@CONCORD

vol. 24 • no. 1 • Spring 2020

The Concord Consortium
concord.org

Perspective:
Environments for Coherent, Inquiry-based Learning

By Chad Dorsey

The arrival of COVID-19 has changed lives around the globe on an unprecedented scale. In the process, it has begun to transform learning for millions of students, introducing many to distance learning for the first time and placing virtual learning resources center stage worldwide. While the migration of classroom teaching to online settings is temporary, the understanding we gain about technology's potential for STEM learning will endure far beyond the current crisis. One of the most important ways technology can foster STEM learning is through robust, open-ended simulations. As we consider the role of virtual learning in a new light, it pays to reflect on key principles that make simulations most powerful for learning.

Robust simulation environments can foster coherent, inquiry-based learning. Indeed, many topics and phenomena are simply not accessible for inquiry in the science classroom—they may be too large or too small, demand timescales that are too long or too short, or require conditions that are too dangerous to create in a school laboratory setting. In such cases, technology is essential. However, while individual simulations can illustrate a phenomenon, far too often they do little more than that—provide an illustrative animation. There is another way.

Instead of creating isolated experiences, the Concord Consortium develops technology-based environments for inquiry. The differences are important, and the implications for flexibility and learning are significant. In our Connected Biology project, for example, one of the learning goals requires that students understand ecosystems. Rather than develop a single simulation showing hawks eating mice and mice eating grass, we designed and developed an explorable, multi-level environment. (Get a sneak peek in "Monday's Lesson" on page 7.)

In this environment, the innate scientific rules of nature govern all interactions from the population level down to the genetic level. As in life itself, organisms and molecules alike follow these central rules—from the random assortment of genes during meiosis to the intricate interplay among organisms and their characteristics that power the process of evolution. With this full environment in place, students can do much more than passively observe an example. Instead they can experiment with it across scientific levels. They can directly engage in coherent, inquiry-based thinking and evolve their thinking over time.

This approach works because we have the ability to leverage our experience and prior work. Twenty-five years of National Science Foundation-supported projects have allowed us to create repurposeable simulation engines for whole classes of phenomena. These engines—computer codebases that allow us to generate authentic, open-ended science learning scenarios—are the "secret sauce" of our simulation environments. Building these into extended curricula transforms students from passive observers into active scientists as they become able, often for the first time, to explore the world's complex phenomena.

Over the past quarter century of designing and developing technology for K-12 science education, we have honed an approach to creating consistent, high-quality inquiry learning. Eight design principles guide our work.

Design Principle 1: Environments should allow students the agency to choose multiple, open-ended paths to investigate phenomena.

Our goal is to design environments that are inherently inquiry based. These environments should allow students to explore phenomena guided by their ideas and intuition, with the ability to discover central scientific concepts. The environments must provide students with the ability to uncover the natural world's mysteries for themselves while also giving them the freedom to make mistakes and sort through extraneous choices on the way.

Design Principle 2: Simulation environments should enable students to navigate freely among multiple interconnected levels of a system.

In order to evoke the important patterns and relationships needed for learning fundamental science concepts, simulation environments should help students connect multiple levels of a system and identify the key mechanisms that underly the phenomena they encounter.

Design Principle 3: Simulation environments should reflect the natural world as authentically as possible, while supporting high-quality pedagogy and balancing grade-level needs.

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

Our goal is to design environments that are inherently inquiry based. These environments should allow students to explore phenomena guided by their ideas and intuition, with the ability to discover central scientific concepts.

Support for learning and pedagogy of the highest quality is the uncompromising goal. Technology for inquiry should demonstrate the greatest accuracy feasible. Rich, accurate simulations should be powered by algorithms and computational models that reflect an authentic world.

Design Principle 4: Students should be able to analyze and compare multiple, dynamic, linked representations of datasets they produce via the environment.

Data represent a special, and essential, form of evidence. Simulation environments should support students in exploring and analyzing complex, multivariable data in an open-ended fashion, using dynamic representations that make clear the structure of the data and allow students to develop and support individual views and investigations.

Design Principle 5: Students should be able to collect artifacts—including meaningful, multivariable data—from the simulation environment for use as evidence to support scientific argumentation.

As part of investigating the natural world through simulation environments, students should have the ability to identify, highlight, and make use of aspects of any environment in ways that represent their thinking and act as supports for dialogue and scientific argumentation.

Design Principle 6: Students should be able to return to simulation environments repeatedly within a unit, and multiple times across units, each time deriving new insights and deepening understanding.

Simulation environments should support students in rich investigation that unfolds over time through multiple, recurring sessions as their knowledge deepens and their ideas grow more sophisticated. Students may return months later to explore an aspect of the natural world they had not examined in their first encounter.

Design Principle 7: The central structure of simulation environments should reflect the structure and hierarchies of the natural world in ways that support reuse.

Simulation environments aim to support investigation of the natural world and thus should reflect the hierarchies and organization of the world itself. For example, our environments support four interlinked levels of structure from the "big picture" system level to intermediate levels that include the entities involved within the system and provide access to their interactions and relationships, all the way down to a look "under the hood," often revealing the dynamics or interactions from which the system's salient phenomena truly emerge.

Design Principle 8: Simulation environments should present "low thresholds" and "high ceilings" to encourage reuse and increasing sophistication.

Rich representations of phenomena can be deployed in multiple areas, each viewed through a different lens. A simulation supporting upper elementary students in one unit may also be used to support high school students in a different unit. A low threshold allows students to begin immediately investigating phenomena with little or no startup explanation or prior understanding while a high ceiling offers expanded abilities to explore the rich, authentic phenomena at a deep level of sophistication.

These principles begin to define the essential elements of simulation environments that take advantage of the true potential of technology for three-dimensional learning. Through our ongoing work, our abiding goal is to make the wonder of science, math, and engineering accessible in ways that bring out the inner scientist in everyone.

Teaching Computational Thinking
Through Weather Prediction in Alaskan Villages

By Carolyn Staudt, Texas Gail Raymond, and Beth Covitt

Carolyn Staudt
(cstaudt@concord.org)
is a senior scientist.

Texas Gail Raymond
(texgail@gmail.com)
is a STEM consultant.

Beth Covitt
(beth.covitt@umontana.edu)
is a science education researcher.

Research shows that to achieve meaningful learning students should be able to relate what they are learning in school to their real-life experiences. So what happens when students live in a unique environment under circumstances not usually addressed by a conventional curriculum? In Alaska, the distances are vast and many villages can only be reached by boat or plane, not roads. The terrain ranges from expansive forests to treeless tundra and even Arctic "weather deserts" where no snow falls at all. The amount of sunlight also changes drastically throughout the year from long hours of daylight to seemingly endless darkness. Many Native Alaskan villages are unique not only in terms of their geography. They lack services familiar to the lower 48 states: movie theaters, shopping malls, and even road signs. And in some villages people primarily speak Inuktitut or other traditional languages. Developing a curriculum that recognizes and values those differences and relates to the local culture can be empowering for Alaskan Native students and a boost to learning.

Our Precipitating Change project, a multi-year collaboration with Argonne National Laboratory, Millersville University, and the University of Illinois at Chicago, is researching a place-based curriculum in three Native Alaskan villages with a majority of Indigenous students (ranging from 67-95% of the population), where understanding and predicting the weather is a necessary survival skill. We are designing and testing instructional materials and technologies that promote middle school students' abilities to apply computational thinking practices and understanding in the context of weather and weather prediction.

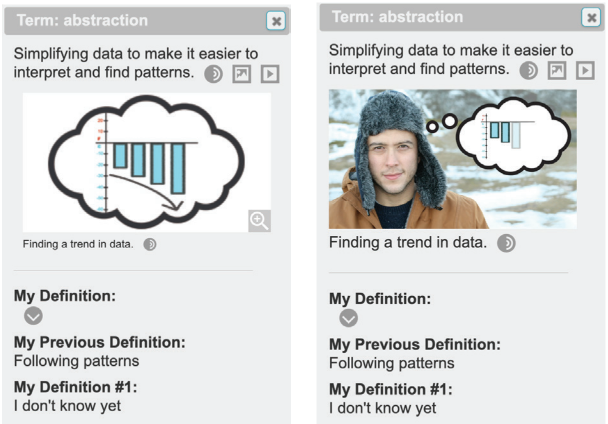
Because there is little local economic infrastructure in many remote villages, the Native Alaskan way of life is often based on subsistence living: trapping, fishing, and hunting. Success is dependent on understanding upcoming weather conditions and avoiding life-threatening situations such as being stranded in a blizzard. Our objective is to engage students in a relevant and meaningful curriculum that combines real Alaskan data with local culture and knowledge of place.

Learning with Alaskan weather data

Three middle school science teachers from three schools in rural Indigenous Alaska communities implemented a four-week weather unit covering everything from using virtual storm technology and making weather predictions to learning about a career as a weather scientist. Activity and content sequencing were inspired by the practices of professional atmospheric and computational scientists. The curriculum also includes a uniquely Alaskan storyline that ensures alignment among the anchoring phenomena, learning experiences, computational thinking practices, and assessment.

Students assume the role of a local event planner who must decide whether or not weather conditions will allow the Alaskan Native Youth Olympics to proceed as planned. During the lessons, students are introduced to an authentic weather dataset through radar maps and weather station readings (e.g., rainfall, temperature, wind speed, wind direction, and moisture content). They use computational thinking tools and skills (e.g., data abstraction, interpolation, extrapolation, rule abstraction, rule testing, and prediction) to aid them in completing the unit challenge of making an informed weather prediction and presenting their decision. Should the games take place?

The curriculum targets two main Next Generation Science Standards: MS-ESS2-5 (collect data to provide evidence for how the motions and complex interactions of air masses result in changes in weather conditions) and MS-ESS3-2 (analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects). Students and teachers participate in hands-on, inquiry-based activities such as an embedded weather phenomenon in which a virtual storm passes through the classroom. They explore computer modeling and authentic data representations to understand and apply weather-related science and mathematics with data, modeling, and computational thinking skills—the same skills used by real weather scientists. In the final lesson, students can use a digital glossary to learn more about various weather and computational thinking skills terms, and view them as pictures or diagrams or watch a short movie about the context of the words. In addition, students can select Native language words read by Athabascan, Inuit, or Yupik elders to help them understand the vocabulary (Figure 1).



Definition of "data abstraction" with text, images, and video.

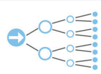
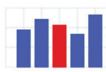
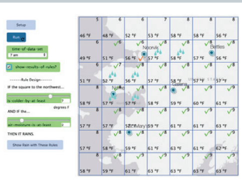
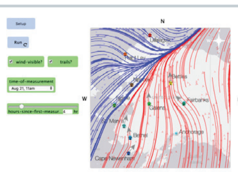
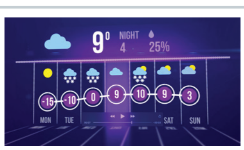
Computational Thinking Skill		Definition
Decomposition		Organizing a large amount of information (data) into smaller more manageable parts.
Pattern Recognition		Recognizing that data or information is repeating in a logical (expected) way.
Interpolation		Estimating an unknown value based on surrounding information.
Extrapolation		Following a pattern beyond the known data points.
Data Aggregation		Collecting and organizing data to better understand the topic.
Data Abstraction		Simplifying data to make it easier to interpret and find patterns.
Rule Abstraction	**IF** it is August **AND** **IF** it was a nice summer } **THEN** there will be lots of berries	Developing a statement of how things work based on the patterns you observed.
Model Evaluation		Looking at the big picture by putting all the components together in the model to see if it works.
Rule Refinement		Modifying a rule to be more precise (exact, careful about details) to work in the model.
Rule Abstraction		Developing a statement of how things work based on the patterns you observed.

Figure 1. Digital glossary of computational terms.

Research

Research is critical to understand if experiencing real weather events and data enhances students' science, math, and computational thinking skills and knowledge. We are currently researching the following questions:

1. What culturally responsive design adaptations were deemed effective by teachers?
2. To what extent is weather an effective STEM subject for increasing middle school students' computational thinking?
3. What are some generalizations that can be made about enhancing students' computational thinking skills in multiple cultural contexts?

We will assess students' ability to apply computational thinking skills to solve problems using our Computational Thinking Embedded Assessment Tool, which has been developed and refined by the research team over the previous three years of classroom implementation in Massachusetts, Indiana, and Alaska. Pre- and post-tests will measure changes in students' computational thinking skills and weather content understanding.

Embedded assessments

Assessments embedded in the curriculum provide opportunities to gauge student understanding without taking time away from instruction. Well-designed embedded assessments seamlessly integrate instruction and assessment. They can provide quality evidence of student knowledge, practice, and development.

The current Precipitating Change curriculum, revised from previous implementations, integrates five learning progression-based embedded assessments designed to elicit students' developing ideas about computational thinking elements like data abstraction, interpolation, and rule testing. In each assessment, a fictional middle school teacher poses a weather modeling question and four fictional students offer different responses. Each assessment is embedded at both the beginning and end of the relevant unit lesson. On the pre-assessment, students choose the answer they agree with most. On the post-assessment, students discuss the question with peers, choose a response, and then write an individual explanation for why they think their choice is best.

For example, in Lesson 2, students have incomplete weather data for an area and need to interpolate, or estimate a value between known values in surrounding areas. An assessment called *How Should We Estimate the Temperature?* is embedded in the lesson (Figure 2). The responses from the fictional students are crafted to represent ideas associated with different levels on a computational thinking learning progression. A teacher guide accompanying each embedded assessment provides teachers with short descriptions of theory and background concerning the computational thinking element that is addressed. In addition, the teacher guide suggests ways teachers can scaffold students toward developing more formal understanding (Table 1).

We believe such embedded assessments hold great promise. First, addressing Research Question 1, we're hopeful that inclusion of optional responses for students provides a safe context for sharing and discussing computational thinking ideas in the classroom. We hypothesize that it is less threatening for students to critique ideas presented by fictional students as opposed to sharing their own

(continued on p. 6)

(continued from p.5)

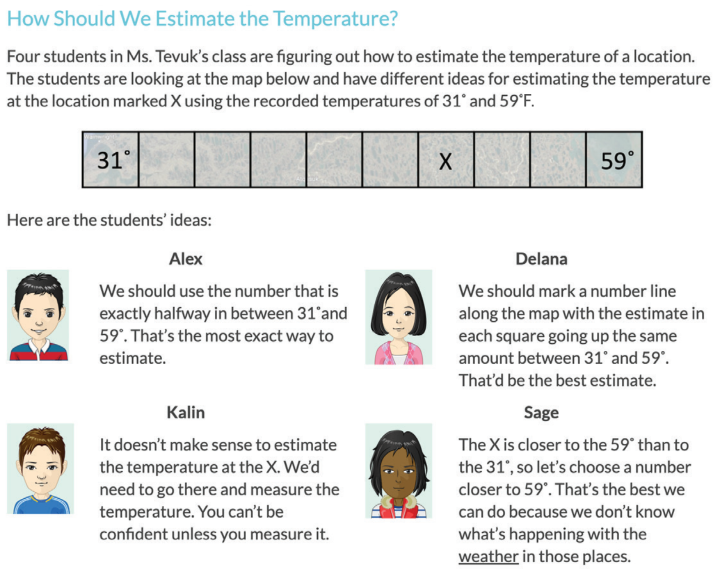


Figure 2. Sample embedded assessment in which a fictional middle school teacher poses a weather modeling question and four fictional students offer different responses.

original ideas or critiquing their classmates' ideas. Second, we are optimistic that teachers will find the assessments and teacher guides to be helpful formative assessment tools, especially for those teachers who are new to teaching computational thinking. Finally, addressing Research Question 2, collecting computational thinking data will provide insights into how students are developing and making sense of more formal computational thinking during instruction. Analysis from the embedded assessment implementation will be available soon.

What have we learned?

We plan to conclude our implementation research at our three sites across Alaska in the early spring. Project researchers have spent approximately two weeks at each site working with teachers and observing the rollout of the new curriculum. We were honored to experience the unique cultures of each village, where we were able to learn about teachers' and students' lifestyles, as well as how they have adapted to vast distances, isolation, living off the land, and volatile weather.

As curriculum authors, our role is to create 21st century learning experiences that engage students, building on their local customs and ways of learning. Although we have not completed formal analysis of all the data that were collected, we saw firsthand that the integration of a distinctively Alaskan storyline into the curriculum was received well by the students. The annual Alaskan Native Youth Olympics is a widely anticipated event across the state with trophies from competitions of past years adorning schools' display cabinets.

We also witnessed variation in curricular needs depending on school size. We visited a village with just 11 students in middle school grades (6–8) and another with over 80 students in eighth grade alone. These differences create great challenges for curriculum adaptation, but we continue to work with local teachers to develop creative solutions so that the curriculum can meet their needs.

Throughout the villages, one thing that unites the students is their access to and dependence on the Internet. Although many aspects of Alaskan life are "off the grid," Alaskans are generally well connected. We hope the Precipitating Change curriculum offers students the chance to expand their computational thinking skills and ultimately contributes in a wide variety of ways to community enrichment.

	Student response and reasoning	Scaffolds
Less Formal Ideas	Kalin's response (it doesn't make sense to estimate; you need to go there and measure) suggests a very concrete thinking approach consistent with the idea that "you've got to see it to believe it."	Students who choose Kalin's response could benefit from discussions about how while estimates and interpolations may not be perfect, they can still give us a sense of what's going on in a system when we have limited data. It might be helpful to discuss that we can never collect all the data in the world; there's too much! Because of this, we need a way to fill in missing values using the data that we do have available.
Middle Level	Both Alex's response (choose the value halfway between) and Sage's response (choose a number closer to 59) might be reasonable estimates in certain circumstances (e.g., for picking out what clothes to wear if you were at location X at that time). These approaches are both better than just choosing a random value as an estimate for X. However, for contexts in which more precision is called for (e.g., making a weather model), then there are ways that we can be more precise in our approaches to interpolation.	Students who choose Alex's and/or Sage's response could benefit from discussions of when and why we sometimes might need to be more precise in our estimation approaches.
More Formal Idea	Delana's response (mark a number line with the estimate in each square going up the same amount between the two measured values) suggests that she understands which mathematical interpolation approach will give the most precise value.	This level of precision will take more time and effort, and may not even be necessary in some circumstances. However, if our goal is to be precise in our interpolation estimate, then Delana's response is the most appropriate of the options.

Table 1. Sample excerpt from the teacher guide suggesting ways teachers can scaffold students toward developing more formal understanding of computational thinking skills.

LINKS

Precipitating Change
concord.org/precipitating-change

Monday's Lesson: Demystifying Punnett Squares with ConnectedBio

Kiley McElroy-Brown
(kmcelroy-brown@concord.org)
is a project manager and scrum master.

By Kiley McElroy-Brown

Most biology students have used a Punnett Square, diligently filling in each cell with combinations of genetic alleles. But when asked to explain the Punnett Square in Figure 1, which shows the probability of fur color in the offspring of a dark brown mouse and a medium brown mouse, students often say, "So, if the parents have four babies, two will always be dark brown." This is not *always* true.

An innovative new breeding simulation helps reveal genetic ratios in offspring. With the heredity level of the ConnectedBio Multi-Level Simulation (MLS), students breed pairs of mice with different fur colors and observe the phenotypic ratios in the resulting offspring. The goal of this activity is to demystify the science behind Punnett Squares and encourage students to explore data and statistical representations in genetics and heredity.

Dark brown mouse (columns); Medium brown mouse (rows)

	R^D	R^D
R^D	R^DR^D	R^DR^D
R^L	R^DR^L	R^DR^L

R^DR^D = Dark brown fur
R^DR^L or R^LR^D = Medium brown fur
R^LR^L = Light brown fur

Figure 1. Punnett Square of fur color in the offspring of a dark brown mouse and a medium brown mouse.

Students investigate the ratios of fur color phenotypes, genotypes, and sex among offspring of a variety of parent mice combinations. There are three possible phenotypes for fur color in deer mice: light brown fur (R^LR^L), medium brown fur (R^LR^D or R^DR^L), and dark brown fur (R^DR^D). After each parent pair breeding, the resulting litter of offspring is shown, along with a pie chart, which updates to display the ratios in the total number of offspring for those parent mice. Students use this data to reason about the differences in offspring ratios and the probabilities of fur colors and genotypes between the various combinations of parent mice.

Explore phenotypic ratios in deer mouse offspring

Launch the ConnectedBio MLS: **http://short.concord.org/lls**

1. Select a pair of mice to breed from one of the nests.
2. Breed the parent mice by clicking Breed (Figure 2).

Notice that each time the mice breed, a new litter appears below the parent mice and the pie chart for that parent pair updates in the data pane on the right.

As your students explore this simulation, have them report their results and tally the class results where everyone can see. Students should notice that as they breed the pairs that produce more than one color, the pie chart initially shows large fluctuations in the ratios of offspring fur colors, but then gradually stabilizes as the number of offspring increases. In other words, random events can give rise to predictable ratios in offspring between parents!

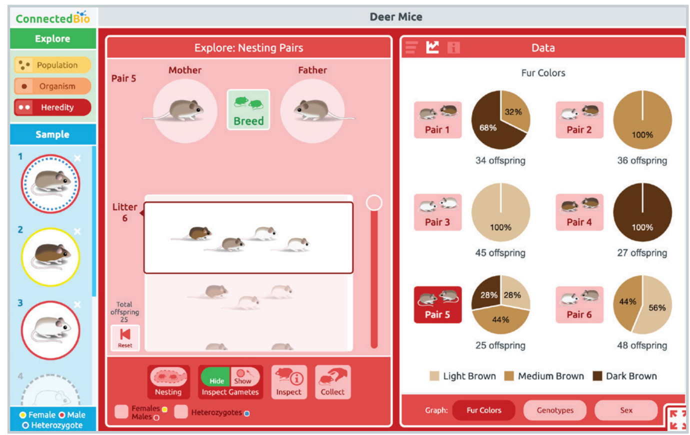


Figure 2. Heredity level of the ConnectedBio Multi-Level Simulation.

Ask students to reflect on:

- Why do some of the pie charts change as you breed the mice?
- Why do the pie charts stabilize?
- Where are the numbers different from the ratios in a Punnett Square? Where are they the same?

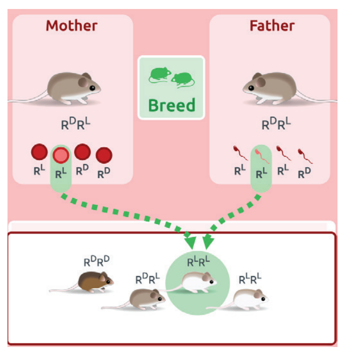


Figure 3. Tracing gametes from parents to offspring.

To dive deeper into the genetics of fur color, use the Show/Hide buttons to reveal the gametes responsible for each offspring and associated genotypes for each mouse. Hover over a gamete or mouse to trace the egg and sperm that give rise to an offspring. This visual display helps students see that each parent generates many gametes, but that each offspring only receives one gamete from each parent (Figure 3).

The ConnectedBio curriculum

The ConnectedBio curriculum helps students create a network of connected biological concepts spanning multiple scales—from the population, organism, molecular, and heredity levels—using a series of online interactive lessons. The materials will be available to the public in July 2020.

LINKS

Connected Biology
connectedbio.org

Sensors and Spinach:
Increasing Student Agency in Biology Class

By Seth Van Doren

Seth Van Doren
(svandoren@concord.org)
is a research assistant.

One student fills a Tupperware container with spinach leaves, wondering if they should add more. Another student looks for the roll of aluminum foil while a third measures a piece of plastic wrap. It's not lunchtime and they aren't preparing salads. They are getting ready to create biospheres with a healthy and stable level of carbon dioxide gas as part of our InSPECT project, which aims to integrate computational tools and computational thinking practices into the high school life science curriculum.

The traditional method of teaching high school biology—lectures and cookbook labs—is far removed from the way real biology lab investigations are done. Further, when students encounter graphs or tables in their textbooks, the graphs are constructed from data produced by unknown scientists for unknown reasons in unknown settings with unknown tools and techniques. The result of this anonymous pedagogical model is a disconnect between students, data, scientific practices, and scientists. The InSPECT project unseals this black box, giving students the opportunity to undertake authentic science investigations and embody real science practices.

Hardware and software for student agency

With a hardware and software suite designed to be intuitive, InSPECT's open-ended, technology-enhanced high school biology experiments facilitate inquiry and integrate computational thinking into core science content and practices. The modular hardware kit (Figure 1) includes multiple components so students have choices as they plan and perform their experiments. The kit includes programmable relays, plus CO_2, light, temperature, humidity, and oxygen sensors. Hubs can connect up to six components using small cables and ports, making it easy to swap out relays or sensors.

Giving students the freedom to mix and match components expands the types of investigations they can pursue. For instance, students can use several CO_2 sensors to check for variance between individual sensors, connect multiple relays and light sensors to create a system that turns itself on and off, or use three CO_2 sensors to monitor the gas levels in three different systems.

InSPECT's Dataflow software is a comprehensive platform for programming, data processing, and real-time data graphing. Within Dataflow, students are able to produce meaningful data and control their data through its lifecycle, making decisions as data flows from the collection device to a representation on screen. Students choose what data is being collected, where to collect it, how to modify or transform it, how to use the data to actuate a relay, how to store that data, and how to view the data.

To program in Dataflow students drag and connect nodes in the workspace. Figure 2 shows an example of a Dataflow program created by a ninth grader. The student uses both a CO_2 sensor and a number node as inputs for a logic node to construct an if-then statement that controls the relay. The student also connects the CO_2 sensor and light sensor nodes to a data storage node, which allows them to view a real-time graph of their data when the program is run. The data pathway is visualized through the wires used to connect Dataflow nodes: data flows from one node to another until it reaches an end point.

Unlike traditional block programming, students choose how to orient nodes in the Dataflow workspace. For example, if a student wants to read their program from right to left, they could position their nodes in that fashion. The node selector in the left-hand column of the workspace offers students additional programming options. A timer node actuates a relay based on a time schedule determined by the student. The generator node generates sine, square, and triangle waves with controllable amplitudes and periods. The math and transform nodes perform operations on the desired input. This wire and node programming style gives students the opportunity to view their program as a pipeline.

InSPECT hardware and software work together in an open-source Internet of Things (IoT) system. IoT functionality expands the number of interactions, activities, and investigations that can be carried out by giving students new things to do with data they produce. For example, students can monitor CO_2 levels in the classroom next door or one thousands of miles away and automatically turn on a warning light if the level becomes unhealthy. Like many modern experiments that rely on remote equipment or are conducted in coordination with groups around the world, IoT systems aren't confined to a classroom.

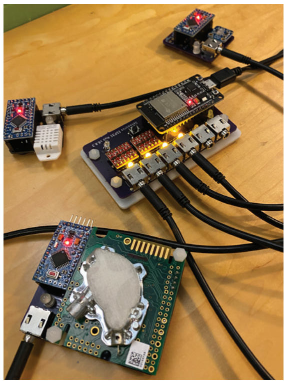


Figure 1. A Dataflow hardware kit composed of a Sensaurus ESP32 hub (center), a carbon dioxide sensor (bottom left), temperature/humidity sensor (top left), and a light sensor.

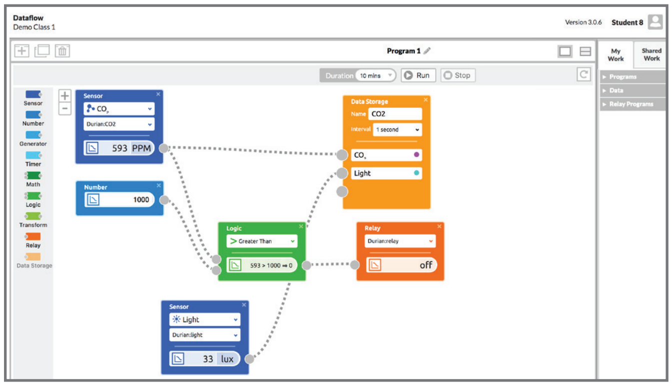


Figure 2. A Dataflow program created by a ninth grade biology student during the Stabilization Lab unit. The program actuates a red-blue LED lamp connected to a relay, and stores and graphs CO_2 and light data during the experiment. When CO_2 levels in the container reached above 1,000 PPM, the student's lamp turned on, initiating photosynthesis in the spinach leaves, which then caused the CO_2 levels to decrease.

Figure 3. A mini-biosphere in preparation, containing spinach, a carbon dioxide sensor, and light sensor. The container would later be sealed using plastic wrap and rubber bands.

The InSPECT curriculum

Our seven-unit "lesson arc" targets Next Generation Science Standards HS-LS1 and HS-LS2 related to Disciplinary Core Ideas LS1.C: Organization for Matter and Energy Flow in Organisms and LS2.B: Cycles of Matter and Energy Transfer in Ecosystems. Students engage in several Science and Engineering Practices: developing and using models, planning and carrying out investigations, constructing explanations and designing solutions, using mathematics and computational thinking, and engaging in argument from evidence.

In the penultimate "Stabilization Lab" unit, students are asked to imagine containers of spinach as mini-biospheres (Figure 3) that need to be kept at healthy CO_2 levels. This lab challenges students to create the flattest CO_2 dataset they can and requires them to use the concepts from the previous photosynthesis and cellular respiration units. For many students this experience helps to finalize and fortify their conceptual models as they learn that cellular respiration is always occurring in plants while photosynthesis is a process that can happen in parallel under the right circumstances. The act of performing authentic investigations is key to building this understanding. When students produce their own data, it's a far more powerful and lasting experience than simply looking at a graph of CO_2 levels in a biosphere.

Student experience in InSPECT

Students are encouraged to approach the challenge in creative and diverse ways. Students who enjoy coding have created programs that actuate a red-blue LED lamp based on the CO_2 sensor readings. Other students modified their physical experimental setups by varying the amount of spinach in their container or the intensity of a red-blue LED lamp. Many students modify both their physical and computational experimental setups.

Students also are able to control the way they carry out their experiments. Some groups plan their strategies ahead of time and only modify their approach after producing data, while others tinker with materials or their program throughout the lab. Students are able to do scientific work in a way that they enjoy.

InSPECT also helped create opportunities for collaboration between students. In a class where small group discussion previously was uncommon, groups of students talked and laughed while setting up experiments or producing data. Most of the more successful groups worked well with each other or were willing to learn from others by either interacting with them directly or through imitation.

Conclusion

Our goal with the InSPECT curriculum is to create something that feels different from "regular school." Since many students had no previous background in programming or using sensors, the experience was novel. Even those who had prior programming and sensor experience found the open-ended nature of this lesson arc new and surprisingly different.

Additionally, not having to follow a thoroughly tested, rigid procedure to reach a predetermined and predictable conclusion allowed students to become comfortable with being uncertain. As students encountered uncertainty and had to make sense of their investigations, they developed their own way to approach challenges within the InSPECT curriculum. Students had more agency in the classroom than usual, which resulted in a new level of engagement, including by students who were often unengaged during traditional instruction.

LINKS

InSPECT
concord.org/inspect

Writing
Data Stories

Bill Finzer
(wfinzer@concord.org)
is a senior scientist.

Michelle Wilkerson
(mwilkers@berkeley.edu)
is an Assistant Professor at the
University of California, Berkeley.

By Bill Finzer and Michelle Wilkerson

Today's students will encounter data in one form or another throughout their lives. The more data fluent they are when they graduate, the better prepared they will be to contribute to society as citizens and to advocate for themselves and their communities. Working with data should be an integral part of schooling, and students should expect that data will be part of their learning experience in every subject.

The goal of our new Writing Data Stories project is to infuse the analysis of existing scientific datasets about important socio-scientific issues (such as nutrition or human impacts on Earth systems) into middle school science through "data storytelling." This National Science Foundation-funded three-year project is a collaboration between the University of California, Berkeley, North Carolina State University, University of Texas at Austin, and the Concord Consortium.

We hope that students will learn to tell stories about patterns they discover in data, and how data help them make decisions in their own lives. We're currently designing curriculum activities that encourage students to tell data stories about questions that matter most to them. Students record information about where the data come from and explain why the data are important, what is included or excluded, and how they wrangled the data into a useful form.

Breakfast nutrition data

In one activity, we introduce middle school students to nutrition and health science topics through relevant experiences in their daily lives. We start by asking students to collect nutrition labels for cereals and other breakfast foods they have eaten recently. Students also make corresponding labels reflecting nutritional information they find online about home-cooked or other foods.

Students then work in small groups to gather their nutrition labels together, creating a physical dataset. They organize the labels—sorting by sugar content or protein to find the healthiest options or grouping the labels into foods that everyone in the group can eat, including those with allergies or other food restrictions. As they start to balance multiple nutritional needs, they develop strategies to organize the nutritional labels along many dimensions—balancing sugar content, fiber, and allergy restrictions. Working with this tangible dataset, they develop a data-informed sense of which foods might be the best breakfast choices.

Common Online Data Analysis Platform

Making "data moves" by grouping and sorting pieces of paper is clumsy, time consuming, and all too frequently frustrating. Students need computational tools to become fluent with the types of large datasets commonly used today. Enter the Common Online Data Analysis Platform (CODAP). Designed as an exploratory, immersive environment for students in grades 5-14 to work with data, CODAP can easily handle even thousands of items and allow students to interact with these data intuitively.

We found a dataset with nutritional information for 77 of the most popular breakfast cereals and presented this data to students using CODAP.* While the dataset provides useful information about what some students may eat for breakfast, it also leaves many other breakfast foods and considerations out. Not everyone eats cereal for breakfast, and not everyone makes breakfast decisions based on nutritional information alone.

Students identify what is missing from the cereals dataset that would help them to make a healthy breakfast decision. They enter data for non-cereal breakfast foods or for cereals that are not currently in the dataset. They can also add new attributes that are important in their decision-making, such as taste and cost.

Because there are a lot of attributes, students use a case card rather than a case table for data entry (Figure 1). These cards look a lot like the paper nutrition labels, allowing an easy transition to thinking about existing measures such as sugar and fiber, and helping students think about new attributes, such as the shelf where a specific cereal is located in the grocery store.

Then it's time for students to ask questions and make conjectures. What do you want to find out? What do you expect to see and how can you see if you're right? Which cereals have the most sugar, fat, or protein? Are the foods that you eat at home healthier than the cereals advertised on television commercials? How do you measure health? Are there relationships between attributes? For example, do cereals with more sugar also have more calories per serving? Can you discover anything about which cereals get placed on which grocery store shelf? If you added attributes that are important to you, such as cost or allergenic ingredients, how do they impact how many healthy options are available?

Small groups of students choose a question to investigate. They keep track of their data moves—adding new foods or attributes like taste or cost, grouping the dataset in particular ways, or building new measures such as a sugar-fiber ratio—and why they

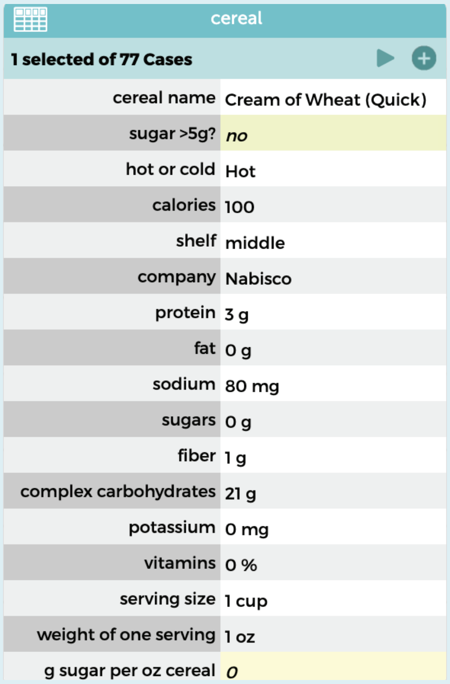


Figure 1. Sample case card with attributes for one breakfast cereal.

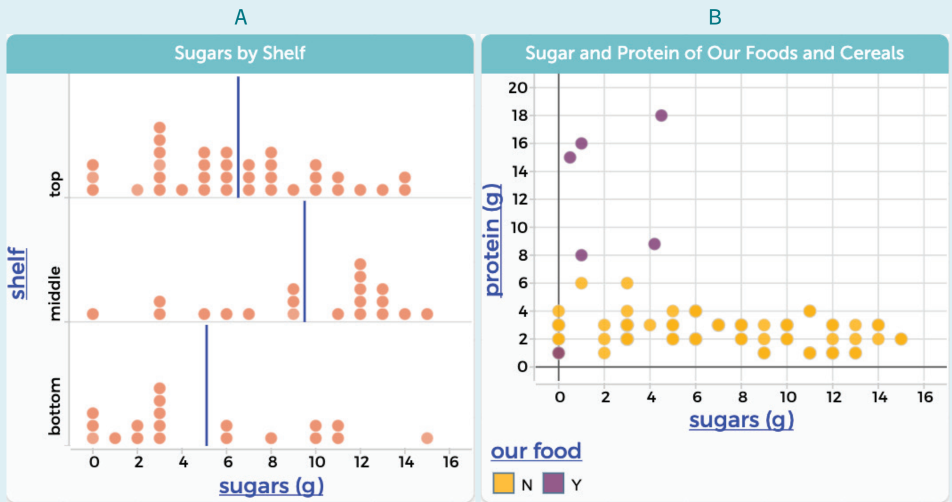


Figure 2. A) CODAP graph showing that cereals positioned on the middle shelf have more sugar on average than cereals on the bottom or top shelves. B) CODAP graph showing selected culturally traditional breakfast foods (purple data points) are higher in protein and lower in sugar than most cereals (yellow data points).

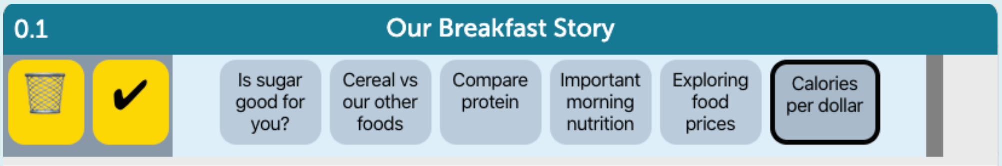


Figure 3. Story Builder prototype. Pages appear as labeled buttons.

are important for their decision-making. As they work with the data to make it useful for their inquiry, they will make new discoveries. One group may find that cereals positioned on the center shelf, which corresponds to the height of many children, seem to have more sugar on average than cereals on the bottom or top shelves (Figure 2A). Another group might find that many of the traditional and regional breakfast foods their families eat (like longganisa sausages, egg wraps, or manaeesh) are lower in sugar and higher in protein and fat than most cereals, which helps them feel full and more ready for school in the morning (Figure 2B).

Story Builder

Many technologies can assist students in writing a data story—word processors, slideshow tools, screencast video makers, and screen capture software for taking simple screenshots. We are also building an easy-to-use tool within CODAP, called the Story Builder, in which students can create and assemble a sequence of story pages for a presentation. During their presentations students are able to interact with CODAP's graphs and tables to demonstrate what happens when you select different cases, plot different attributes, or make additional graphs.

In our current Story Builder prototype, pages appear as labeled buttons (Figure 3). Students write labels to describe the content of each page. When students click on a page, CODAP reconfigures the data to appear just as it was when they originally "captured" the page via a special "shutter snapshot" button. Students can reorder or delete pages as they work on their data story. Story Builder pages are saved with the original CODAP document.

Students add pictures and video to their stories by simply dragging them into the document. They can include narrative text to help them remember the storyline when they present to the class, and add captions to help their audience understand.

We hope that as students create these data stories, they experience data as relevant and they feel ownership of the data and their data discoveries. Young people are natural storytellers, and they should feel confident with data as a new medium for telling their stories.

* The cereals dataset was gathered and cleaned by Petra Isenberg, Pierre Dragicevic, and Yvonne Jansen. The original source is available at: https://perso.telecom-paristech.fr/eagan/class/igr204/datasets

Invitation to the Future **of Energy Education**

By Joyce Massicotte, Xudong Huang, and Elena Sereiviene

Joyce Massicotte
(jmassicotte@concord.org)
is a project manager.

Xudong Huang
(xhuang@concord.org) is a
postdoctoral researcher.

Elena Sereiviene
(esereiviene@concord.org)
is a consultant project manager.

Two projects are helping teachers and students to better understand energy by focusing on authentic issues. Our infrared technology app allows secondary students to create school and home energy evaluations while also doing classroom energy experiments. And with our computer-aided design (CAD) energy software, students can design innovative solar solutions that offset the use of fossil fuels.

Authentic learning with infrared technology

Our energy activities are designed to be modular, so that teachers can use one or more individual activities based on their interest and schedule. The Exploring the Thermal World unit uses a simple infrared camera attached to a smartphone and our free SmartIR app, with a few materials easily found in a classroom, to record thermal imaging data (Figure 1). For example, students use jars filled with hot water, paper, and a binder clip to explore thermal energy transfer. In a conduction experiment, SmartIR helps students augment their sense perceptions of which material—a wooden ruler or a metal ruler—conducts more heat away from their hands. Or using a cup of water and a piece of paper or cardstock with SmartIR, students can observe heat released during phase change from gas to liquid. SmartIR can take photos and videos that analyze the unseen world of heat transfer.

Once students understand the modes of heat transfer, they can take the next step and complete a school or home energy assessment. A task normally performed by building performance professionals, energy assessments investigate areas of heat loss through building materials, as well as air leaks through windows and doors. Our SmartIR app empowers students to perform these real-world tasks themselves.

Students become solar designers

Our Solarize Your World curriculum goes further, using Energy3D software to assess the solar potential of a school or home by giving students tools used by professionals: accurate weather data, integration with Google Maps, and other specialized features. With Energy3D CAD capabilities, students can simulate any type of solar power system and calculate its hourly, daily, or yearly outputs. Reports generated by Energy3D have produced results that match actual solar array monitoring systems.

But before student groups launch into designing their own solar array systems, they can prepare by completing several inquiry-based tutorials that explore solar science concepts such as daily and seasonal changes of the sun's angle, the sun's path in different parts of the world, projection effect, the effect of air mass, the effect of weather, solar radiation pathways, and other self-directed activities for independent student work. Additional game-based activities challenge students to maximize the solar output of a single solar panel given fixed constraints and test their innovative engineering design techniques.

Expanding our teacher network with workshops

To reach teachers with these curriculum resources and technologies, we have hosted a number of workshops with more than 150 teachers from over 55 schools in 9 states. Teachers spend three days together, diving into scientific inquiry-based activities and engineering design tasks using innovative technologies like our SmartIR app and Energy3D software to explore energy phenomena and solar energy solutions.

The main goal of the workshops is to provide teachers with new ways of approaching energy science and engineering design and provide technologies to expand their toolbox to teach real-world energy-based projects. We encourage teachers to take advantage of our open-source technologies and activities and customize them for their own use.

We are delighted to share reports from teachers who have done just that:

Danielle Fredericks from Blanchard Memorial School in Boxborough, Massachusetts, recently implemented SmartIR activities in her sixth grade classroom. Intrigued by the potential of the activities and curious about the best pedagogical approach to use them with her students, Danielle and our team delivered the conduction experiment in two different ways. In one class, students were given the instructions and asked to complete the activity with a partner. In another, Danielle demonstrated the activity at the

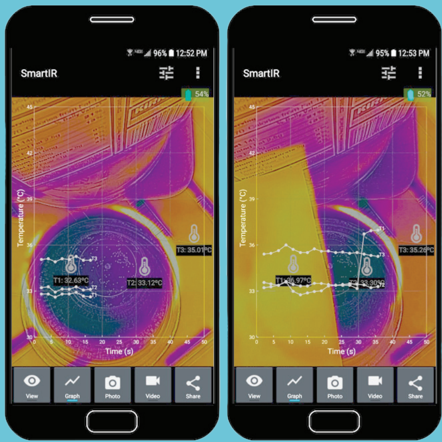


Figure 1. SmartIR app running on a mobile phone records thermal imaging data.

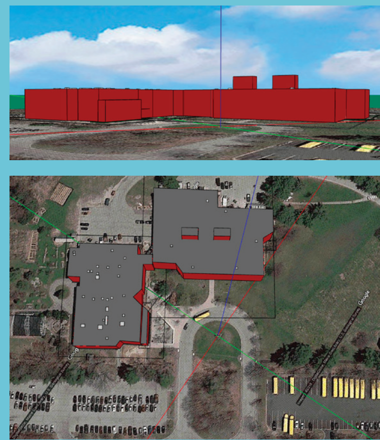


Figure 2. In the Solarize Your School curriculum, students design a replica of their school in Energy3D and add virtual solar panels.

Figure 3. With the Solarize Your House activity, students create a model of their home and investigate different solar panel layouts to improve the total energy output.

front of the classroom and projected the SmartIR app results on the board. Through a whole-class discussion, students discovered the learning objective: heat moves through different materials at different rates depending on their conductivity. Students then each ran the experiment independently, and were instructed to make careful observations during their own experiments. Danielle was surprised to see that the second method was more effective. She also noted a significant difference in student engagement and enthusiasm when students had the chance to conduct the experiment after her demonstration.

Anne Loughlin from Casco Bay High School in Portland, Maine, expanded our activities and engineered a way to analyze the solar output of real photovoltaic (PV) panels in the classroom using Energy3D. Her students completed the Solarize Your School project in small groups and designed both ground and roof systems for the school (Figure 2). Each team developed four to five solar array designs, compared their efficiency, selected the best design, and then presented their designs and recommendation to the City of Portland's Director of Sustainability. A local solar company, ReVision Energy, gave students a tour of a nearby solar farm that was installed over a landfill and provided students with online consultation while working on their Solarize Your School design project.* ReVision is currently installing solar systems on five school buildings in Portland, including Casco Bay High School.

In another creative twist on our curriculum, Anne adapted our energy transfer SmartIR activities to look at the science of candy making. In order for candy to turn into sweet treats, the ingredients (e.g., sugar, corn syrup, water) are boiled to extremely high temperatures. Students analyzed that delicious transformational process using the SmartIR app.

*Chao, J., Xie, C., Massicotte, J., Schimpf, C., Lockwood, J., Huang, X., & Beaulieu, C. (2018). Solarize your school: A solar energy system design challenge. *The Science Teacher, 86*(4), 40–47.

Matt Dransfield from South Burlington High School in South Burlington, Vermont, also used Energy3D with real PV solar cells to lay the groundwork for students to complete our Solarize Your House project (Figure 3). Matt's students created a model of their home, then explored different solar panel layouts that might improve their total energy output. Students compared their actual home electricity bills with similar automatic calculations in Energy3D. Then they chose from several house templates (e.g., a standard ranch, Cape, or Colonial) in Energy3D, and adjusted them to better reflect their own home. Matt used Energy3D to build a model of his home and installed virtual solar panels corresponding to the actual solar array on his roof. He was able to verify that the solar output data provided by Energy3D is accurate and matched the output of his solar panels in real life.

Learn more

Our energy activities have been used by pioneering Earth science, physics and physical science, and engineering teachers. We are always looking for enthusiastic educators interested in working with us as we develop cutting-edge technologies and pedagogies. To learn more about our latest projects or connect with our team, email energy@concord.org. Together we can bring the future of energy education to the next generation of learners.

LINKS

Solarize Your World
https://energy.concord.org/energy3d/projects.html

Energy3D
energy.concord.org/energy3d/index.html

Under the Hood:

Sharing Real-time Collaborative Documents *By Leslie Bondaryk*

Leslie Bondaryk (lbondaryk@concord.org) is Director of Technology.

Four middle school students are each at their own computers, busy working on a mathematics problem. Thanks to an innovative collaborative platform developed in collaboration with Michigan State University, they're able to work together with digital inscriptions. They can observe and borrow from each other's solutions, sharing digital artifacts freely by reusing content from their teammates, the curriculum, and their teacher. As they iteratively refine ideas and contribute back to the group solution, they build mathematical understanding.

The trick to this collaborative platform was to design shared content in ways that are supportive but not invasive. We chose to make groupmates' work copyable but not editable in place, meaning that students and their teacher needed to be able to see updates in documents in real time. To connect users we store their files in Firebase, a real-time, NoSQL cloud database, which allows users in a class to access the same content.

We designed a single document format for curriculum and user work. The format saves the content—graphs, text, tables, photos, and drawings—as well as the sequence of actions that produced it. Sequenced storage of edits allows individual objects (e.g., points and lines on a graph, rows in a table) to be inserted and rebuilt in alternate content, following a set of creation instructions (Figure 1).

A table in the file storage format

```
[
 {
  action: "create",
  target: "table",
  props: {
   name: "My Table",
   columns: [
    { id: ${col1Id}, name: "x" },
    { id: ${col1Id}, name: "y" }
   ]
  }
 },
 {
  action: "create",
  target: "rows",
  ids: [${row1Id}, ${row2Id}, ${row3Id}],
  props: {
   rows: [
    { [${col1Id}]: 1, [${col2Id}]: 1 },
    { [${col1Id}]: 2, [${col2Id}]: 2 },
    { [${col1Id}]: 3, [${col2Id}]: 2 }
   ]
  }
 },
 {
  action: "update",
  target: "rows",
  ids: [${row3Id}],
  props: [
    { [${col2Id}]: 3 }
  ]
 }
]
```

Figure 1. Code snippet that shows the sequential building and editing of values in a table.

This design makes it possible to excise and insert small pieces of content into other documents, and to recreate document changes in many simultaneous views. As objects are added and actions are performed in one document, all other views of that document perform the same transformation actions. This strategy allows us to update the real-time progressive display in the four-pane student view (Figure 2), as well as the teacher dashboard, which monitors the entire class in real time. And it makes it possible to offer features like undo. This style of document serialization also aids in research: actions are logged with their sequence and source, so we can trace the path of assets or the journey of students through their group scaffolding.

But sequential, action-based document serialization creates architectural challenges. In some cases, there is not enough information when playing history backwards to recreate content in its previous state. For example, if a student deletes a point in a shape, application rules delete the shape that contained it. If the student then reverses that deletion, the point comes back, but not the shape. Other side effects arise due to potential interrelationships between tiles (e.g., a table can be used to populate points on a graph). We currently resolve this issue by redrawing history from the beginning each time, rather than popping actions on and off the end of the history, though the impact is a longer re-rendering as more actions are added.

We are testing the UI and using log files to understand the learning experience for students. The goal is to build a robust collaborative environment to help students enhance their learning—about math and about collaboration in the 21st century.

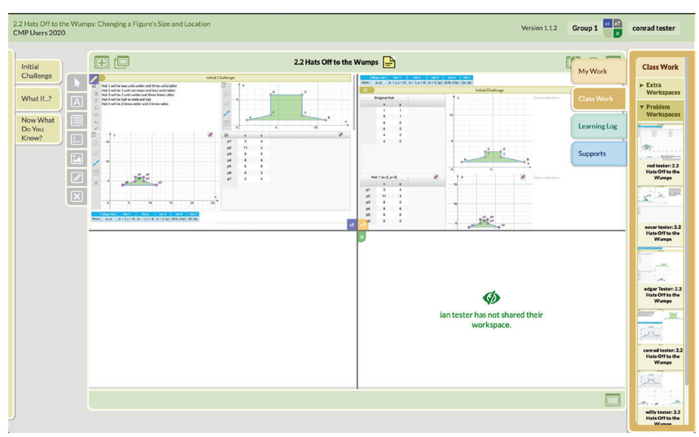


Figure 2. A student's screen with a four-pane view. Students can see their teammates' work if it's been shared. They can select and drag shapes, tables, or any other object into their own workspace and continue to edit it as they refine their ideas.

LINKS

Digital Inscriptions
concord.org/digital-inscriptions

Open-source code repository
https://github.com/concord-consortium/collaborative-learning

Innovator Interview:
Sarah Haavind

shaavind@concord.org

Sarah is now working on our InSPECT and InquirySpace projects, where students do science like scientists do science, which she describes as "Bob's legacy."

Almost three decades ago, drinking coffee in a local café with friends, Sarah never imagined this collegial coffee klatch would lead to a long-term relationship with the Concord Consortium. The group included Concord Consortium founder and visionary Bob Tinker, and it still convenes annually. During the intervening years, Sarah has served on Concord Consortium's Board of Directors, contributed to the groundbreaking Virtual High School, co-authored a book about online facilitation, taught at every level from grade school to college, lived on both coasts, and earned an Ed.D. She is now working on our InSPECT and InquirySpace projects, where students *do science like scientists do science*, which she describes as "Bob's legacy."

Before joining the Concord Consortium, in 1997, Sarah worked at Bolt Beranek and Newman (BBN), even though she had once picketed in their parking lot ("No nukes!") because they were engaged in government war programs. But their education technologies department hired her to develop problem-based learning CD-ROMs about EarthWatch field studies. She's still passionate about Orca whales of the Pacific Northwest as a result. "They're matrilineal, live to their nineties, and swim in familial lines. They're extraordinary," she laughs.

This was the incredible era in which the World Wide Web was created at BBN. One of her colleagues then, Andee Rubin, who ironically now serves on the InquirySpace advisory board, first presented to her team the potential of the Mosaic browser for education. The Internet subsequently launched a revolution in business, communications, and education. Sarah has been fortunate to work near prescient technologists. (A *Los Angeles Times* article dated August 25, 1970, pinned to her office bulletin board, quotes her farsighted father, *Electronics* magazine editor Bob Haavind, "Home computers likely in U.S.")

In 1996, Sarah was at the forefront of a new wave of technology. She co-authored with Bob Tinker one of the earliest articles on "netcourses." Their work resulted in a grant from the Department of Education to develop the Virtual High School (VHS), which led to the seminal book *Facilitating Online Learning: Effective Strategies for Moderators* that Sarah co-authored.

Fascinated by the value of online learning communities, Sarah completed a doctorate at the Harvard Graduate School of Education focused on online collaborative pedagogy at VHS. In the earliest days of online courses, she observes, people wrote "long letters" that were inefficient for others to read and for the development of deep conversations. So she conceived a new framework for online conversations that would deepen naturally towards collaborative learning with text-based discussion.

She's now putting her skills into practice in InSPECT, which is creating affordable IoT (Internet of Things) sensors and software to help students learn to produce their own data, rather than passively collect data. "If you want students to tinker and figure out what data to produce, then you need to rewrite the curriculum and the role of the teacher," she says, "keeping learner agency with the student and relearning your role as someone supporting that." As a project researcher she loves scouring classroom videos and pinpointing the moment the teacher asks a reflective question and the student (sometimes while manipulating a sensor in their hands, which she describes as "kinesthetic learning") has an aha! discovery.

The goal of both InquirySpace and InSPECT is for students to use technology that enables them to experience their own agency as scientists. "That's what got Bob up in the morning," Sarah says. And it's important to her to continue his legacy. In 2019 she returned to the Concord Consortium full time: "I just feel like I'm at the right place. I'm home."

The Concord Consortium
25 Love Lane, Concord, MA 01742

Larry Behan
New Chief Financial Officer

We are delighted to welcome Larry Behan as our new Chief Financial Officer. Before joining the Concord Consortium, Larry served as Vice President of Administration and Finance at the Massachusetts College of Liberal Arts, overseeing a wide array of projects from overall finances to facilities and technology. He has held executive-level positions in private healthcare, the University of Massachusetts Medical School, and the Commonwealth of Massachusetts.

A Boston area native and avid outdoor enthusiast with two main recreational seasons—golf and ski—Larry initially studied forest engineering at Oregon State University before working for the National Park Service at Olympic National Park in Washington for a year. After living in the Bay Area for a time, he moved back to the East Coast, where he earned a B.S. in economics from Northeastern University and a Master of Business Administration from Suffolk University.

With a background in higher education and experience with research projects in academia and healthcare, Larry explains that he was drawn to the opportunity to work in a mission-driven organization dedicated to educational innovation. He notes, "The Concord Consortium is made up of a great group who are passionate about their work, and have a fun, collaborative style."

Narrative Modeling with StoryQ

We are proud to announce a new grant funded by the National Science Foundation to help high school students envision their future careers as powered by Artificial Intelligence (AI): *Narrative Modeling with StoryQ—Integrating Mathematics, Language Arts, and Computing to Create Pathways to Artificial Intelligence Careers.* AI is reshaping the world and all students will soon enter a workforce powered and transformed by ubiquitous intelligent agents. Today's students must gain a fundamental understanding of how intelligence in computers is created, how machines learn from data, and how data are prepared for computers to learn meaningful patterns. Yet AI learning opportunities remain abstract and inaccessible, especially to underrepresented youth.

This project will leverage existing data exploration and text mining technologies and research-based pedagogical approaches to bridge this critical gap. Focusing on narrative modeling, one of the oldest fields in artificial intelligence, we will combine mathematics, language arts, and computing concepts and integrate them into a coherent learning experience for high school students. Led by learning technology and data experts from the Concord Consortium, machine learning experts from Carnegie Mellon University, and experts in the integration of narrative modeling and mathematics learning from North Carolina State University, we will create and test StoryQ, a web-based text mining and narrative modeling platform and an associated curriculum, and research student learning in text mining and development of AI career interest. Our goal is to broaden participation among underrepresented and underserved student populations.

Enhancing middle school mathematics learning

Thanks to funding from the National Science Foundation to the Concord Consortium and Michigan State University, we have developed and refined an innovative learning platform designed to engage middle school mathematics students in collaborative problem-solving based on the Connected Mathematics Project (CMP) problem-based curricula. With mathematics tools that include linked graphs and tables, text, images, and drawing tools, and the ability for students to share their work with teammates, the digital platform is designed to enhance student learning and promote productive disciplinary engagement. Using a class dashboard and full-featured teacher workspace, teachers can access and use student work for pedagogical decisions and create robust just-in-time supports for individual students, small groups, or the whole class.

If you are a middle grade math teacher who plans to teach the CMP3 units Stretching and Shrinking or Moving Straight Ahead to your seventh grade students in the 2020-21 school year and are interested in using this free software, we invite you to complete a short application:
https://connectedmath.msu.edu/participate/

Editor: **Chad Dorsey** | Managing Editor: **Cynthia McIntyre** | Design: **Jan Streitburger** | **concord.org**
The Concord Consortium | **Concord, MA** | **Emeryville, CA** | **978-405-3200** | **fax: 978-405-2076**
@Concord is published two times a year by The Concord Consortium, a nonprofit research and development organization dedicated to transforming STEM education through technology. This material is based upon work supported by the National Science Foundation under several grants (DRL-1640088, DRL-1620910, DRL-1640054, DRL-1900606, DRL-1503196, DRL-1620874, DRL-1621301, DRL-1949110, and DRL-1660926).