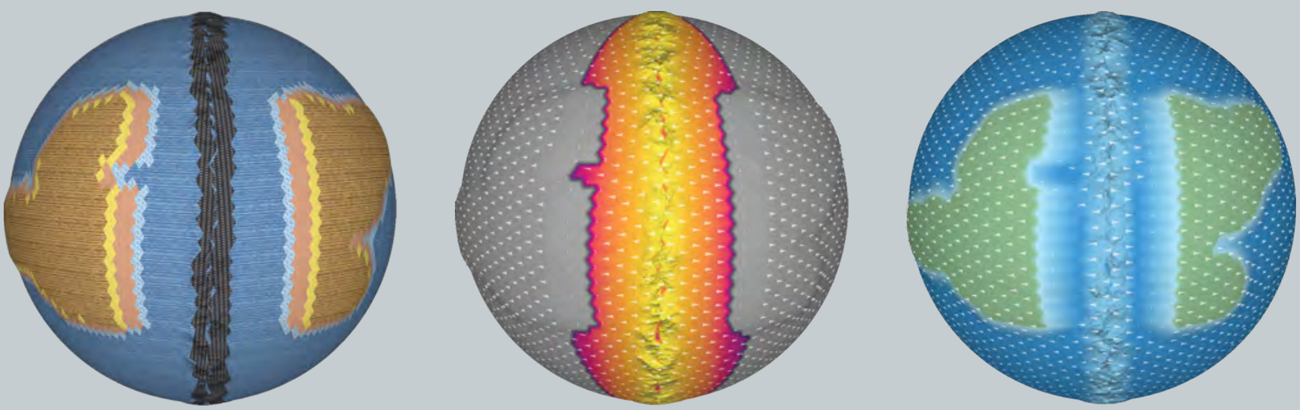
@CONCORD

vol. 27 • no. 1 • Spring 2023



The Concord Consortium
concord.org

Perspective:
AI and the Future of Education

By Chad Dorsey

"That it will be of very great use cannot be questioned, but how will its uses add to the happiness of mankind?"

"You give [them] only the semblance of truth.... They will appear to be omniscient and will generally know nothing...having the show of wisdom without the reality."

With all the hype around artificial intelligence, you might assume these quotes were written about the power of modern AI. However, the first, penned in a *New York Times* story about the earliest successful test of a transatlantic telegraph cable, is dated August 19, 1858. As communication times between Europe and the United States dropped from three days to three minutes overnight, the author was aghast at the unimaginable societal horrors surely in store. The second quote depicts Socrates' classic concern about students' being consumed by the dangers of the newest 370 BCE technology—the written word.

Unlike the authors of these alarmist proclamations, I am indeed writing here about AI. As we attempt to understand a future in which AI plays a prominent role, concerns about this seemingly mystical technology often occupy center stage. However, the bigger picture embraces anticipation and excitement as much as caution and concern. Where AI and learning intersect, intriguing questions—and more than a few surprises—await.

Checking our assumptions

If history reveals anything with certainty, it is that when groundbreaking new technology appears on the scene, *un*certainty is sure to follow. No matter the specific example—AI, telegraphs, bicycles, umbrellas, or forks—new technology and fears about the future are close cousins. According to Genevieve Bell at Intel, moral panic sets in any time a technology changes our relationship to time, space, and people—three categories AI will undoubtedly engulf, if it hasn't already. Given this, it's our responsibility to search through the hype and panic to unearth AI's true promise and to understand which concerns are justified.

In Kevin Roose's recent exploration *Futureproof*, he investigates some of the crosscutting assumptions about AI and automation: *AI will make things better by doing the boring work for us. Humans and AI won't compete; they'll collaborate. We'll come up with jobs we can't even imagine today.*

His conclusion? The future isn't as simple as such pithy proclamations imply—and it's not all rosy either.

According to Roose, AI will usher in a new industrial revolution. Importantly, this one is likely to be different. In particular, it will undoubtedly be a white collar revolution—ChatGPT has already shown the ability to pass complex licensure tests, including the bar exam, with flying colors.

In addition, a view of past such revolutions shows that while they have improved many things, each has also left repetitive jobs and significant inequity in its wake.

Finding the silver lining

Still, there are reasons to be optimistic. As part of his thesis, Roose lays out a set of rules "for humans in the age of automation." Indeed, these rules will be disruptive for many, as some jobs are clearly in jeopardy. However, Roose's rules offer consolation to those in education. Roles most impervious to AI takeover, he predicts, are those that change significantly from day to day, hinge extensively on social interaction, and do not lend themselves easily to predictable, data-intensive recipes. That describes every teacher I know.

Nevertheless, while the art of teaching may be safe from the AI bots (for now), there's still some pretty solid change on the horizon. Let's look at some of the positive potential, from "adjacent possible" near-present scenarios to some wild future ideas worth envisioning.

Looking to the AI future

Teaching and learning are a complex pastiche. AI and automation have the potential to provide valuable transformation in many places—from serving as highly intelligent resources to providing solutions to currently vexing problems and opening up new synergistic opportunities.

For example, imagine educators had the information and real-time guidance to easily orchestrate extended, open-ended learning experiences while simultaneously providing tailored assistance to individual students. AI and automation could monitor and manage the logistical challenges of coordinating project-based learning, render the intricacies of differentiation

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

AI may finally allow us to truly view education as a broader endeavor informed by a diverse set of informational inputs, bringing the promise of equity in learning closer than ever.

and scaffolding for individual students tractable, and enable teachers to understand where each student sits along a desired trajectory of learning or instruction.

We can think more broadly as well. With better information available about learning both in the moment and over time, performance assessment, portfolios, and competency-based learning could become more effective. AI could find paths toward promoting and improving student collaboration and could gauge cross-disciplinary learning to boot.

The possibilities for improving engagement, fueling student-centered approaches, and ensuring relevance to students and society are immense. AI may finally allow us to truly view education as a broader endeavor informed by a diverse set of informational inputs, bringing the promise of equity in learning closer than ever.

Preparing learners for an AI-filled future

Of course, we must also consider students' post-graduation future. What do learners need to be ready for? After all, the rapid innovation we're seeing in AI is by no means limited to the classroom. AI is *already* actively transforming the world our students will enter. What does the future of writing look like in a world where ChatGPT can write robust, detailed essays? What's the future of design in a world where technology can generate art, three-dimensional structures, and even full videos from whole cloth?

And what thousand things are we not yet imagining? Even now, innovators and artists are using ChatGPT to generate concepts, employing DALL-E to create an image sequence from them, then feeding the sequence into another platform to produce animated visualizations. Truly transformational tools are already difficult to wrap one's head around. When it's possible to combine them in *multiplicative* chains, the resulting potential is truly unimaginable.

When such possibilities arrive seemingly overnight, we can be left feeling adrift. But taking the broad view offers important perspective and useful starting points. While our first instinct may be to wall off students from chatbots, what if we instead take for granted their role as constant companions and begin to examine their potential? Rather than wring our hands about questions of copyright in generative art, what if we put our energy into exploring the green fields of creativity waiting to be unlocked? Just imagine the opportunities if we were to view AI tools through the lens of combination and connection, pouring our unbridled human creativity into the search for unexpected and unexplored synergies.

Generative AI has already helped design buildings and predict protein structures. Why shouldn't it generate new classroom configurations, diagram novel learning trajectories, or uncover new ways of viewing longstanding problems in engineering, science, or mathematics? Chat-based learning models could give us the seeds for student feedback, generate unexpected lesson plan concepts, or provide novel approaches for differentiating student learning.

While we must indeed proceed with care and with eyes wide open, our roles as scientists, innovators, and explorers compel us to embrace the excitement of the unknown. As we look ahead, we must acknowledge and welcome our students as active participants in shaping the future that the existence of these tools will create. The years ahead promise amazing things. We need to stay open to their potential.

MAKING CONNECTIONS:
Rocks & Tectonics

By Stephanie Seevers and Amy Pallant

"Rocks are the records of events that took place at the time they formed. They are books. They have a different vocabulary, a different alphabet, but you learn how to read them."

– John McPhee, *Annals of the Former World*

Stephanie Seevers
(spseevers@gmail.com) is a teacher at Evergreen High School, CO, and a consultant for the Concord Consortium.

Amy Pallant
(apallant@concord.org) is a senior research scientist.

Earth science teachers often have a collection of rock and mineral samples accompanied by scratch plates and vinegar droppers tucked away in their supply closets. These "rocks in a box" are pulled out for hands-on labs in which students learn to differentiate between calcite and quartz, granite and gneiss, shale and slate. However, labs about rocks and minerals miss the bigger story of their context within larger Earth systems. Funded by the National Science Foundation, the Geological Construction of Rock Arrangements from Tectonics: Systems Modeling Across Scales project, called TecRocks for short, aims to change that. Our goal is to help students develop explanations that connect rock type formation with the conditions and processes found in tectonic environments, using simulations and computer-based tools to observe the geologic processes that would otherwise be inaccessible.

Most of us have seen (or taught from) a "rock cycle" diagram (Figure 1), but if you look at it long enough, you realize it is both abstract and misleading. With arrows pointing from one rock type to another, the rock cycle implies that rocks transform from one rock type to another over and over. But rocks do not go through such continuous transformation. While rocks may transform over the course of geologic time, they typically do not go round and round the cycle. Further, the processes in the rock cycle—weathering, melting, cooling—are not linked to the tectonic processes and environments that produce the transformations. For example, igneous rocks can become metamorphic rocks through heat and pressure, but the rock cycle diagram doesn't indicate where or why this happens.

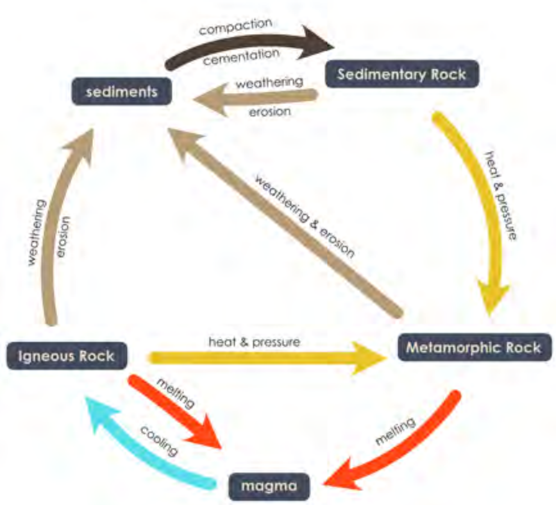


Figure 1. A typical rock cycle with no reference to tectonic processes and environments.

TecRocks Explorer and the Rocks & Tectonics module

The NGSS standards for middle and high school Earth science emphasize teaching about the Earth through the development and use of models and, more specifically, teaching about Earth's materials within the context of the processes that produce them. When we started planning the TecRocks curriculum module to address these standards, we asked what students should learn about the origin and formation of rocks. Should they even be identifying minerals?

To begin, we needed to show how rock-forming processes and tectonic processes are interconnected. We developed a unique online computational model and simulation for students to investigate the relationship between Earth's tectonic system and the location of rock-forming environments. The TecRocks Explorer model offers students the opportunity to investigate rock formation within the context of a planet-wide system of plate tectonics. Students set up tectonic plate interactions on an Earth-like planet and observe and collect data focused on how and why different rocks form and are distributed on Earth.

Figure 2. A screenshot of the TecRocks Explorer model showing a cross-section of an oceanic-continental convergent boundary.

For example, students can see magma being formed in the mantle above the subducting plate at an oceanic-continental convergent boundary (Figure 2). They can analyze the change in the rock types forming as magma rises and solidifies at different depths. They can also observe the basalt and gabbro undergoing metamorphism as the rock layers move deeper because they are experiencing temperature and pressure changes as the plate subducts.

We also developed a curriculum module centered around TecRocks Explorer to help transform the traditional teaching sequence about rocks, landforms, and plate tectonics as separate entities and events to a holistic view that is driven by tectonics. The "Rocks & Tectonics" module explores real-world phenomena related to the formation and distribution of rocks on Earth and connects them to plate tectonics.

The module leads students to deeper reasoning about the connections between tectonic settings on Earth, the conditions present there, and the resulting types of rocks that form. While typical rock cycle lessons are organized by rock type and describe the characteristics of rocks primarily for the purpose of classification, our TecRocks module is organized by tectonic setting and connects those settings to the conditions present that result in rock formation.

Students explore divergent and convergent boundaries; investigate magma-forming processes that create island arcs or continental volcanic mountains; explore rock transformation processes

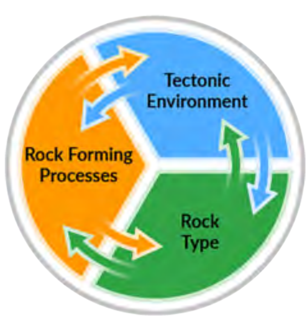


Figure 3. The TecRocks reasoning framework. Connecting ideas helps students reason about the interrelationships among tectonic environments, rock-forming processes, and rock types.

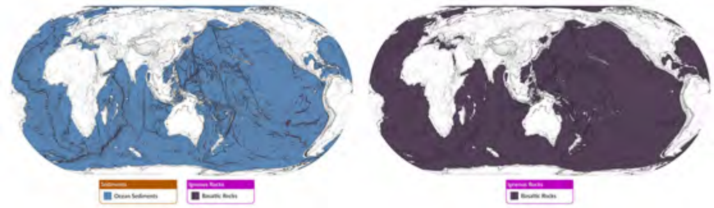


Figure 4. The ocean floor covered in ocean sediment (left). When sediment is removed, the ocean floor around the world is all made of basaltic rocks (right).

in subduction zones and along continental collisions; and research sedimentary rock formation along passive continental margins (places away from tectonic boundaries). (See the "Rocks & Tectonics Module Overview" sidebar on page 6 for activity descriptions.)

Throughout the module, students should be able to use reasoning that reflects the integration of ideas related to the tectonic environment, rock type, and rock-forming process. Figure 3 represents a flow for how the ideas are connected. The arrows show the sensemaking necessary to build explanations that connect tectonic environments to rock-forming processes to rock types.

For example, in one activity, students are shown maps of the rock types on the ocean floors as if all the sediment were removed (Figure 4). They observe that all ocean floors are made of one rock type, basalt. To investigate this phenomenon, students use TecRocks Explorer. When they draw a cross-section across a divergent boundary between two oceanic tectonic plates, they observe where magma forms (Figure 5), the type of plate motion, and the different rock types that form as the magma cools. Students can follow the rock that forms along the mid-ocean ridge and moves away from the plate boundary and use evidence from the model to reason that oceanic crust is formed at divergent plate boundaries and that the ocean floor is made up entirely of basalt. (Try the "Monday's Lesson" on page 7 with your students to learn more about basalt.)

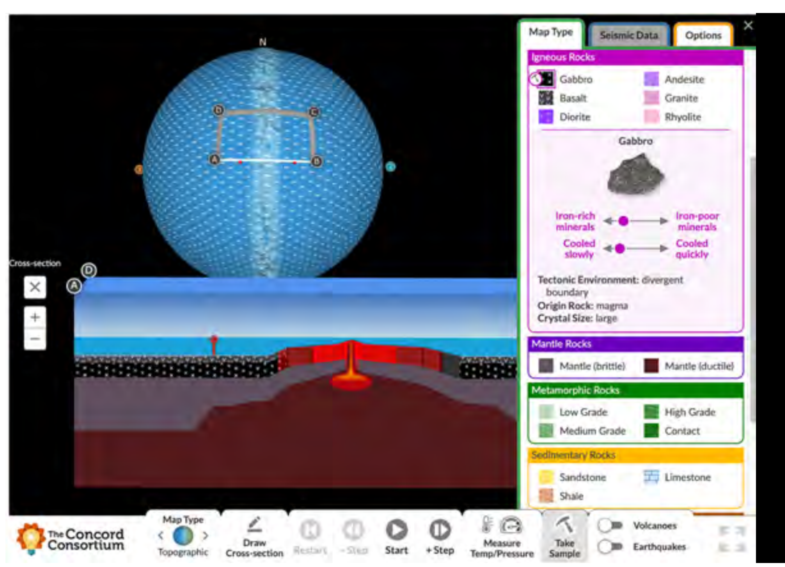


Figure 5. With TecRocks Explorer set up to show a divergent boundary, students can see magma rising and cooling as it adds rocks to the plates on either side of the boundary.

(continued on p. 6)

(continued from p. 5)

Pin	Category	Type	Iron Content
1	Igneous	Gabbro	Iron-rich minerals — Iron-poor minerals
2	Igneous	Diorite	Iron-rich minerals — Iron-poor minerals
3	Igneous	Granite	Iron-rich minerals — Iron-poor minerals
4	Igneous	Rhyolite	Iron-rich minerals — Iron-poor minerals

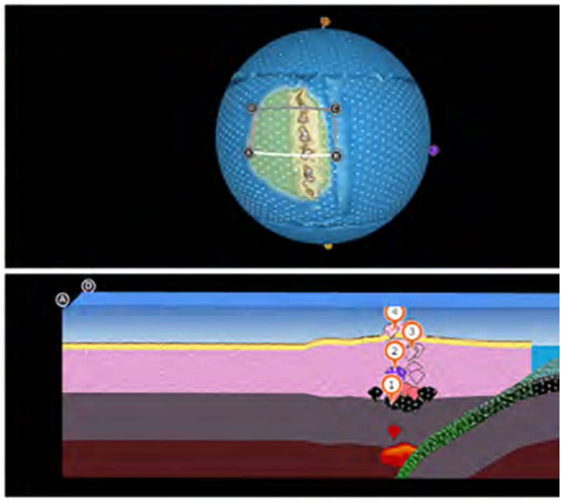


Figure 6. Students can click in the model to collect data, which is populated in a table. Tags in the model show where data was collected.

In a traditional approach, students are able to identify the characteristics of basalt, describing it as an igneous rock that is black and has small, nearly invisible crystals. In the TecRocks approach, students can sample rock types and use a pressure/temperature tool to explore conditions with the goal that they are able to reason about how the formation of basalt happens where magma rises from the mantle and cools between diverging plates.

To help students determine other relationships between variables (e.g., depth and rock composition), TecRocks Explorer also has a data collection tool. Students can click anywhere in the cross-section to collect data that is then organized into a data table to help them discern patterns (Figure 6).

Curriculum pilot

During the first TecRocks pilot in November 2022, students were able to demonstrate reasoning between rock type, tectonic environment, and rock-forming process. For example, when asked to provide an explanation for the rocks that are forming on the Pacific Ocean floor, many students linked rock formation to either the divergent boundary, the magma formation, or both. One student said, "As plates move away from each other, magma is allowed to rise up to the surface at the ocean floor, where it crystallizes and spreads out to make quick-cooling basaltic rocks." Another reasoned, "The ocean floor at the East Pacific Ridge is formed from magma because the plates at the Ridge are divergent, this means that when the plates move away from each other that lets magma from the mantle to push up and form rocks when cooled. You can see this in the [model] because there is a magma chamber in the ductile mantle that can be brought to the surface and make rocks like gabbro and basalt."

We also heard from teachers about the pilot implementation. One teacher described how she used the module in conjunction with her previous lessons on igneous rocks, weaving various activities together. After her students finished the TecRocks module, they took the usual igneous rocks quiz, during which they moved around the room to stations with different igneous rock samples and were asked about the conditions of their formation as well as tectonic settings. The teacher compared students' average quiz scores to those of previous years and found a significant improvement.

Conclusion

All rock types—metamorphic, igneous, and sedimentary—hold stories about the conditions and processes that existed while they were forming. They also reveal information about the location on Earth where they likely were formed. With the TecRocks Explorer students can employ authentic scientific practices such as modeling and data collection to investigate rock formation and develop sophisticated reasoning about the interconnections between tectonic environments, rock-forming processes, and rock types. Like geoscientists, students can begin thinking about what a rock tells us about Earth in the past when it was formed. Knowing how to read the stories told by rocks is far more interesting than simply memorizing their names.

Rocks & Tectonics Module Overview

Activity 1: You rock!
Demographic and curiosity survey.

Activity 2: Earth: It's rocky out there!
There are different types of rocks and there are patterns to their distribution. What could cause this?

Activity 3: Eruptions everywhere
Magma formation and volcanoes on Earth are associated with certain types of tectonic settings. Magma cools to form igneous rocks that can create new land or new ocean crust.

Activity 4: Recipes for rock
Converging plates can cause one to subduct, which results in deep magma formation. The way magma cools as it rises slowly through overlying crust results in the formation of increasingly iron-poor igneous rocks.

Activity 5: Rock transformation
Along convergent boundaries, the changes in pressure and heat that rocks experience when they are subducted or compressed result in the formation of metamorphic rocks.

Activity 6: From sediment to rock
Active plate boundaries aren't the only places that rocks can form. Sediments that are transported by wind and water and settle in a location far from active plate boundaries form sedimentary rock layers.

LINKS

TecRocks
learn.concord.org/geo-tecrocks

Monday's Lesson:

All About Basalt

By Christopher Lore

Christopher Lore
(clore@concord.org)
is a research assistant.

There are over 4,000 types of minerals on Earth. These minerals combine in various amounts to form thousands of different rock types. Look at a geologic map of the United States and you'll see a kaleidoscope of colorful streaks, each representing a unique rock type. But look at a geologic map of the ocean and you'll see just one rock: basalt. It's true. This singular igneous rock forms the surface layer of every ocean basin on Earth, covering about 60% of the entire globe. Why is this one rock type so abundant on the ocean floor? And how did it get there?

Our TecRocks Explorer allows students to investigate such questions and uncover the connection between rock formations and the environments and processes that generate them. With this dynamic, Earth-like model, students can set up plate tectonic simulations, explore emergent phenomena, and develop explanations about the distribution and types of rocks forming in various tectonic environments.

1 Open TecRocks Explorer

Go to **https://tectonic-explorer.concord.org/index.html?rocks=true**

- **Select layout of the planet.** Select the number plates for your planet.
- **Draw continents.** Click and drag your cursor to draw continents, which appear as green blobs. If you want continents around the planet, click Rotate Planet, then click and hold the mouse to move the planet. Click the Next button.
- **Assign boundary types.** Hover over the boundary between plates (the pink lines), then click to select how the plates move in relation to each other. They can either collide (converge) or diverge. For this investigation, set at least one boundary type to Divergent. Click the Next button.
- **Order plates.** Finally, choose the density of each plate in relation to each other. Click Finish when you are done with your planet setup.

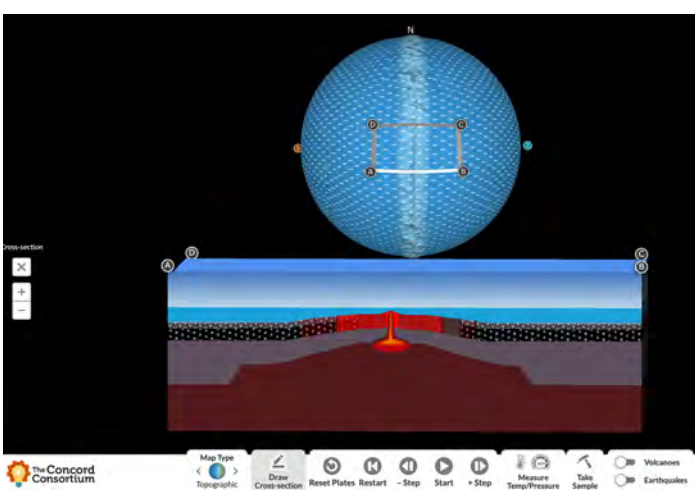


Figure 1. The TecRocks Explorer helps connect plate tectonics with rock formation.

2 Draw a cross-section

In the toolbar below the model, click the Draw Cross-section button. Your cursor changes to a cross. Click and drag from one side of the divergent boundary to the other. The cross-sectional view cuts a vertical slice through the Earth-like planet so you can look at it from the side and see what's going on below the surface of the Earth (Figure 1). The different colors and patterns each represent a different type of rock. Press Start to run the model. Watch as the plates on either side of the divergent boundary begin to move away from each other.

3 Dig deeper (literally)

Watch the cross-section view while running the model. Notice that magma moves at the divergent boundary, upwelling out of the mantle and onto the surface of the Earth, where it quickly solidifies and hardens into rock due to the cold temperatures at the bottom of the ocean.

To find out what types of rock form through this process, use the Take Sample tool. Click the various rock layers, and refer to the key to learn more about the different rock types.

4 Discuss

Using a map of plate boundaries around the Earth, point out that all oceans have divergent boundaries running through them. Ask students how this plate movement explains why basalt covers the entire ocean floor. How does this tectonic environment create the conditions for basalt to form? Where would you expect to find the oldest basalt in the ocean?

Looking for more?

Created by our TecRocks project, the TecRocks Explorer is embedded in a weeklong curriculum unit for middle and high school classes. Students use the TecRocks Explorer and data visualizations to reason about tectonic environments, rock-forming processes, and rock types.

LINKS

Tectonics Module
learn.concord.org/geo-tecrocks

Tectonics Explorer
https://tectonic-explorer.concord.org/index.html?rocks=true

Engaging Multiple Perspectives in Alaskan and Hawaiian Classrooms

By Carolyn Staudt, Beth Covitt, and Noelani Puniwai

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

Beth Covitt
(Beth.Covitt@mso.umt.edu) is a science education researcher at the University of Montana.

Noelani Puniwai
(npuniwai@hawaii.edu) is an Associate Professor at the University of Hawaii.

Precipitating Change with Alaskan and Hawaiian Schools is a National Science Foundation-funded project with partners from Alaskan and Hawaiian Native communities, multiple universities, and the Concord Consortium. Together, we are exploring approaches to designing, testing, and refining multi-perspective, middle school science instruction about coasts and coastal change.

Figure 1. Making a traditional lei, part of building connection and relationship to a place that gives life to the community.

Coastal regions in Alaska and Hawai'i have always experienced change, but recently the speed and intensity of change has been increasing in response to human development and climate change. In Indigenous communities, where people have longstanding cultural connections with place and rely on subsistence practices of hunting, fishing, and gathering traditional foods from the land and ocean, changes to the coast are relevant to many students' lives. Investigating coasts and coastal change can involve employing both Indigenous and Eurocentric science approaches, as well as diving into related areas, including history, culture, and community decision-making.

Exploring and valuing multiple ways of knowing

Indigenous children represent a significant portion of school populations in Alaska and Hawai'i, but Native students often experience science class as disconnected from their communities' cultures and ways of knowing. Thus, instruction concerning coasts and coastal change in Alaska and Hawai'i calls for a multi-perspective approach.

As we work together to understand approaches to and implications of enacting multi-perspective instructional activities, we are actively grappling with some fundamental questions:

- How can multiple perspectives be appropriately included in instruction in ways that equitably demonstrate respect and value, rather than some perspectives being represented in deep ways while others are represented in shallow ways?
- What does "learning" look like when it authentically represents multiple perspectives?

To better meet teachers' and students' needs and to engage students more authentically with multiple perspectives, we are currently redesigning the project's curriculum.

Below is a description of the unit piloted by seven teachers in 2022-23. The unit drew on Cajete's Creative Process Instructional Model* as a foundation for designing culturally congruent instruction. The four-lesson unit utilizes Universal Design for Learning (UDL) elements such as a multiple-representation glossary and translations into local languages, including Hawaiian, Marshallese, Yugtun, and Alutiiq. We are also working to align the unit with the cultural education standards in both states.

Lesson 1: Encountering First Insights provides a coastal Indigenous cultural experience (Figure 1). Students explore memories and different relationships that community members (including Elders and families) hold with their coastline. Students also begin a community education project where they can deepen their own relationships with their place, share what they learn, and contribute to community preparations for changes to their coasts in the future.

Lesson 2: Preparing and Immersing introduces Eurocentric approaches to monitoring and modeling what is happening along the coast. Students explore ways to measure their beach to figure out how it might be changing over time (Figure 2). Students use data they collect to create a graph and compare their data with measurements from a decade ago. They build both cardboard 3D and digital 2D models using their data. They turn their classroom into a coastline replica and work in teams to create a beach profile using a computer simulation (Figure 3). Finally, they consider different ways of monitoring their beaches and reflect on how multiple approaches can promote understanding.

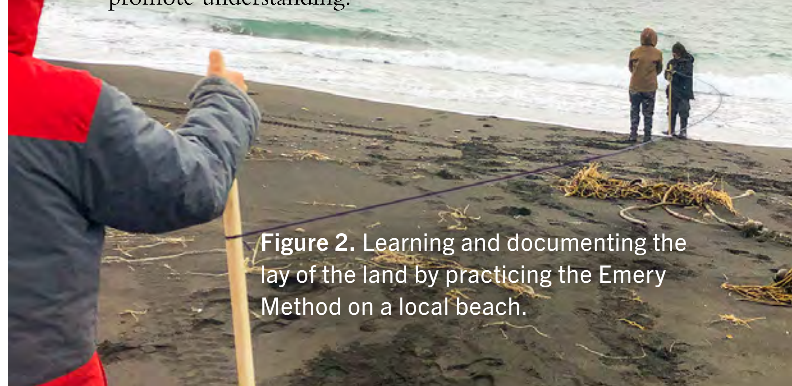


Figure 2. Learning and documenting the lay of the land by practicing the Emery Method on a local beach.

Figure 3. A simple method of measuring beach profiles on the ground is enacted using a simulation. Students work in teams with one student viewing seaward and lining up their measuring rod with another student whose view is facing landward.

Lesson 3: Inventing and Creating invites students to dig deeper through investigation, exploration, art, stories, experimentation, and modeling while drawing on multiple perspectives. Students explore what causes a beach to change over time. They investigate waves using computer models and a table-size model wave tank (Figure 4). Beaches change largely because of the action of waves, and students model wave action in the tank to investigate how waves may impact their beach. They connect local stories they hear and remember, and share ways of examining how events occur in the past and present.

Figure 4. Creating a standing wave in a wave tank to understand a natural phenomenon in the ocean.

Lesson 4: Evaluating supports students in enacting written and spoken learning performances. Students consider different adaptations that other communities have made to protect their beaches and interview people in their community to see what, if anything, community members think should be done about local coastal change. They work on a community education project designed to contribute to their community's understanding of what's happening on their coastline (Figure 5). Finally, students share their project with their class, with other students across the two states, and with their families and communities.

Classroom context

During a recent visit to the Hawaiian partner schools, we witnessed students engaging with their own ways of knowing their beaches. One young girl stayed after class to explore the wave tank and told us stories about going to the local beach to fish with her grandfather on weekends.

Teachers are noticing changes in student engagement. One teacher in Hawai'i noted, "What motivated and engaged my students was the opportunity to communicate their own personal/familial experiences and opinions about a location that was personal to them. Communicating about a location that is tangible and familiar affords them a feeling of success and valuable contribution in the classroom setting. For some students, this has even allowed them a rare or first-time opportunity to access classroom learning in a meaningful way."

A teacher in Alaska told us, "What engaged my students was the multitude of hands-on learning opportunities. The work outdoors, the wave tank, and the drawings of their beach were all assignments that motivated them the most because they were able to put their own words and experiences into science, rather than trying to fit themselves into a pre-scripted science curriculum. This goes beyond place-based learning and implements student-based learning."

We are excited to continue learning and working with Alaskan and Hawaiian communities, and look forward to ongoing collaboration with our many partners to develop culturally appropriate approaches to exploring coasts with middle school students.

Figure 5. Snapshot from a student's community education project.

* Cajete, G. (1999). *Igniting the sparkle: An indigenous science education model.* Kivaki Press.

LINKS

Precipitating Change
concord.org/precipitating-change-alaska-hawaii/

Systems Engineering: Design Challenges for the Internet of Things

By Chad Dorsey

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

In the classic egg drop challenge, students use cardboard, tissue paper, balloons, and more to protect poor Humpty Dumpty from a fall. Other early engineering design challenges include constructing a bridge with popsicle sticks or creating a geometric structure with toothpicks and marshmallows. While such activities can help students learn about design, they differ markedly from the challenges of current real-world engineering. The SEE-IT (Science and Engineering Education for Infrastructure Transformation) project leverages the modern-day Internet of Things to engage students in thinking about design from a systems perspective.

According to industry experts, we currently sit in the midst of the fourth industrial revolution. Termed Industry 4.0 (or 4IR), this era is characterized by a confluence of connectivity, data and analytics, automation, and advanced manufacturing technology. Prime among its elements is the Internet of Things (IoT), the under-the-radar network of devices in appliances, manufacturing plants, packaging, and shipping containers that act in concert to power this revolution. Such devices monitor and collect data on processes and conditions all over the world, relaying it to enormous central networks for analysis. The resulting hum of activity forms the heartbeat of the changes sweeping modern industry. Broadly deployed networks of IoT devices enable corporations to sense problems and failures proactively, adjust smart manufacturing processes to fluctuating consumer demand, and control conditions across global supply chains or within individual smart buildings.

Systems engineering and the Fourth Revolution

Introducing advanced, technology-laden scenarios demands the development of new processes, analyses, and methods of response. As the industrial world navigates the complex shift to a 4IR mindset, education must engage students in similar thinking. In doing so, the key principle of *systems engineering* assumes center stage.

A simple concept with complex ramifications, systems engineering involves designing and managing interactions within systems of interconnected components. Implementing it in the classroom poses true challenges for teaching and learning. For one, systems thinking and systems engineering represent significant departures from the curriculum of many standard engineering classes. Engineered systems involve multiple components, all of which can operate independently and in reaction to local conditions. As a result, these components combine to form complex systems—with all the complicated emergent phenomena, such as feedback loops, inherent to them.

Systems engineering in SEE-IT

The SEE-IT project aims to engage students with systems engineering through the lens of IoT devices and networking, providing them crucial experiences with concepts and components essential to the ongoing shifts in the world of industry and infrastructure. By monitoring a network of interconnected sensors and triggering controllable actuators via remotely delivered electronic signals, students learn to see the world not only as something from which they can actively gather data, but also as something they can react to themselves.

In one example system, students monitor and control the temperature and humidity within a plastic enclosure (Figure 1), which mimics applications ranging from greenhouse-like agricultural scenarios to office building HVAC systems. They make decisions about how to maintain an optimal system state, or how to change conditions to achieve a new desired state.

Students use Dataflow, our node-based visual data programming environment, to create programs that monitor and react to external streams of data in real time (Figure 2). By expressing data streams visibly within a programming environment, Dataflow enables students to imagine and respond to them as entities in themselves. Encoding their thinking and responses within a programmatic artifact allows students to present their design patterns in observable and iterable fashion. Because the code is visual and easily shared, students can exchange code designs with others and discuss the reasoning behind them.

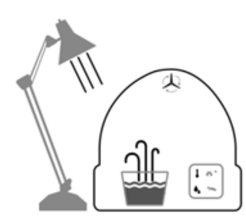


Figure 1. A heat lamp outside a microbiome with temperature and humidity sensors inside the enclosure.

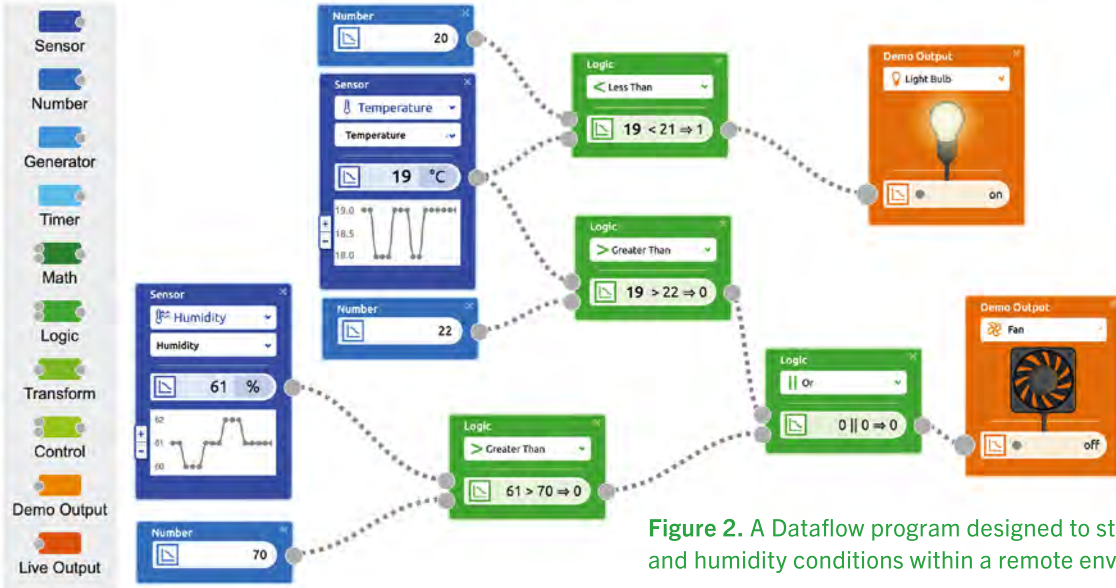


Figure 2. A Dataflow program designed to stabilize temperature and humidity conditions within a remote environment.

The Dataflow environment design also makes it easy to introduce new layers of complexity. Students may initially encounter a single temperature sensor and heat lamp. Later, they may face situations involving a humidity sensor and humidifier, or decide to add an exhaust fan to exchange the air in the microbiome.

Systems of systems

To help students appreciate the nature of complex systems design, SEE-IT enables students to connect multiple enclosed microbiomes to form a combined, multi-enclosure system (Figure 3). Such an extension makes feedback and control loops highly relevant. For example, two groups may have designed Dataflow programs to maintain different temperature and humidity conditions within their individual enclosures. By combining the two enclosures, however, the groups may find their actuators working in a two-party iterating loop targeting an ever-elusive equilibrium or in an escalating "bidding war" endlessly trying to raise their enclosure's temperature or humidity.

Such examples drive home the fraught nature of attempting to control complex systems and shed useful light on similar behaviors seen in real-world systems, from cruise control systems in cars to thermostats in buildings, and in automation anomalies such as bot-driven online pricing wars. By introducing the intent of other individuals and groups as a key factor, they also highlight the vital importance of considering social interactions when seeking systems engineering solutions.

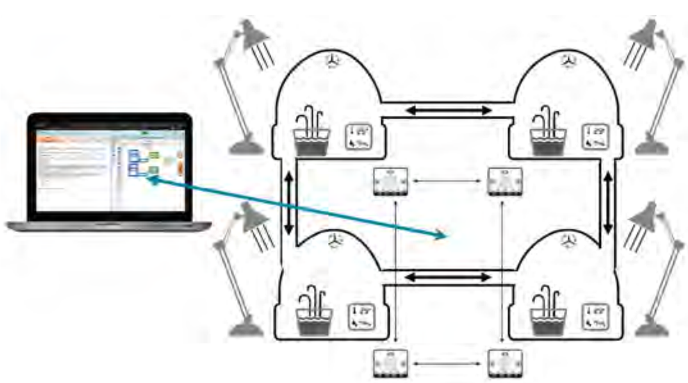


Figure 3. A complex system of multiple microbiomes connected and monitored by the Dataflow environment.

Virtual systems as well as physical systems

In the SEE-IT project, the use of IoT devices offers a final system-based layer for students to encounter. Because communication with their enclosure happens via remote microcontroller boards (currently moderated via micro:bit devices), students gain firsthand experience with digital systems networking and communication.

In the scenario described above, individual students or groups directly control actuators within one enclosed microbiome. To communicate with that system, however, they send messages across a digital network comprising all micro:bits within the classroom. Arranged to act as part of a mesh network, each micro:bit passes all messages it receives to its nearest neighbor, creating a constant flow of messages across the classroom. Because data about every enclosure passes across all devices in the network, students can monitor conditions within other groups' microbiomes as well as their own. In situations where multiple enclosures are connected together, students can use this information to design programs that maximize efficiency.

For example, students may recognize that after connecting two enclosures, their existing algorithm—designed for a single isolated enclosure—"fights" a similar algorithm from the opposing group. Students who adjust both algorithms to instead target the average between their goal temperature and the other enclosure's current temperature may discover they have generated a more efficient solution. Alternatively, students may leverage the properties of digital networking systems themselves by distributing their enclosures across the classroom to attempt to pass signals from one micro:bit to another across a large distance, arranging enclosures to test the efficiency of hub-and-spoke configurations, or using one enclosure and its micro:bit as a repeater bridge to connect networks in two separate classrooms.

By employing simple, observable setups that evoke complex computing ideas and exposing students to such ideas using a programming environment that welcomes student collaboration, we have the opportunity to make complicated ideas such as signal encoding and communications networking tangible and relevant to students. By engaging with IoT devices, systems engineering challenges, and modern design scenarios, students build their ability and confidence for working with interactive, connected systems central to the fourth industrial revolution.

Data Detectives Clubs

Combine Narrative, Data, and Sound

By Penny Noyce, Jan Mokros, and Bill Finzer

Penny Noyce
(pendrednoyce@gmail.com) is a founder of Tumblehome, Inc.

Jan Mokros
(jan@tumblehomelearning.com) is a lead researcher at Tumblehome, Inc.

Bill Finzer
(wfinzer@concord.org) is a senior scientist and lead developer of CODAP.

Stories help us understand the events and phenomena around us. When a new respiratory disease disrupted our lives in early 2020, children wanted to know where it came from, how it spread, how many people were affected, and how to get through it. Tumblehome, Inc. told the story of the pandemic through a middle school adventure novel, *The Case of the COVID Crisis*. The book is now the centerpiece of a project funded by the National Science Foundation designed to empower young people to understand data science through epidemiology.

The COVID-Inspired Data Science Education through Epidemiology project has developed ten sessions for youth as part of "Data Detectives Clubs." Middle school students read *The Case of the COVID Crisis* and engage in related data activities using CODAP and NetLogo.

The adventure story follows two middle school students, Clinton and Mae, as they travel through time on a mission to learn about pandemics of the past and present (Figure 1). Young readers learn from the adventures of these time travelers that others have also suffered through disease outbreaks, often without the tools—testing, vaccines, medications—that science offers today. *The Case of the COVID Crisis* presents an accurate portrait of efforts to conquer smallpox, the 1918 flu, measles, Nipah, Ebola, and COVID. Equal parts discovery, danger, math, and science, the story portrays diverse scientists in places as far apart as the U.S., Bangladesh, Brazil, and the Congo.

Figure 1. In *The Case of the COVID Crisis*, Clinton helps bring a young Ebola victim to a clinic.

The roles of narrative and data

Narrative, especially historical narrative, can engage and motivate students while teaching how science is done. Stories—with their twists and turns, climax, and denouement—can mirror the nature of science, with all its uncertainties, errors, and disputes. Narrative can also inspire. Placing readers in cultural and historical settings where scientific problems arise allows youth to imagine themselves as heroes responding to the challenges of their time with science. Finally, stories allow readers to identify with diverse, often young, characters who overcome their own hesitations to become passionate learners and defenders of science.

But the story of COVID-19 is best told through more than words. Data tell their own story, and there has never been a pandemic more steeped in data. COVID data are fine-grained and available in near real time from the Centers for Disease Control (CDC), the World Health Organization (WHO), and others. To create curated datasets and data exploration activities for Data Detectives Clubs, Tumblehome partnered with the Concord Consortium.

Together, we built a plugin for the Common Online Data Analysis Platform (CODAP) that connects to current data from the CDC. Students can download datasets with both categorical and numerical data about COVID, including number of cases and vaccinations by state and county. They can transform data tables into graphs by dragging and dropping variables onto the horizontal and vertical axes. Students can make additional data moves by creating nested, hierarchical data, such as by country, state, and city.

In one activity, middle school youth compare time-series data on the number of people infected or vaccinated by country, say, Italy or Brazil, or state, for example, California and Louisiana. They

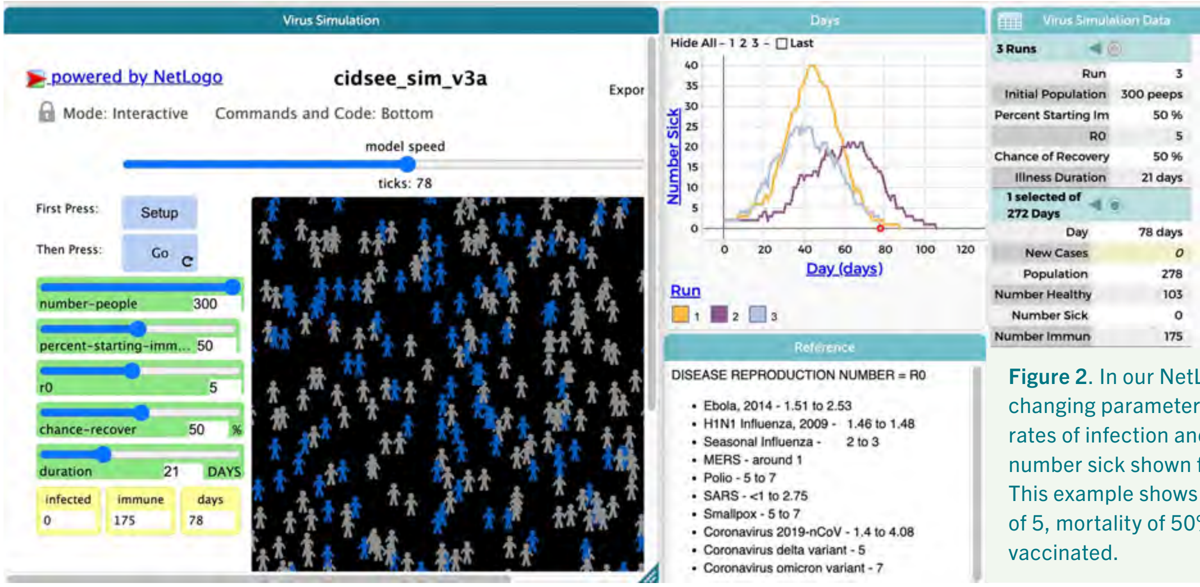


Figure 2. In our NetLogo/CODAP simulation, changing parameters (left) leads to different rates of infection and immunity, with the number sick shown for three different runs. This example shows a disease with an R_0 of 5, mortality of 50%, and 50% of peeps vaccinated.

can compare the pandemic over time, including its magnitude and infection rate in different countries while linking daily incidence of infection to cumulative numbers of infected people.

In another activity, students use CODAP's mapping tool to explore how smallpox waxed and waned in waves across continents until it finally disappeared through a worldwide vaccination campaign. The quantitative data is represented as colors on the map that change over time.

NetLogo simulation

We also developed a simulation of the spread of a virus using the free, agent-based modeling program NetLogo, which we integrated into CODAP as a plugin (Figure 2). The simulation begins with 300 icons of people (called "peeps"), two of them colored red to show that they are infected. As the peeps move and randomly bump into one another, they change color to show themselves becoming infected or immune. Simultaneously, CODAP creates a corresponding time-series graph showing how the number of currently infected peeps rises and falls.

Students explore the simulation and data visualization to understand how the course of an outbreak is affected by the number of non-immune people that each infected person is likely to infect (R0, or R-naught). Changing the starting R0 to be similar to SARS-1, COVID, Ebola, or measles changes the peak and duration of the infection curve. Running a simulation several times with the same starting parameters allows students to observe how random variation makes precise prediction difficult.

In a culminating activity, youth explore the concept of herd immunity by varying only the percentage of peeps who start off immune (or vaccinated). They discover that for a disease with the infectivity of COVID-19, there is a threshold once approximately 75% of the population has been vaccinated. At that level, further vaccination provides little additional benefit, even in a hypothetical disease with an unlikely death rate of 50%.

The sound of data

Sound can tell a story, too. Think of the sound of footsteps or a fire engine approaching and receding. We recently piloted the idea of sonifying data, providing students with kazoos and challenging them to "play" a graph, changing pitch as the graph rises and falls. When they looked at data of infected people, students played a high pitch when more people were getting sick and a low pitch during a time of relative disease quiescence.

We plan to build a new sonification feature for CODAP, which will create a continuous "line" of sound, varying in pitch or volume, that echoes movement in the value of a variable over time. In a more complex graph, comparing two different lines, students could hear two instruments, each playing its own line. And for the NetLogo simulation of infection spread, a beep or tick could sound each time a new person is infected, alerting users to changes in the infection's rate of spread.

Conclusion

To date, over 750 youth in grades 4–8 in communities around the U.S. have participated in Data Detectives Clubs. They have shown consistent growth in measures of STEM engagement, STEM identity, STEM career interest, and data scientist identity. Future research will examine what variations in sound can add to young people's understanding of change over time.

We are thrilled that an adventure story about science—combined with interactive data activities that use real-world data—makes young readers want to learn more about the science. Narratives should not stand alone. Scientists collect and interpret data on their adventures. Students should, too.

LINKS

Tumblehome– tumblehomebooks.org

The Case of the COVID Crisis– tumblehomebooks.org/book/the-case-of-the-covid-crisis

CODAP– codap.concord.org

CDC plugin for CODAP– https://bit.ly/DDCODAPportal

NetLogo simulation– http://bit.ly/CCCODAPNetLogo

CODAP smallpox dataset– https://bit.ly/37wuqTL

Program leader guide for Data Detectives Clubs– http://short.concord.org/lt9

Under the Hood:

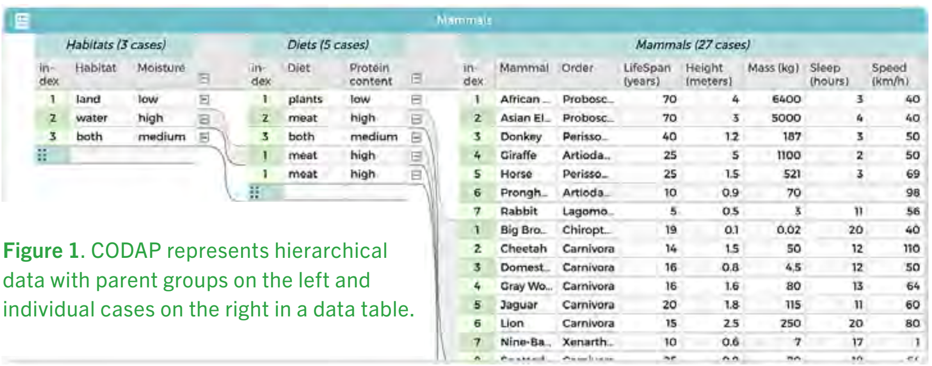
New CODAP Plugin Displays Hierarchical Data

Dan Damelin
(ddamelin@concord.org)
is a senior scientist.

Lucy Blagg
(lblagg@concord.org)
is a software engineer.

By Dan Damelin and Lucy Blagg

Our web-based Common Online Data Analysis Platform (CODAP) is a robust environment where students use a simple drag-and-drop interface to organize, transform, and create visualizations of data. CODAP is also a powerful dual development environment. First, developers can build *on top of* CODAP, as we did with our system modeling tool SageModeler. Second, developers can build plugins *within* CODAP using an API that allows the plugin to both talk to CODAP and to monitor what the user is doing in CODAP, so it can respond appropriately.



Mammals

Habitats (3 cases)

index	Habitat	Moisture
1	land	low
2	water	high
3	both	medium

Diets (5 cases)

index	Diet	Protein content
1	plants	low
2	meat	high
3	both	medium
1	meat	high
1	meat	high

Mammals (27 cases)

index	Mammal	Order	LifeSpan (years)	Height (meters)	Mass (kg)	Sleep (hours)	Speed (km/h)
1	African ...	Probosc...	70	4	6400	3	40
2	Asian El...	Probosc...	70	3	5000	4	40
3	Donkey	Perisso...	40	1.2	187	3	50
4	Giraffe	Artioda...	25	5	1100	2	50
5	Horse	Perisso...	25	1.5	521	3	69
6	Prongh...	Artioda...	10	0.9	70		98
7	Rabbit	Lagomo...	5	0.5	3	11	56
1	Big Bro...	Chiropt...	19	0.1	0.02	20	40
2	Cheetah	Carnivora	14	1.5	50	12	110
3	Domest...	Carnivora	16	0.8	4.5	12	50
4	Gray Wo...	Carnivora	16	1.6	80	13	64
5	Jaguar	Carnivora	20	1.8	115	11	60
6	Lion	Carnivora	15	2.5	250	20	80
7	Nine-Ba...	Xenarth...	10	0.6	7	17	1

Figure 1. CODAP represents hierarchical data with parent groups on the left and individual cases on the right in a data table.

Our Supporting Reasoning with Multi-dimensional Datasets project, funded by the National Science Foundation, is exploring new ways of working with complex data using CODAP's plugin capabilities. The goals are to study how students conceptualize and work with multidimensional data and to develop ways to assist in sense-making with this kind of data.

Data are often formatted in a two-dimensional "flat" display of rows and columns. However, grouping can help reveal patterns. For instance, you might want to look at data about households within counties within states. Or you might be interested in data about animals that live in different habitats, and decide to group them by land, water, or both.

In CODAP, users can visualize such hierarchical data in a standard CODAP table representation (Figure 1). While this representation is compact, research shows that the hierarchical relationships between cases are not clear to every user. We hope to provide additional representations to make analyzing such data easier. For instance, Figure 2 shows one way our new MultiData plugin represents the same data using colors and a "box within a box" type structure.

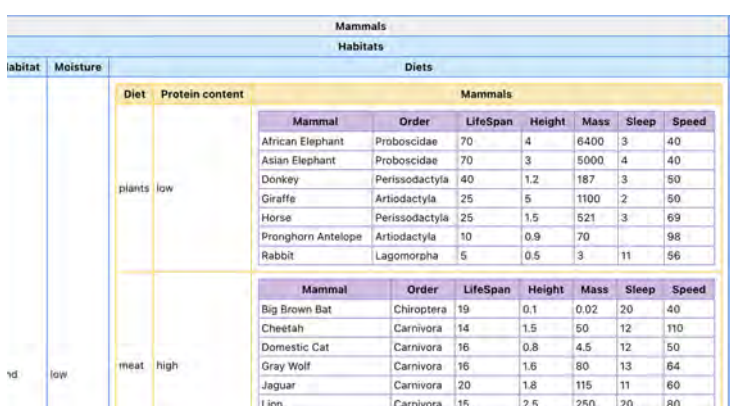
Furthermore, the plugin allows the user to switch between different representations of the hierarchical data. And since it's a plug-in, the user can compare—simultaneously on screen—the MultiData representation to the standard CODAP table.

The CODAP Plugin API is built on top of the window.postMessage() API, which allows for cross-origin communication between a webpage and a pop-up or iFrame. The MultiData plugin makes use of the CODAP Plugin API to get information about the CODAP table data, then subscribes to notifications from CODAP so that anytime the data changes, the plugin can update itself accordingly.

The Plugin API also supports adding listeners to the CODAP table, which can be used to allow the CODAP table to monitor changes in the plugin. Consequently, changes made by interacting with the plugin are simultaneously reflected in the CODAP table structure.

The next phase of work on the Multi-Data plugin will involve utilizing this aspect of the API so that the plugin is not just an alternate representation of the hierarchically structured data, but also becomes a user interface for organizing data into different structures.

The CODAP Plugin API is well documented, and we encourage developers to build their own CODAP plugins. See some of what's possible by clicking the Plugins button in the CODAP toolbar.



Mammals

Habitats

abitat | Moisture | Diets

Diet	Protein content	Mammal	Order	LifeSpan	Height	Mass	Sleep	Speed
plants	low	African Elephant	Proboscidae	70	4	6400	3	40
		Asian Elephant	Proboscidae	70	3	5000	4	40
		Donkey	Perissodactyla	40	1.2	187	3	50
		Giraffe	Artiodactyla	25	5	1100	2	50
		Horse	Perissodactyla	25	1.5	521	3	69
		Pronghorn Antelope	Artiodactyla	10	0.9	70		98
		Rabbit	Lagomorpha	5	0.5	3	11	56
meat	high	Big Brown Bat	Chiroptera	19	0.1	0.02	20	40
		Cheetah	Carnivora	14	1.5	50	12	110
		Domestic Cat	Carnivora	16	0.8	4.5	12	50
		Gray Wolf	Carnivora	16	1.6	80	13	64
		Jaguar	Carnivora	20	1.8	115	11	60
		Lion	Carnivora	15	2.5	250	20	80

Figure 2. A new way to represent hierarchical data in CODAP using the MultiData plugin.

LINKS

CODAP—**codap.concord.org**

SageModeler—**sagemodeler.concord.org**

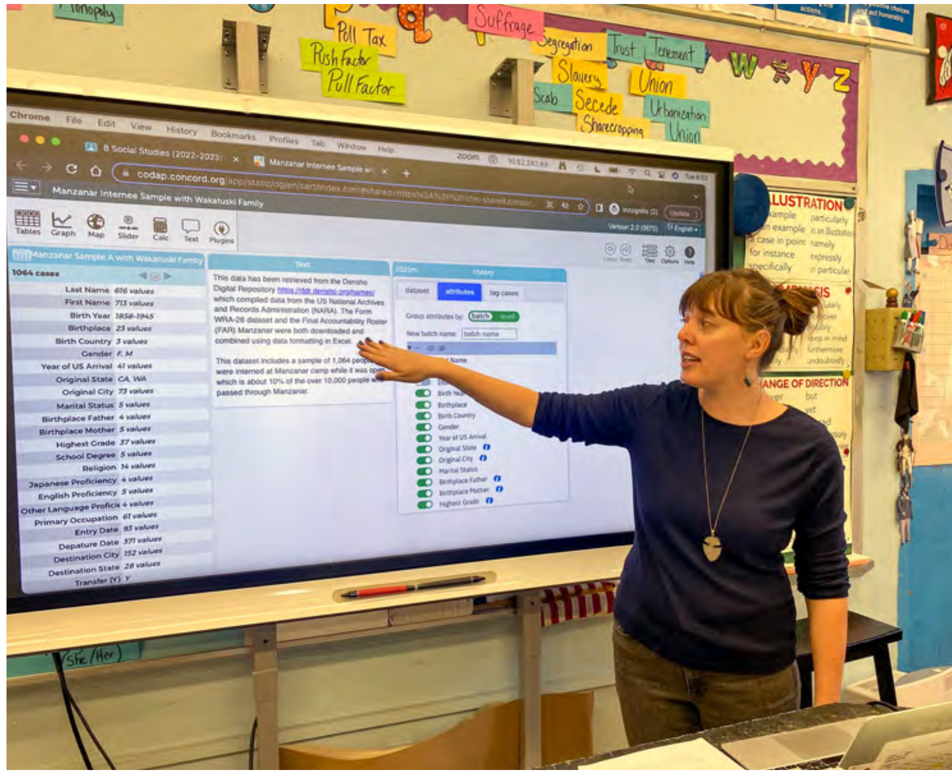
Supporting Reasoning with Multidimensional Datasets—**concord.org/multidata**

CODAP Data Interactive Plugin API—**github.com/concord-consortium/codap/wiki/CODAP-Data-Interactive-Plugin-API**

Teacher Innovator Interview:
Rachel Folger

Middle school social studies teacher, New York City

Rachel Folger laughs when she recounts the time one of the students in her eighth grade social studies class exclaimed, "Whoa, Ms. Folger! Did you know that this is just what we're doing in math?" Rachel is thrilled that her students—who typically "walk through their day in these very isolated subject areas"—are making connections across the curriculum. As part of our Contextualizing Data Education via Project-Based Learning (DataPBL for short) project, she is integrating datasets into a module on the Japanese American internment and having her students use CODAP to explore the data with tables, maps, and graphs. And, yes, she knows that her students are also analyzing graphs in their math class.



A politics junkie in college, Rachel had planned on a career in law. Just before graduation, however, she decided to become a civics education major and go into teaching. She added a fifth year to her studies and became certified to teach history. After earning her degree, Rachel applied to Teach for America and was assigned to a middle school in the Manhattan neighborhood of Washington Heights. Although she had expected to move to the high school level "because those students would soon become voters," she loved the "eagerness and curiosity" of middle school students, and has continued to teach seventh and eighth graders for the past sixteen years.

Rachel is a firm believer in combining not just humanities and STEM, but also science and social studies. According to Rachel, these subjects all exist together. As a social studies teacher with an eye on helping students make connections between historical and current events, she wants students to understand real-world data, especially through conversations around the importance of media literacy and "fake news." Her goal is to help students navigate "all the graphs and pie charts they see in the news."

Although she admits to shying away from data herself in the past, Rachel is now more confident with CODAP and with allowing her students to find patterns in data, thanks to support from the DataPBL team and from "having the space to talk to other teachers and think collaboratively." The DataPBL project, which is infusing data experiences into two eighth grade EL Education modules—Lessons from the Japanese American Internment and Food Choices—aims to foster just the kind of curriculum intersections Rachel describes.

"Using datasets has been the tool that we've been looking for," says Rachel. Now, in addition to using historical texts and photographs, she can incorporate data as a source of information for students to investigate and humanize history. Students can move from looking at one data point or case to looking for larger patterns and trends. Rachel explains, "It's exciting to situate stories in the data."

Rachel is also excited to be part of a shift in post-pandemic educational goals. She believes teachers and administrators are now "looking at students more holistically," helping them consider who they are going to be in the world. She is especially interested in ensuring that students have access to civic society and feel confident asking questions about what's going on in the world.

Rachel's own world has not strayed much since her Teach for America days. She still lives and teaches just ten blocks from her initial teaching assignment in the same New York City neighborhood. Even in a place as crowded as the Big Apple, she loves the community feel. But with a "heart for the mountains"—Rachel grew up in Montana—she summers in Big Sky Country. Of course, big skies call for big dreams, and Rachel is already dreaming about other places to incorporate CODAP, including more modules in her social studies class and in other classes, be it math or beyond.

The Concord Consortium
25 Love Lane, Concord, MA 01742

Integrating Language-based AI Across the Curriculum

With partners at Carnegie Mellon University and North Carolina State University, we are developing and researching a novel program that integrates natural language-based artificial intelligence (AI) concepts and practices into high school mathematics, English language arts, and history classes. This new National Science Foundation-funded project builds on the success of our Narrative Modeling with StoryQ project, which developed a web-based text mining and machine learning environment called StoryQ, and embedded the app in curriculum modules to introduce high school students to core AI concepts and AI-powered career opportunities.

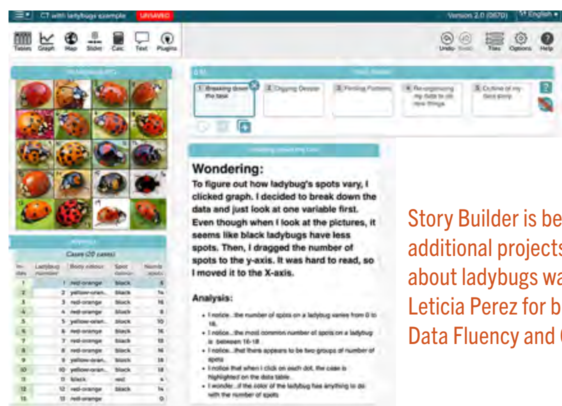
Developed as a plugin for CODAP, StoryQ introduces students to machine learning with unstructured text data without coding. StoryQ features dynamically linked data representations that promote meaningful inquiries across tables, graphs, and texts, making machine learning models transparent, explainable, and engaging. Students can use StoryQ to train, test, and troubleshoot text classification models using feature extraction tools and visualizations designed to support young learners and non-computing teachers. A professional development program helps teachers develop the competencies required to implement the modules in a coordinated fashion and offer students coherent learning experiences across disciplines.

We are thrilled to work with the San Joaquin County Office of Education in California and the Maryland Center for Computing Education and with two school districts, one in California and one in Maryland, that serve student populations underrepresented in the field of AI.

Project research is studying how students' social and disciplinary identities shape their participation in learning of AI knowledge and AI-rich careers, what and how new ideas are generated by teachers as they seek to coordinate their efforts to integrate AI across the curriculum, and to what extent, for whom, and under what conditions the AI Across the Curriculum program supports students to develop knowledge of and interest in AI-rich careers.

Students Write Their Own Data Stories with Story Builder

With pie charts and all manner of graphs, news stories come to us filled with data. As twenty-first century citizens, students must be able to both interpret and create data visualizations. The goal of the National Science Foundation-funded Writing Data Stories project is to help middle school students become "data storytellers," describing patterns they discover in data and sharing how data help them make decisions in their own lives. The project is a collaboration between the University of California, Berkeley, North Carolina State University, and the Concord Consortium.



Story Builder is being used in additional projects. This data story about ladybugs was created by Leticia Perez for both Boosting Data Fluency and GAISE II.

We developed the Story Builder plugin for CODAP that allows students to build story "moments," with each interactive moment capturing the state of the CODAP document at a given time. Students can include text, images, videos, and web pages to create a multimedia presentation. Writing Data Stories curriculum activities include three key features: 1) Data explorations are grounded in students' everyday experiences and local contexts, 2) Students highlight their own perspectives and experiences through data transformations such as merging datasets, adding new variables, and grouping and filtering data to center questions on the people and places they care about most, and 3) Students learn to tell data stories that describe their rationale, findings, and actions they can take to address socio-scientific issues.

Editor: **Chad Dorsey** | Managing Editor: **Cynthia McIntyre** | Design: **Jan Streitburger** | **concord.org**
The Concord Consortium | **Concord, MA** | **El Cerrito, 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 innovating and inspiring equitable, large-scale improvements in STEM teaching and learning through technology.
This material is based upon work supported by the National Science Foundation under several grants (DRL-2006144, DRL-2101198, DRL-2131097, DRL-2048463, DRL-2201177, DRL-2200887, DRL-1949110, DRL-2241669, and DRL-1900606)