simple visual interface that students can program to collect data and trigger actuators within experiments.

Figure 3. A student at Lighthouse Community Charter School uses sensors to collect data from an eco-column.

InSPECT teachers thoughtfully lead students through planning an experiment, making decisions about data collection rates, reasoning about data received from sensors, and examining real-time graphs to see how a dynamic biological system responds to different environmental factors. The plethora of data generated allows students to investigate how changing light levels affect rates of CO_2 consumption in plants, or how the humidity level increases during plant transpiration—trends not observable otherwise. Pairing this Internet of Things (IoT) sensor capability with the Dataflow software enhances a standard observational biology activity.

Supporting teachers

Many teachers are struggling to respond to an unprecedented emphasis on teaching science practices. This sets up a tension between developing activities that shoehorn critical new material into an existing curriculum versus developing longer and more complex activities that add content but can't be easily embedded into an existing curriculum.

InSPECT developers decided to try both. In schools where the syllabus is less flexible, we are developing activities that fit seamlessly. Schools with more scheduling latitude provide an opportunity to test more complex units. Ultimately, we want to push the boundaries of IoT technologies to support student inquiry and deepen concepts teachers are already targeting.

Lighthouse Community Charter School, in Oakland, California, is the first school to pilot our eco-column and seed germination activities (Figure 3). Through this pilot we have learned how much support teachers need as they integrate the science practices and IoT sensors. For this reason, the project supplied Lighthouse with technology kits that included plug-in sensors and actuators, sophisticated microcontrollers, computer boards, and software. The school also received technical assistance, online resources, classroom assistance, and support integrating InSPECT units into their curriculum. Lighthouse is a K-12 school serving a predominantly low-income community of 750 students.

Long-term implications

Currently the project is collecting and analyzing pilot data to understand how students use sensor data in their biology investigations, and how these ongoing scientific practices can offer opportunities for students to engage in computational thinking. The impact of our research may reach to other biology topics, grade levels, and science disciplines. By providing realistic hands-on examples of the central role of computing in STEM disciplines, InSPECT is engaging students in integrated scientific and computational practices. It is teaching students not simply about data acquisition, but how to act on data: make a motor move, or a fan turn, or open a door to a plant chamber. InSPECT is challenging students to think intentionally about how they produce and work with data—and analyze not only *why* things happen, but how they can *make* something happen.

Data is everywhere. It can be pulled off the web or collected by a sensor that sends it over a network to a distant computer where it displays on a scientist's screen as a graph or triggers an action. Data flows between things in control and feedback systems in biology, but also in robotics and heating systems, and even the toaster in your own home.

LINKS

InSPECT
https://concord.org/inspect

The Challenge
to Solarize the World

By Charles Xie

Charles Xie
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is a senior scientist who works at the intersection between computational science and learning science.

More and more nations and regions in the world are planning to switch their power supplies to 100% renewable resources by midcentury. However, there has been a debate among scientists about the feasibility of powering the entire United States with only wind, water, and solar energy. Both proponents and opponents are leading energy researchers who support their theories with sophisticated computational models. Given the magnitude and complexity of the problem, there will likely be no clear winner in the near future. But the debate will continue to influence our energy and environmental policies in the years to come.

Since the world also belongs to the young, we are obliged to find a way to engage them in this high-stakes debate. Regardless of the sides people take, few would dispute the strategic importance of educating and preparing the energy consumers and workforce of tomorrow. Motivating youth is so vital in Bill Gates's call for an "energy miracle" that he urged high school students to get involved in the energy quest in his 2016 annual letter. But, apart from becoming a conscientious user of energy, how can students make meaningful contributions?

We envision a cyberinfrastructure that works like an "Energy Minecraft" to inspire and support millions of students to take on the energy challenge on a global scale at the grassroots level. On this platform, students will learn basic science concepts and engineering principles. Equipped with knowledge and skills, they will then crowd-design an unprecedentedly fine-grained computational model that consists of millions of virtual solar panels, reflecting mirrors, and wind turbines accurately positioned around the world and connected to virtual storage and grids. A multiscale model with all these low-level details does not exist yet, but it may be a holy grail in energy research that can potentially settle the case and even provide a blueprint going forward to a 100% renewable energy future, if possible.

This article introduces the *Solarize Your World* program, the first step towards realizing this vision. Although the program currently focuses on solar energy, it has the essential elements of a computational model capable of supporting both STEM education and energy research. And it can be extended to include other renewables such as wind, hydroelectric, and geothermal energy.

The complexity of modeling solar power in the real world

The sun is a gigantic nuclear fusion reactor in the sky that emits a massive amount of energy. Elon Musk has famously asserted that covering "a fairly small corner" of a state like Nevada with solar panels can generate enough energy for the whole country. This makes you wonder what scientists are really debating.

It turns out that building a reliable solar infrastructure is not as simple as laying down billions of solar panels in a square of 100×100 miles. In reality, there are countless technical, economic, and social constraints for solar deployment. For example, people do not have unlimited space and budgets. Some are concerned about the aesthetics of buildings and landscapes with solar panels in sight. Governmental policies drive the cost of solar energy, hence public interest, up and down. Energy storage is needed to overcome solar intermittency to provide electricity after sunset and grid stability at all times. A significant amount of energy is lost during the transmission from utility-scale solar power plants to population centers. All things considered, we have a problem far more complicated than Musk's ballpark statement. This is why the National Renewable Energy Laboratory has been developing computational assessment of the solar energy potential of the country.

A crowdsourcing model that integrates education and research

A more accurate assessment of the planet's true solar potential would be to identify all possible locations where suitable types of solar power can be realistically deployed and compute their minute-by-minute outputs to global grids and storage for a cycle of 24 hours under typical meteorological conditions. To evaluate the cost effectiveness of this giant distributed network, a mix of financing models driven by local economics and policies can be used to estimate the scale of investment. Creating such a multiscale, time-dependent model with details down to instantaneous outputs and levelized costs of individual solar modules is a daunting task that no single researcher can do. But we can call for help from millions of students who know and care about their corners of the world more than any outsider. The challenge is to teach them the science and empower them with appropriate engineering tools so that they can join the energy quest.

Solarize Your World is based on our Energy3D software, a CAD tool anyone can use to design any type of solar power system in cyberspace and calculate its hourly, daily, or yearly outputs based on numerical simulation from first principles. With weather data of over 600 regions in 190

Figure 1. Energy3D covers over 600 regions in 190 countries.

PART I: **Learn**

Guided activities that prepare students with the knowledge and skills needed to undertake the challenges.

PART II: **Apply**

Open-ended, real-world engineering projects that turn Google Earth into a global engineering lab.

PART III: **Explore**

Out-of-school citizen science programs that support independent, unlimited exploration.

Figure 2. The Learn-Apply-Explore pathway.

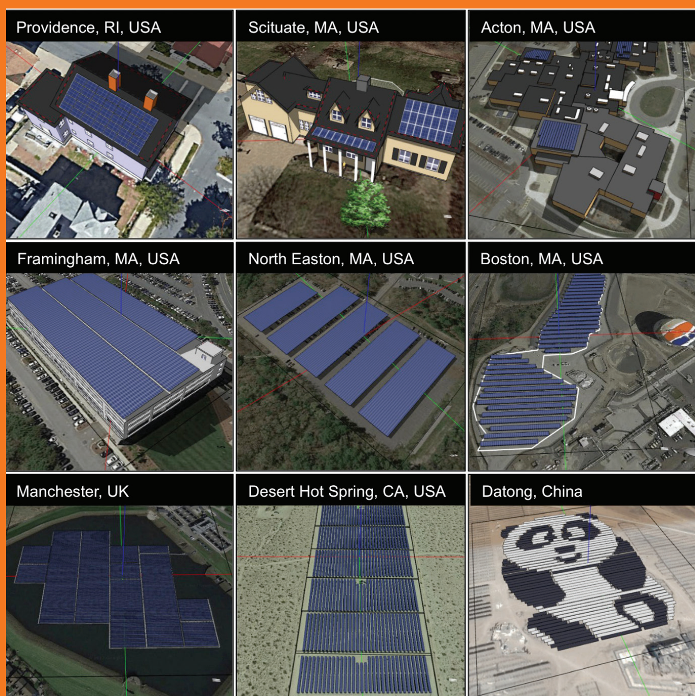

Figure 3. Energy3D can be used to design a wide variety of photovoltaic systems, including residential rooftop systems, commercial rooftop systems, parking lot canopies, ground-mounted arrays, floating solar farms, and solar tracking systems.

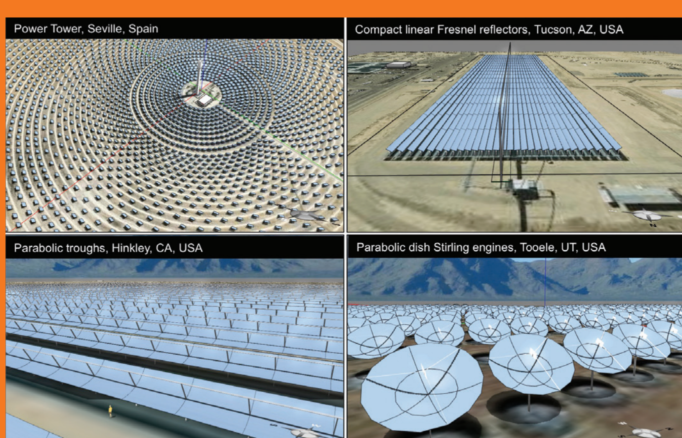

Figure 4. Energy3D can be used to design four types of concentrated solar power plants: solar power towers, linear Fresnel reflectors, parabolic troughs, and parabolic dishes.

countries (Figure 1), Energy3D can produce satisfactory results for most parts of the inhabited world, enabling millions to work on local projects. The ultimate goal of Energy3D is to turn the tedious job of engineering design into a fun game like Minecraft, making learning, discovery, and invention a playful experience.

A curriculum for learning and practicing science and engineering

For students to succeed in creating authentic models of solar energy systems valuable to research, *Solarize Your World* provides comprehensive curriculum materials and classroom-to-afterschool pathways (Figure 2) that lead students to: 1) design solar energy systems for their homes, schools, villages, and cities; 2) design any type of photovoltaic and concentrated solar power plants wherever applicable; and 3) communicate their designs to potential stakeholders whenever appropriate. Figures 3 and 4 show solar power systems of different types and sizes on top of satellite images from Google Maps. (Some of these systems were modeled or designed by students in our 2017 pilot tests.)

The *Solarize Your World* curriculum consists of three parts. Part I teaches students the three dimensions of the Next Generation Science Standards. The disciplinary core ideas cover Earth science, heat transfer, geometric optics, and electric circuits that are fundamental to solar power. The crosscutting concepts include energy and systems that are necessary to understand how the energy from the sun can be converted into electricity to power the world. This part also strives to familiarize students with the practices of scientific inquiry and engineering design. Part II provides scores of open-ended, real-world projects for students to choose. For instance, students can design solar energy systems for their own homes or schools. If students cannot finish a project in the classroom or wish to undertake more projects out of school, Part III supports them to continue in an online community, possibly in collaboration with many other participants similar to Minecraft.

The road ahead

According to the International Energy Agency, global solar power grew faster than all other forms of power for the first time in 2016 and will likely dominate renewables in the future. The U.S. Department of Energy also announced on September 12, 2017, that the 2020 utility-scale solar cost goal set by its SunShot Initiative had been met three years early. The price of utility-scale solar energy has now fallen to six cents per kilowatt hour. Despite the phenomenal cost plummet and market growth, the road to a 100% renewable energy future is still unclear and debatable. We invite students and teachers worldwide to join our *Solarize Your World* initiative to pave the way. Rarely have students been given a chance to help answer a question so crucial to humanity.

LINKS

http://energy3d.concord.org

Under the Hood:

Sensors in the Browser with Web Bluetooth

By Scott Cytacki

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

Web Bluetooth makes connecting sensors to a browser easier than ever before. All you need is a Bluetooth Low Energy sensor and the Chrome browser. No plugins or additional software are needed.

Five years ago, we prototyped an Ethernet-enabled Arduino, which made sensors in the Web browser possible without installing any software. (See "Under the Hood: Streaming Arduino Data to a Browser" in the Spring 2012 *@Concord*.) However, that solution was not easy to use on mobile devices, relied on a hidden feature of most operating systems, and was not supported by any educational sensor vendors. We then created a background service that connects many wired educational sensors to the browser called SensorConnector. Unfortunately, background services like the SensorConnector can only run on desktops and require an administrator to install them.

Bluetooth Low Energy (BLE) and Web Bluetooth solve all these problems. BLE is supported by every modern mobile and desktop operating system. Earlier this year, Web Bluetooth was released by Google for Chrome on Chromebook, Android, Linux, and OS X as an API that web pages can use to communicate with BLE devices. No plugins or apps are needed to use Web

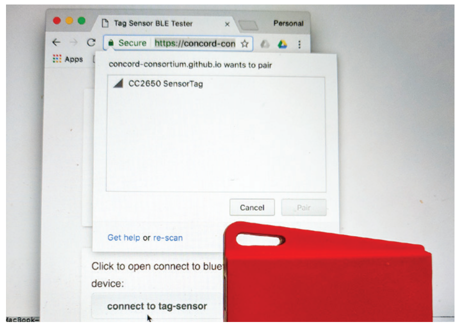

Figure 1. TI SensorTag with multiple built-in sensors connected to a browser.

Bluetooth on the supported platforms. This is exciting because BLE sensors are cheap and easy to create. For $25 you can purchase a full-featured Arduino-compatible BLE device. Or for $35 you can get a Raspberry Pi with built-in BLE support.* With lots of examples and support groups, the Arduino and Raspberry Pi ecosystems are easy starting points to build custom browser-connected devices.

Even more exciting is that two of the major educational sensor vendors have already created several BLE sensors. We're currently working with these vendors to see if we can connect to their devices directly from the browser, and we hope to have examples of these connections sometime next year.

In the meantime, we've put together a simple demo that connects with the TI SensorTag, a small, cheap self-contained device with multiple built-in sensors (Figure 1). Most important, it has a simple documented interface. Figure 2 shows example code that reads the light value every second. Getting the data out of the TI SensorTag is done using the GATT protocol, which is a key part of BLE. This protocol defines how central devices like phones or desktops send data back and forth to peripheral devices like the SensorTag. The GATT protocol data is divided into services. Each service can have one or more characteristics, which contain numbers or strings that can be read from or written to. Web Bluetooth provides an asynchronous API, so it's easy to work with the GATT system of services and characteristics. And the SensorTag uses GATT effectively, which makes it simple to retrieve data from it. Other devices do not take this approach, so it can be harder to pull data out of them.

We're passionate about making tools that open up opportunities for inquiry to as many people as possible. We're excited these latest developments make sensors even easier to connect to browsers. Try it out yourself in the online version of this article, and find several links to learn more about Web Bluetooth.

Request device, browser shows user a chooser with devices that match filters	`device = await navigator.bluetooth.requestDevice({`
	`  filters: [{ services:[SENSOR_TAG_ID] }],`
	`  optionalServices:[LIGHT_SERVICE_ADDR]});`

Connect to device	`server = await device.gatt.connect();`
Get light service	`service = await server.getPrimaryService(LIGHT_SERVICE_ADDR);`

Enable light sensor	`enableChar =`
	`  await service.getCharacteristic(LIGHT_ENABLE_ADDR);`
	`await enableChar.writeValue(new Uint8Array([0x01]));`

Get light characteristic	`valueChar = await service.getCharacteristic(LIGHT_VALUE_ADDR);`
Start loop	`setInterval(async () => {`
Read light value	`  byteArray = await valueChar.readValue();`
Convert to integer	`  lightValue = byteArray.getUint16(0, true);`
Display value	`  displayLight(lightValue);`
Repeat every second	`},1000);`

Figure 2. This is a simplified snippet of code from the example online. Error handling, status updates, and variable declarations have been removed. The *_ADDR constants hold the SensorTag GATT addresses.

* We purchased these devices in 2017. Prices may change.

LINKS

Online version of this article
https://concord.org/newsletter/2017-fall/sensors-in-the-browser-with-web-bluetooth

Innovator Interview:

Chris Hart

chart@concord.org

Sitting at home in Birmingham, England, in 2009, Chris Hart made plans to move her family and her life to Boston. She had never even been to New England before, but as an avid video game enthusiast, she was accustomed to visiting unseen worlds.

Second Life is where she met up with a husband-and-wife team of developers interested in the potential of virtual worlds for education. She brainstormed with their avatars, and together they decided to found a startup. Using Open Simulator, an open-source code base written in C# that emulated the same communication interface as Second Life, they rented virtual spaces to educators and businesses.

"One group was doing role play. Another was focused on art with a virtual gallery, while yet another taught about the solar system," Chris recalls. She learned from a teacher about a group of students who had built castles in their 256 cubic meter grid in the virtual world. Some students who had never answered questions in class became leaders of their online groups. That's when she knew all her hard work was worthwhile.

"Open Simulator was very much alpha, so it crashed a lot," she explains. "We spent a lot of time keeping it running. It was fun, but not profitable." After two years of development, Chris built a virtual world platform using the Unity game engine, bringing virtual worlds and multiplayer serious games to the Web. "Installing custom software and reconfiguring firewalls just isn't possible in many locations, so we worked to lower the entry bar to virtual collaboration."

After four years, and now firmly settled in the States, Chris moved to a Boston-area startup developing map-based visualizations focused on agriculture data, then to a local video game studio, before joining the Concord Consortium in 2016.

It's no surprise that Chris has made a career in software development. Her father bought her an Atari 65XE when she was ten years old, and she read the manual cover to cover. Then when she twisted her ankle in elementary school and couldn't play netball, she took computer classes. She credits her interest in computers to this inauspicious beginning.

After college, Chris worked her way into IT, starting out by selling computer training. A core part of her work turned out to be learning how to build networks. More on-the-job IT training came from editing technical books at Wrox Press. She learned ADO, the data access platform, by editing a manual and testing the code. When Microsoft.NET launched, she got her feet wet with a new programming framework and language while editing a book on ASP.NET when it was still known as ASP+. "The work was intense and really good fun," she says. "You don't realize how quickly you can master a new topic until you're forced to edit a book on it in six weeks."

At the Concord Consortium, Chris has worked on programming augmented reality simulations (see "Under the Hood: Hands-on Interactive Activities with Leap Motion" in the Fall 2016 @*Concord*), created simulations for museum exhibits and other out-of-school platforms, and most recently has worked on an early-stage prototype Virtual Reality version of our Next-Generation Molecular Workbench. "I love the way you can play around with micro and macro scale simulations and concepts that you can't see in real world," she explains. "It's all about playing with the impossible, and I'm excited about giving young people an appreciation and excitement for how the world works."

Chris takes her love of virtual worlds home with her, too. She plays social co-op and role-playing games on her HTC VIVE, where she continues to make online friends. They laugh and talk about their day as they battle together in sites unseen in the real world.

"It's all about playing with the impossible, and I'm excited about giving young people an appreciation and excitement for how the world works."

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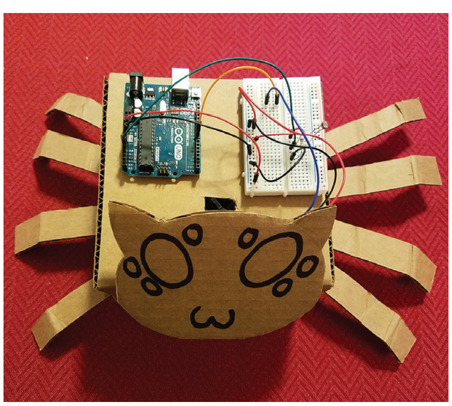
The Concord Consortium is happy to announce the following new grants from the **National Science Foundation.**

Paper Mechatronics

Engineering design requires interdisciplinary ideas and imagination. A resourceful engineer finds ways to build models, use new materials, and solve unexpected problems. Schools, museums, and afterschool programs are providing engineering activities. Yet their ability to offer high-quality experiences that introduce engineering design practices to a broad audience is limited by cost, complexity, and poor educational design. The Concord Consortium, with the University of Colorado's Craft Technology Lab and the Children's Creativity Museum in San Francisco, is creating a new genre of "high-low tech" learning materials that blend classic papercrafts and cutting-edge "Maker" electronics technologies. The goal is to improve young people's ability to undertake creative, compelling, open-ended engineering design projects. Projects include design problems, computationally enhanced papercrafts, "smart" crafting tools, design software, and instructional resources. Project research explores how novices develop adaptive expertise in this technologically rich learning environment.



Crowdsolving the Energy Challenge

The Concord Consortium will develop and test a citizen science program that engages youth in energy issues through scientific inquiry using innovative technology. The project will create the Infrared Street View, a program that aims to produce a thermal version of Google's Street View using an affordable infrared camera attached to a smartphone that collects thousands of temperature data points each time a picture is taken. The Infrared Street View program provides a web-based platform to view and analyze massive aggregated, geotagged thermal data to identify energy losses. The project will start with school, public, and commercial buildings in select areas where performing a thermal scan of the buildings and publishing their thermal images for educational and research purposes are permitted. Students can become change makers by contributing trustworthy scientific data and authentic engineering solutions to crowdsourcing programs to help solve the energy challenge.

Computing with R for Mathematical Modeling

The problems facing the nation and the globe increasingly demand complex, computational solutions. To prepare students, a new project is integrating computing into high school mathematics classrooms. Mathematics and computing are inherently connected: computing builds upon many mathematical concepts and skills, and math achievement is linked with computational thinking skills. Yet mathematics and computing are both challenging domains, and developing expertise in either is not easy. This project will support students in integrated learning of the complex domains of math and computing, interweaving the two disciplines for mutual reinforcement. Leveraging R's open-source ecosystem, it will develop and deploy a learning platform that integrates R computing resources, curriculum materials, automated assessment and tutoring, and teacher professional development resources.

Science and Engineering Education for Infrastructure Transformation

The Concord Consortium and Purdue University are conducting research and development on engineering education with the goal of inspiring and preparing high school students to meet the challenge of building tomorrow's infrastructure. Innovative technologies and curriculum materials support project-based learning of science, engineering, and computational thinking applied to the "smart" and "green" aspects of the infrastructure. The project is developing two innovations: 1) The Smart High School, an engineering platform for designing Internet of Things systems to manage the resources, space, and processes of a school based on real-time analysis of data collected by sensors deployed by students on campus and 2) the Virtual Solar World, a computational modeling platform for students to design, deploy, and connect virtual solar power solutions for their homes, schools, and regions. The research seeks to identify technology-enhanced instructional strategies that can foster the growth of skills and self-efficacy in scientific reasoning, design thinking, and computational thinking.

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