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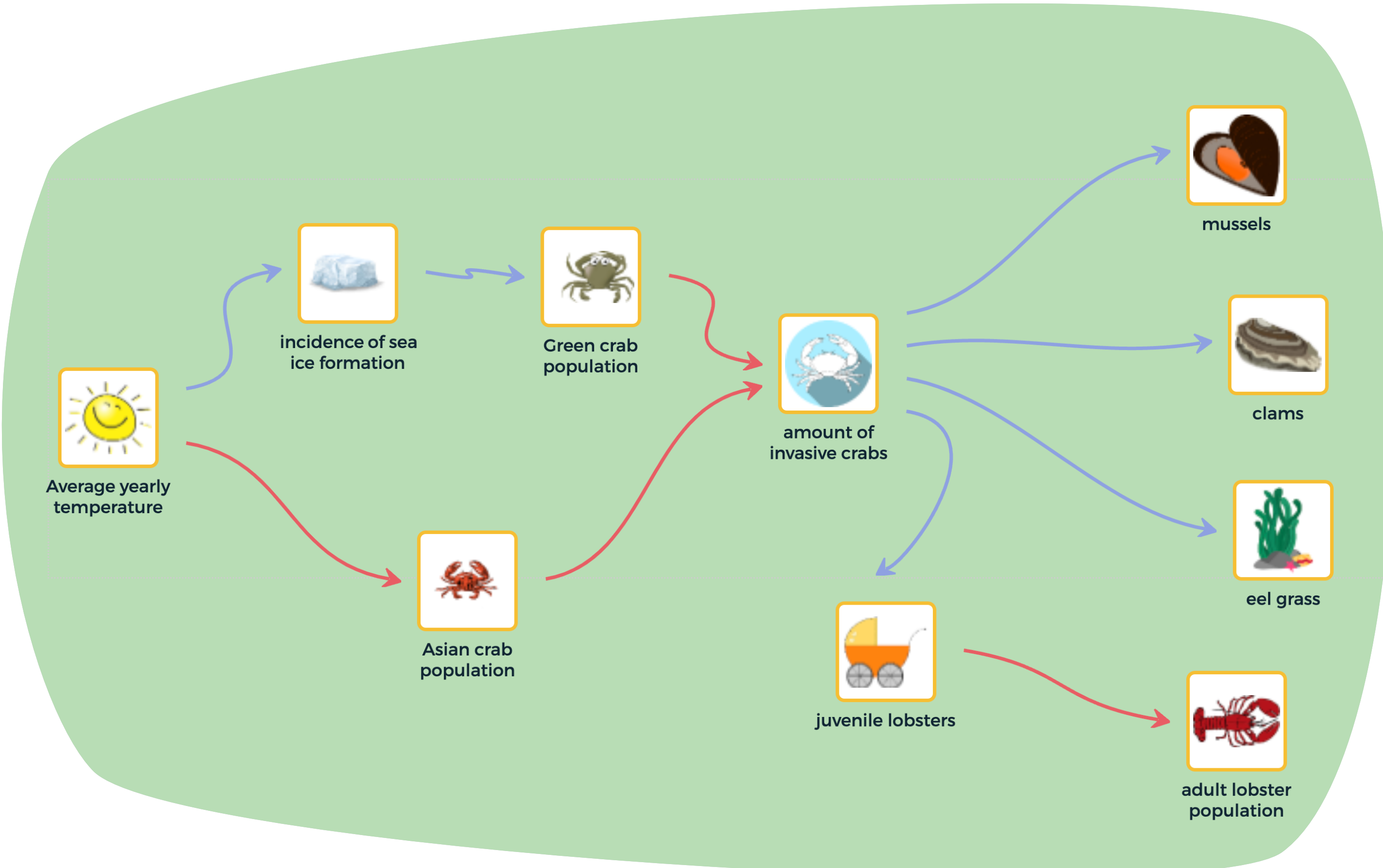
vol. 27 • no. 2 • Fall 2023



The Concord Consortium
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Perspective:
The Nature of Innovation and Educational Technology Design

By Chad Dorsey

Travel offers a portal to many things, but perhaps the most fascinating is the perspective it provides on how humans approach design. To visit a new place is to bear witness to the endless variety of solutions humans create to meet our needs. It was for this reason that I recently found myself pondering what a rubber squeegee and a three-foot-long shoehorn had to do with innovation and educational technology design.

On one family trip, two phenomena intersected: the constant presence of a broom-length rubber squeegee and the regular formation of a large puddle across the tile bathroom floor. During a second trip, an unexpected tool became familiar: a long-handled shoehorn in the entryway of nearly every home we visited.

At first glance, these affordances seem remarkably similar. From a design perspective, however, they represent polar opposites. The squeegee was a workaround to a core design flaw in the bathroom floor, while the long-handled shoehorn presented a solution to a problem we hadn't realized we had—easily donning shoes for outdoor treks. The contrast between the two offers an important lesson about why and how humans design. It also sheds light on how careful attention to technology design can bring teaching and learning to new levels.

Responding to needs. Workarounds are controversial. On the one hand, they demonstrate the failure of an intended solution. At the same time, they represent important signposts. As design guru Donald Norman observed, "Hacks and workarounds are the soul of innovation." Designers often see workarounds as signals that someone *needs* something enough that they have gone out of their way to *do* something about it. Famous examples abound. An organist needs to reposition taped paper notes in his music; the sticky note revolution is born. Nokia engineers observe people navigating the dark via glowing flip phone screens and invent the smartphone flashlight button.

Education presents some distinct design constraints. While consumers buy products to solve problems they have encountered in the past, by definition learning engages us with things we have not seen or known before, making it often difficult or impossible for learners to know their needs in advance. In addition, consumers typically are free to choose the solutions they purchase, while most educational settings place learners on the receiving end, often providing topics or materials learners may or may not be naturally inclined to choose themselves. These differences impose particular added demands on educational designs. Fortunately, such constraints strengthen the case for new creativity and innovation. The core pursuit remains unchanged. By watching what people desire and reach for, we can design the world to better fit their grasp.

Piggybacking. Author, engineer, and innovation researcher Paulo Savaget likes to explore innovative solutions to problems where resources are scarce and stakes are high. In his book *The Four Workarounds*, Savaget identifies problem-solving strategies he claims have led to successful solutions to some of the world's most intractable issues. One strategy, *piggybacking*, holds particular resonance for the innovations we develop at the Concord Consortium.

Savaget describes piggybacking as the strategy of capitalizing on seemingly unrelated relationships, leveraging something that already exists to bring about something new. This strategy has indeed helped crack some enormous problems. Medical advocates recognized long ago that using salt to deliver crucial trace amounts of iodine could curtail developmental deficiencies for hundreds of millions of people worldwide. More recently, an entrepreneur in rural Africa planned to use a soft drink's ubiquitous presence to create a medicine packet for treating dehydration that fits between bottles in drink crates, taking advantage of a robust distribution network to deliver much-needed treatments.

Though global supply chains may seem far removed from educational technology, with the right lens, key similarities arise. In fact, the strategy of piggybacking is practically second nature to anyone involved in education. To succeed in the complex environment of the classroom, educational solutions demand piggybacking, in this case leveraging learners' attention and innate proclivities in novel and important ways. Especially at the intersection of STEM learning and technology, such piggybacking is central to designing successful innovations.

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Finding and leveraging learners' curiosity, so they can ask and answer questions they didn't know they had. This is the key to designing successful STEM educational technology.

The currency of curiosity. Young children are driven by an engine of unflagging curiosity. This fire exists inside everyone, simply waiting to be found and stoked. This is our piggybacking opportunity: finding and leveraging learners' curiosity, so they can ask and answer questions they didn't know they had. This is the key to designing successful STEM educational technology.

To do so, we employ the same process designers everywhere use: find the existing interests hiding within a learner's natural tendencies, then design toward them in a way that makes curiosity inevitable and open exploration the norm. Two questions drive this approach: *Where's the curiosity?* and *How can we leverage it for engaged learning?* In this newsletter issue alone, we see notable examples.

One article describes CODAP's role in the data science education revolution. At its heart, CODAP as a tool helps answer one question over and over: **What's going on there?** By making data visible and explorable, CODAP leverages our human curiosity to make sense of connections and patterns. CODAP's feature of dynamic linking—in which highlighting a data point in one location highlights the same data in all other representations simultaneously—is at its heart a research-based answer to this recurring question.

Another article offers a readymade lesson using our M2Studio modeling environment, an amazing suite of tools for unlocking the power of mathematical modeling that focuses on one fundamental question: **How would that work?** By providing a straightforward path for learners to identify a scenario of interest, explore and develop its mathematical underpinnings, and generate explanations via predictive models, M2Studio is a natural laboratory for satisfying curiosity. Its embedded tools are designed to explicitly link across graphical, mathematical, and written modalities.

Another article makes clear that SageModeler is driven by curiosity from the start. While it engages learners in many ways, one of the most vital is how it takes advantage of our need to ask **What if I change that?** The models in SageModeler do not simply provide an overall depiction of a complex system and its components. Rather, they provide an interactive view of how elements of that system depend upon each other. By moving sliders attached to different nodes and observing the corresponding graphs across the entire system, learners can identify the unusual, emergent dynamics that serve as hallmarks of complex systems.

Whether inside this issue or across our hundreds of resources, the design pattern of using curiosity to encourage exploration plays out repeatedly. MothEd's data cards entice students by asking **What does that represent?** and show them connections and relationships in their data collections. Interactive three-dimensional cross-sections in our Earth science tools make asking and answering the question **What's underneath that?** second nature. Deliberate use of multiple-screen views in our CLUE learning environment tempts students to ask **What does my classmate think?** in a way that informs and evokes rich conversations about different strategies and solutions for mathematical and scientific problems.

All these examples comprise the essence of our ongoing quest to innovate and inspire equitable, large-scale improvements in STEM teaching and learning through technology. As we continue to develop and research new ways to leverage technology's unique ability to enable better learning, we invite you to join us on the journey.

The State of Data Science Education: Where It's Headed and Why It Matters

By Zac Opps and Jacob Sagrans

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In 2013, Bill Finzer, lead developer of CODAP, declared there was a "data science education dilemma"[1] and described a pressing need for more people to become fluent with data. That same year, Chad Dorsey outlined in these pages the state of the data revolution—already nearly a half century in the making—and its immense ramifications for education. A review of the past ten years reveals seminal developments that have launched us towards future advancements.

As society has grown more reliant on data to make critical decisions, policymakers and educators have become increasingly aware of the importance of data fluency in order for students to be productive and competitive in today's workforce. As Finzer and Dorsey observed, as society's dependence on data grows, so too does our need to prepare learners for a data-saturated future. Data fluency—the ability to explore, interpret, visualize, and transform data into actionable next steps—can help youth become informed citizens and leaders, able to critically and creatively engage with all manner of datasets, make original discoveries, and help solve some of the world's most pressing problems.

In 2016, the National Science Foundation prioritized Harnessing the Data Revolution as one of their *10 Big Ideas*. The following year, the Concord Consortium hosted the Data Science Education Technology (DSET) conference, which brought together over a dozen educational organizations in one of the first gatherings of the data science education community. The DSET conference was both a watershed moment and a signifier of interest, with over 100 teachers, researchers, technology designers, and others convening around the importance of data science education.

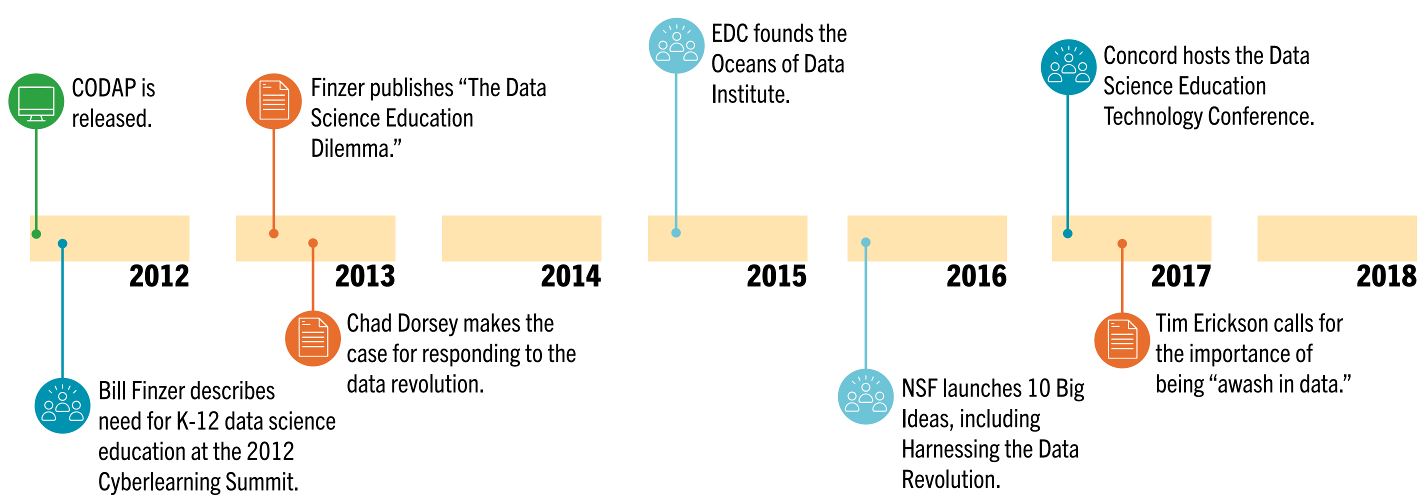
In 2019, we again hosted a critical conference, Designing 2030: Thinking and Doing with Data. This convening further catalyzed a group of education leaders to advance the conversation on how to achieve data fluency and support data science education for all. The goal was to consider how open data and innovative technologies can transform the way we teach and learn science and can broaden participation by more learners.

Building on the surprisingly strong reaction to an episode of the *Freakonomics* podcast[2] in 2019, the Data Science for Everyone (DS4E) initiative and coalition was born, created by the University of Chicago Center for RISC and organized in partnership with the Concord Consortium and the Learning Agency. In 2021, DS4E officially launched with a national call to action, and gathered nearly 300 organizations to commit to the cause. DS4E supports a growing community that is working to expand K-12 data science education for every student. (Read an interview with Chad Dorsey and DS4E Director Zarek Drozda on page 6.)

A vision for data science education

With the importance of data science education clearly established, a multitude of efforts have worked to answer the next vital question: What should students know and be able to do with data? In 2020, the National Council of Teachers of Mathematics released the *Pre-K-12 Guidelines for Assessment and Instruction in Statistics Education II* (GAISE II) detailing a variety of skills necessary for making sense of contemporary data. And then in 2022, the National Academies Foundations of Data Science for Students in Grades K-12 workshop brought K-12 data science education experts together to identify the goals of data science instruction and the supports necessary to enhance student learning.

However, there was one key challenge to implementation: educators and students needed developmentally appropriate tools, curricula, and datasets. While professional-caliber data science software can be powerful, the high level of programming skills it



demands can stand as a barrier to entry for K-12 students. Back when the "data science education dilemma" was first being discussed, we began developing the Common Online Data Analysis Platform, a novel browser-based software designed for learning and data exploration, visualization, and analysis. CODAP, which grew out of KCP Technologies' Fathom Dynamic Data Software project, reduced many barriers to K-12 data science education—it is free and open source, does not require installation, and is accessible to students in Grades 5–12 with no programming background.

Resources geared toward K-12 data science education have also come a long way. In addition to the many resources that the Concord Consortium has designed to accompany CODAP (see, for example, Figure 1), groups including Tuva Labs, UCLA's Introduction to Data Science Project, Bootstrap, DataClassroom, Stanford's YouCubed, CodeHS, and other providers have developed a range of curricula, datasets, and data analysis tools aimed at K-12 classrooms.

New challenges and directions

One of the most significant obstacles facing K-12 data science education is the availability of appropriately curated datasets. While real-world datasets are available from many trusted sources, they can be large and unwieldy, with attributes that are added over time, units that are missing, or attributes that are difficult to understand (e.g., complex rates).

We are currently exploring the challenge of how best to support teachers and students with appropriate resources and tools. Properly designed data portals could greatly aid teachers in searching through collections of datasets to identify topics and related datasets of appropriate size and complexity, and to discover questions to investigate with students. Scaffolds for learners such as pre-made data visualizations can help them more readily learn to explore data on their own. Similarly, students can benefit from first interpreting data to answer a provided question, then deepening their inquiry by devising and answering their own questions when engaging with data. Creating data experiences and datasets along this spectrum is key for supporting the accelerating uptake of data science education across grades and subject areas.

We are also re-engineering CODAP's underlying source code using a modern web application architecture to ensure its availability for years to come and expanding the CODAP community.

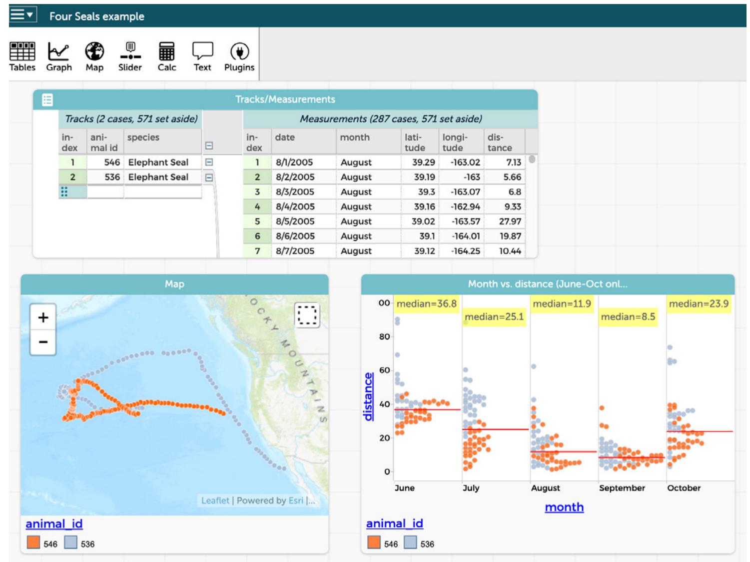


Figure 1. The Four Seals CODAP document developed in collaboration with EDC's Oceans of Data Institute.

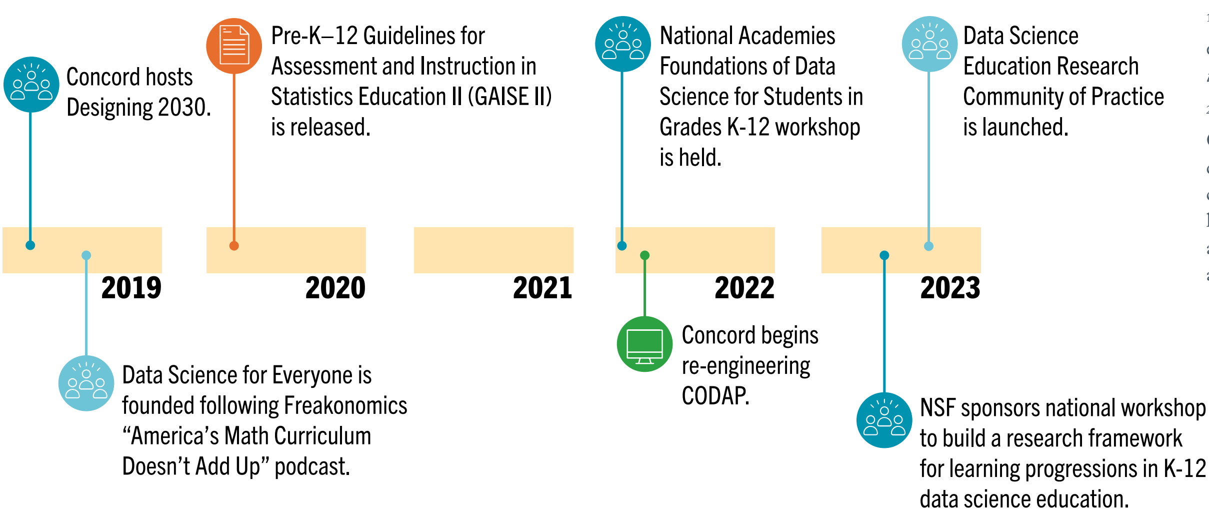
We are further supporting engagement by outside contributors to CODAP's open-source code base, as well as collaborators who integrate CODAP in curriculum development and educational research, K-12 students and teachers, members involved in citizen science projects, higher education faculty, and others.

Lastly, this quickly growing field needs a strong foundation of research upon which to base everything from pedagogical techniques to assessments and new curricular approaches. We are actively supporting the data science education research community and recently launched the Data Science Education Research Community of Practice Database as a way to help make work visible and encourage connections. Leveraging empirical research and proven best practices is key to answering questions about how to best support students' development of data fluency.

LINKS

Data fluency—concord.org/data-fluency

Data Science Education Research Community of Practice Database—concord.org/dse-research-community



[1] Finzer, W. (2013). The data science education dilemma. *Technology Innovations in Statistics Education, 7*(2).

[2] Levitt, S., & Dubner, S. (2019, October 2). America's math curriculum doesn't add up (No. 391) [Audio podcast episode]. In *Freakonomics Radio*. https://freakonomics.com/podcast/americas-math-curriculum-doesnt-add-up-ep-391/

(continued on p.6)

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The Concord Consortium is a founding member of Data Science for Everyone (DS4E), a coalition created by the University of Chicago Center for RISC and organized in partnership with the Learning Agency in order to expand K-12 data science education for every student. We sat down with Concord Consortium President and CEO Chad Dorsey and DS4E Director Zarek Drozda to discuss the importance of K-12 data science education and keys for improving data fluency across the country.

Q. Why is data science education so important?

Dorsey: All students need to understand how to work with data. We have realized for some time now that there is a deluge of data and that data are important outside of just mathematics or statistics courses. Data need to be in classrooms everywhere, and learning about and with data should be an interdisciplinary enterprise in a way that reflects the actual work of data scientists.

Drozda: Technologies are moving quickly and students need relevant educational experiences. For example, when students hear the word "data," they think about cellular service. We need to show that data—quantitative information in a data table—can help them solve problems that are relevant to their community or explore things they find exciting, whether it's Spotify trends, NBA scores, or a local policy issue. We also need students to know the value of working with data. Data are increasingly part of every industry sector, from agriculture to advanced manufacturing, health care, finance, small business management, and more. Every student will need to know the basics of data before they graduate high school or they will not be able to access 21st-century jobs.

Q. Where do you think data science belongs in K-12 education?

Dorsey: Data need to be incorporated into all subjects. Data scientists see themselves as floating across disciplines in many ways. K-12 data science education should take the same view.

Drozda: Introductory data science deserves explicit time in the school schedule. Currently it fits best in the math classroom because it connects math, statistics, and computer science. There are also many opportunities to integrate data science into existing school subjects that can empower and enliven content.

Dorsey: The larger goal should be that students come to see data analysis as a lens they can use to study phenomena everywhere.

Q. What resources are available for educators who want to bring data science into their teaching?

Dorsey: CODAP is a free and powerful tool for exploring data with students. Concord has worked extensively with many other researchers and curriculum developers to integrate CODAP into data science education approaches and activities and to create resources that help educators and students learn to use CODAP. Over 50 CODAP example documents with datasets on a wide range of topics are available.

Drozda: Data Science for Everyone has a large resource hub, which includes CODAP as well as other tools and curriculum resources. CODAP is a great tool for classroom use, especially for students who aren't necessarily looking for an R or Python scripting experience. CODAP provides a powerful and approachable way to engage in learning data science without a high barrier to entry.

Q. What is the future of K-12 data science education?

Drozda: The field needs a common learning framework for states, districts, researchers, and assessment developers to draw upon as the priority learning outcomes for data science and to make all high school graduates data literate. That said, there is not a one-size-fits-all approach to data science education. Seventeen states now have official data science education programs, and we expect that number to increase.

Dorsey: The need for data science education and data literacy will continue to be critical with ever-growing datasets and continually transforming technologies, as we have seen over the past year with the rise of big-data-driven large language models like ChatGPT. Concord will continue to create resources and foster the K-12 data science education community. We are excited about our work to overhaul CODAP and related resources as well as our new Data Science Education Research Community of Practice specifically designed for networking and sharing resources. This is an ongoing effort to create a research-based framework for data science education learning progressions, and work toward larger conferences for practitioners and researchers. Overall, I'm very optimistic about the continued growth of data science education.

Explore CODAP at **codap.concord.org**

Learn more about Data Science for Everyone at **datascience4everyone.org**

Monday's Lesson:

Are We There Yet?

By Rebecca Ellis

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"Are we there yet?" is a common refrain on many car trips. And yet, since every trip is different and contains multiple variables (including some that change in real time), it can be hard to predict. In this Monday's Lesson, students learn how to build a mathematical model using M2Studio to calculate how long it takes to get somewhere. Designed to help students think about modeling real-world scenarios and presenting models in meaningful ways, the lesson supports students in strengthening Common Core Practice 4: Model with Mathematics.

Before you get started

- Make a copy of the Google slide deck with speaker notes designed to help you prepare for and use this activity with students (short.concord.org/LUU).
- Create an account on the STEM Resource Finder.
- Assign this Monday's Lesson to your digital class.
- Have students create accounts on the STEM Resource Finder.

Introduce math modeling

Math modeling is the process of using math to solve real-world, open-ended problems, working with incomplete information (as is typical in the real world), and making and documenting strategic choices. Importantly, math modeling includes iterative revisions to make the result better and useful to others.

Pose the challenge

- Ask students: Where can you walk to from school?
- Brainstorm a list of places with the class, then consider the variables that help determine how long it takes to get there. (Hint: There may be traffic lights or other obstacles along the way, which means you may need to stop and wait.)
- Have students work in pairs to sketch out a path to a chosen destination with time estimates.

Introduce M2Studio

Share an example of a model created in M2Studio and explain that M2Studio is a web-based learning environment with a semi-structured workspace and dynamically linked representations. As students make a change in one variable (e.g., walking speed in miles per hour), that change is reflected throughout.

M2Studio includes a rich text editor, a drawing tool, and a diagrammatic programming tool. When students select text that represents a factor that has a numerical value, they can choose to make that variable a "chip," which also displays as a "card" in the diagram space (Figure 1).

Use M2Studio to build the model

- Launch M2Studio and support students to use the text and drawing spaces to digitize their ideas.
- Ask students which information represents important variables or parameters.
- Support students to use those to create variable chips and cards.
- Guide students to connect their variables with expressions that define the relationships.

Share and discuss

- Pair students with new partners to see if their model can be used to help others determine their travel time and discuss how they might make changes to improve their models.
- Hold a full class discussion on the process of using M2Studio to build and share models.

Want more?

This short activity corresponds with the Introductory Lesson in the full M2Studio curriculum module, a 10-hour experience currently under development. If you are interested in piloting the curriculum with your secondary students, please reach out to m2studio@concord.org.

Feedback

After using this lesson with your students, please complete this five-question survey: short.concord.org/LUK

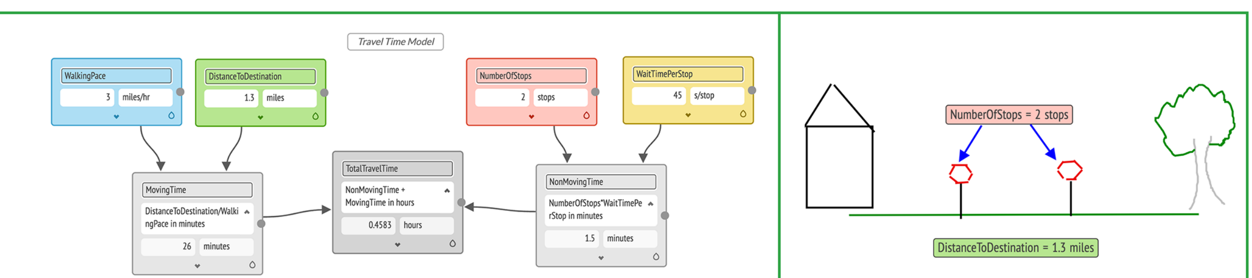

Figure 1. In the M2Studio diagram space (left), students add and link variable cards to represent their conceptual understanding of the problem. In the drawing space (right), students use the same variables as chips to label their sketch.

LINKS

Mathematical Modeling with M2Studio—concord.org/m2studio

M2Studio Teacher User Guide—short.concord.org/LUV

Building Capacity for 3D Assessment and Instruction **in Elementary Classrooms**

By Dan Damelin

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is a senior scientist.

When teachers focus on developing their young elementary school students' literacy and math skills, the three R's rule. Science typically gets less emphasis than reading, writing, and arithmetic. Furthermore, elementary teachers commonly self-report low confidence levels in their own science content knowledge. The Building Elementary Teachers' Capacity project is supporting upper elementary school teachers in taking a three-dimensional approach (using disciplinary core ideas, science practices, and crosscutting concepts) to assessment and instruction.

Teachers have found it challenging to make the shift to three-dimensional teaching as envisioned in *A Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS). For those with less scientific experience and coursework, the transition can be even more daunting. Over the past four years, the Building Elementary Teachers' Capacity team at the University of Illinois at Chicago, UChicago STEM Education, the University of Kansas Achievement and Assessment Institute, and the Concord Consortium has worked with teachers in two school districts in the Chicago area, one urban and one suburban, to help them overcome the challenge of 3D teaching. Together we co-developed formative assessments aligned to the NGSS and supported a virtual learning community for peer support.

Professional learning

Professional learning sessions, including both in-person and virtual settings, were essential for engaging teachers in task development and classroom implementation. To facilitate a virtual learning community, the project created the Understanding Progress in Science website. The website offers teacher resources for each assessment task, provides information and teaching strategies for aligning instruction and assessment with the NGSS, and hosts a forum for supporting collaboration and community. During the course of their participation, teachers gained expertise in the three dimensions of the NGSS performance expectations.

To date, the project has published 41 assessment tasks for grades 3 through 5 in the Next Generation Science Assessment Portal, which contains both elementary and middle school NGSS-aligned assessments. Tasks are organized by NGSS standard or performance expectation (PE), which are further unpacked into several learning performances (LPs) (Figure 1). Taken together, the LPs describe a scaffolded set of student performances that move students toward an understanding of the overall PE. Each LP has at least two formative assessment tasks.

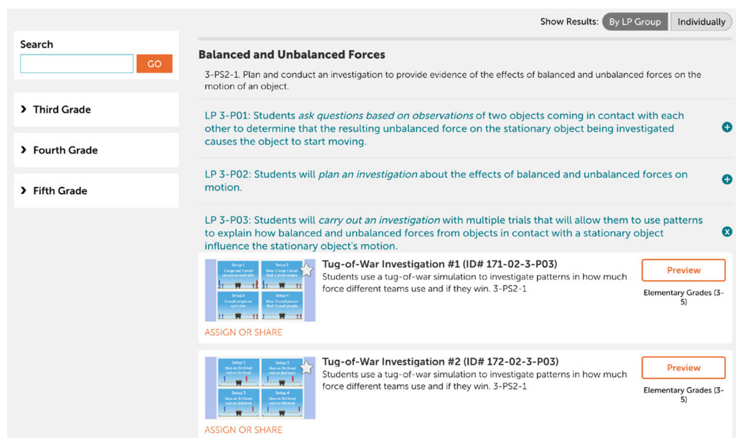

Figure 1. Sample tasks, aligned to NGSS performance expectations.

To create the tasks with teachers, the project used a framework that begins by identifying target performance expectations, unpacking the three dimensions, and identifying opportunities for equity and inclusion (Figure 2).

Throughout the task development process, the work was guided by an equity and inclusion lens to ensure the tasks were accessible to all learners. As described in the forthcoming book *Creating and Using Instructionally Supportive Assessments in NGSS Classrooms**, equity and inclusion involves applying two broad design principles: (1) fostering student engagement with learning and (2) providing appropriate language supports.

Fostering student engagement with learning involves:

- considering what real-world context the item uses for engaging the student, such that the task is framed around a phenomenon that is relevant and builds on prior knowledge;
- considering how the task might reduce stereotyping around gender, race, socioeconomic status, or religion; and
- supporting comprehension by providing multiple visual aids such as images, simulations, and interactive components.

Providing appropriate language supports involves:

- writing clear and direct prompts;
- considering appropriate language and vocabulary and using visual representations to aid in comprehension of potentially more challenging language and terms;
- supporting student comprehension by drawing upon prior student knowledge, clearly labeling and organizing information, and using terms consistently throughout the task; and
- providing varied ways for students to show understanding through utilizing text, audio recording, drawing, and saved states of interactive components to express their knowledge.

Technology is also crucial in three-dimensional assessment. Simulations and videos can introduce the context for a phenomenon, and their interactive components can provide unique opportunities for students to demonstrate their ability to show evidence of science and engineering practices (SEPs). Students might be challenged to use a simulation to plan and carry out an experiment or use graph visualization tools to analyze and interpret data. Furthermore, technology can make the assessment tasks more accessible, for example, by reading text aloud, allowing students to speak their answers rather than type them, or providing a mechanism for magnifying the screen to support students with visual impairments.

Results from pilot use

We piloted the first set of assessments in eight teachers' classrooms. Based on anonymous surveys, teachers reported that their attitudes about science improved and their instruction became more three-dimensional as they developed a deeper understanding of the NGSS. Teachers also described a better understanding of the interconnectedness of assessment and instruction, for instance, how instruction provides the skills that assessments measure. According to one teacher, "Learning how to assess in a 3D way was very important to my practice, and I've been able to use the kinds of questions we developed to help me judge how my students are working towards the PE."

Additionally, teachers reported giving more frequent formative assessments, using student responses to inform instruction, asking more questions in class to make inferences about students' progress, and designing assessments to measure all three dimensions. One teacher noted, "When I'm assessing, I'm seeing how students can demonstrate the skills of a scientist." Another said, "The SEPs are where the kids do science instead of learning about science. They're super critical, and the most important part of NGSS, in my opinion. Learning to make observations and predictions, take and analyze data, etc. is how the students develop their own understandings of science."

One participating teacher summed up the work this way: "Science can be found in everything. This project has helped me be more mindful about the things around me and to look for phenomena in everyday occurrences." Indeed, scientific phenomena are everywhere. The goal of the Building Elementary Teachers' Capacity project is to make NGSS-aligned early science education as commonplace as the three R's.

Final tasks

During the 2023-2024 school year, 20 teachers will field test the existing tasks in addition to newly drafted tasks, participate in the virtual learning community, and help further refine the tasks and teacher resources. The final versions of all tasks will be published by June 2024.

Figure 2. The task design framework. For more details on this evidence-centered design process see: **http://nextgenscienceassessment.org/design-process/**

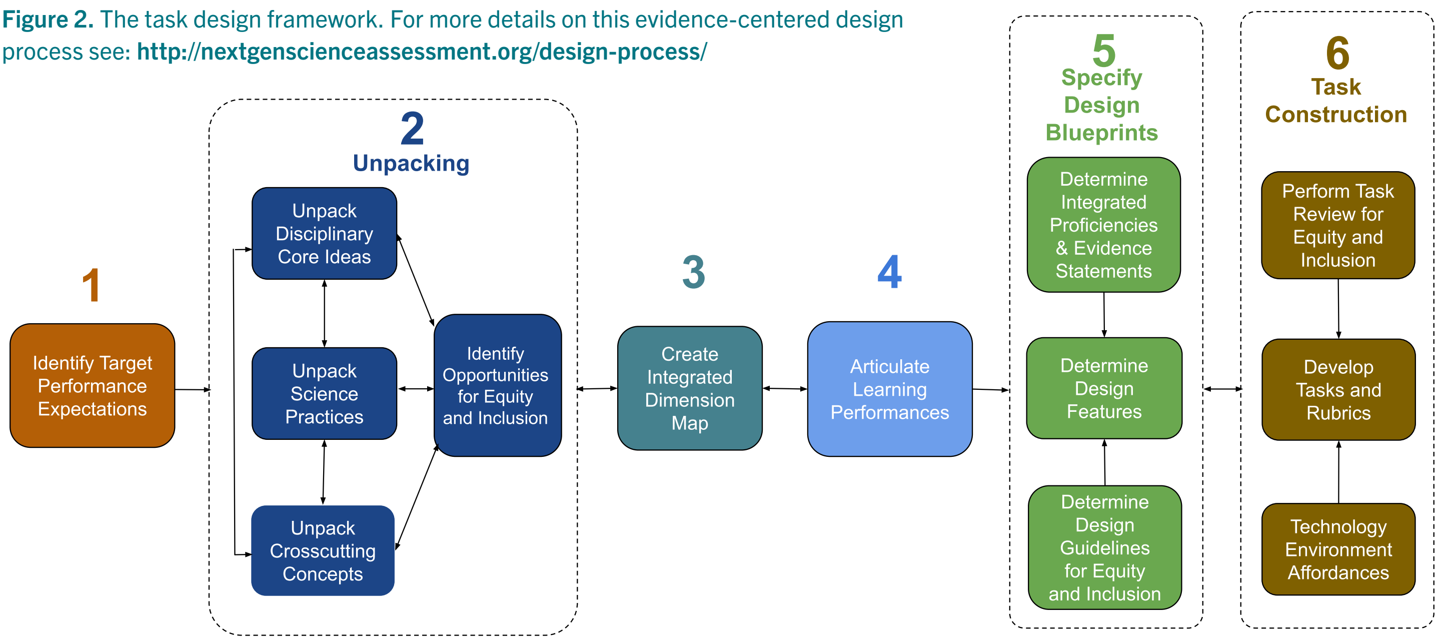

Image used with permission. Harris, C. J., Krajcik, J. S., & Pellegrino, J. W. (Eds.) (in press). *Creating and using instructionally supportive assessments in NGSS classrooms.* NSTA Press.

* Alozie, N., Madden, K., Damelin, D., Krajcik, J., & Pellegrino, J. (in press). Attending to equity and inclusion in the assessment design process. In C. J. Harris, J. S. Krajcik, & J. W. Pellegrino (Eds.), *Creating and using instructionally supportive assessments in NGSS classrooms*. NSTA Press.

LINKS

Next Generation Science Assessment Portal
nextgenscienceassessment.org/task-portal/

Understanding Progress in Science
upinscience.org/

Critical Tools
for Solving Today's Complex Problems

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By Dan Damelin

From local environmental justice issues to global climate change and pandemics, the world faces critical challenges. Because these threats often impact communities inequitably, we need diverse perspectives—in terms of culture, ethnicity, gender, and expertise—to address these complex problems. Effective approaches for understanding these multifaceted phenomena rely on a systems perspective and use real-world data and modeling to inform scientific understanding and generate legislative policies. A systems approach is critical for designing solutions.

A Framework for K-12 Science Education and the Next Generation Science Standards (NGSS) include *Systems and System Models* as one of the seven crosscutting concepts and *Developing and Using Models* as one of the eight science and engineering practices, highlighting their importance across disciplines. However, it is rare for people outside of professional circles to apply systems thinking and system modeling to explain or develop an understanding of phenomena. Indeed, even professionals sometimes fail to take a systems perspective. Consider, for example, a well-meaning intervention gone wrong that was intended to stem a malaria outbreak.

A failure to think systemically

About 70 years ago the Dayak people on the island of Borneo experienced a severe outbreak of malaria. The World Health Organization (WHO) sprayed large amounts of pesticide to kill the mosquitos that carried malaria and infected people. In the short term the pesticide worked well, killing many mosquitos and reducing the incidence of malaria. However, there were unexpected side effects, which started with the collapse of many thatch roofs, a common roofing material for the Dayak homes. The pesticide killed not only the mosquitos, it also wiped out the population of parasitic wasps that preyed upon a caterpillar that eats thatch. Without the wasps, the caterpillar population grew exponentially, damaging the roofs of many dwellings. Furthermore, the ground was littered with dead insects that were poisonous because of the pesticide they had ingested. Geckos ate the poisoned insects, then cats ate the geckos and died. Without cats to keep the rat population in check, the number of rats exploded and spread diseases such as plague and typhus. Ultimately, the WHO parachuted in 14,000 cats in crates to address the outbreak of these two new diseases.

This situation serves as a stark warning and exemplifies the need for both a systems lens when addressing the interconnected world we live in and a set of diverse perspectives to design solutions to local problems. Because the human mind cannot compute and predict all relevant interactions in a complex system, computational systems modeling is a critical tool for solving some of our most pressing problems. Using SageModeler, a systems modeling tool developed with students in mind, we can model the situation in Borneo (Figure 1).

SageModeler has been used in elementary to undergraduate classrooms. Depending on the students and the type of phenomenon or system being modeled, any of the following modeling approaches might be the most appropriate.

Diagramming the system

SageModeler can be used as a diagramming tool, similar to other concept or mind mapping tools. This approach is most commonly used at the elementary level, but depending on your goal it could be used in many other situations. Students add nodes to the canvas, which can represent components of the system, either objects or variables. They connect these components with arrows and can add text descriptions. If all of the nodes represent measurable variables, they can also color the arrows that link the components to indicate how a change in one component would affect the other. However, there is no way to simulate the resulting diagram, which simply represents an illustration of the system.

Understanding basic relationships

Static equilibrium modeling is appropriate when the goal is to understand basic relationships between components in a system (Figure 2). It is based on chains of cause and effect where a change in any independent variable instantaneously ripples through the system, causing all other linked variables to change their value accordingly. Students use nodes and arrows as in a

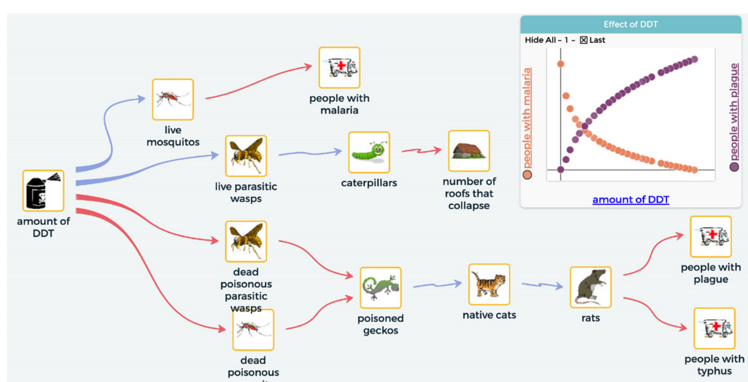

Figure 1. A model of the interconnectedness of the Borneo ecosystem and the impact of pesticide application to address a malarial outbreak.

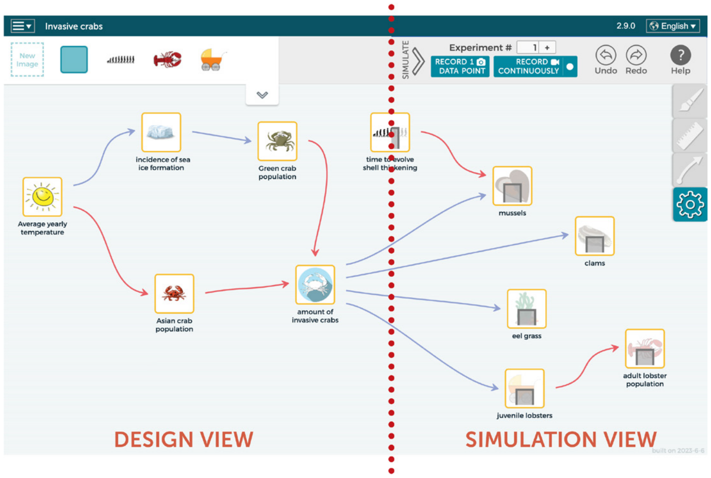

Figure 2. A static equilibrium model of the impact of invasive crabs. The left side shows the model when not simulating. Once simulation is turned on, the images representing each variable are overlaid with a bar representing their value.

system diagram, but each system component must represent a quantifiable variable and the links must specify the direction of cause and effect, so that the whole model can be simulated. Each arrow represents a relationship between variables that can be defined semi-quantitatively, using written descriptions and pictures of graphs depicting the relationship. By simulating the model, students can test their ideas about how the system will function as they change independent variables and see how those changes affect the state of the system. Bar graphs represent a single value based on the current model input settings.

Exploring how systems evolve

Dynamic time-based modeling is a form of system dynamics modeling used when the goal is to explore how a system evolves over time and when there is feedback in the system. Global warming, the shape of a pandemic infection curve, and a biochemical reaction pathway are all examples of systems that evolve over time. A classic example of such a system is a predator-prey ecosystem as shown in Figure 3. Notice that the graphs inside each variable are now line graphs, which show how the value of the variable changes over time. Students can import real-world data into SageModeler for comparison to the model output, and explore ways to modify their model as they compare its behavior to what happens in the real world.

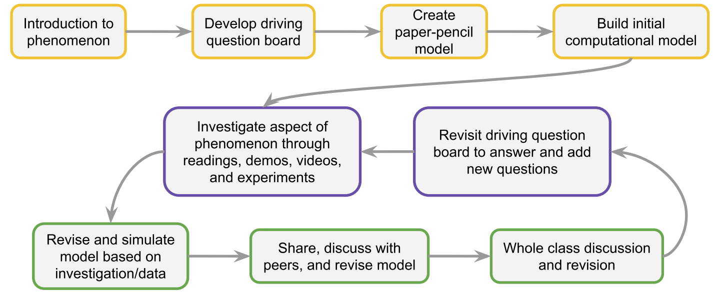

Figure 4. The flow of a curricular unit that infuses computational systems modeling.

A pedagogical approach to systems thinking

The Multilevel Computational Modeling project, a collaboration between the Concord Consortium and the CREATE for STEM Institute at Michigan State University, developed SageModeler and worked with teachers to design a pedagogical model for infusing curriculum units with a systems modeling approach. We started from a project-based learning framework, which includes engaging students in relevant and meaningful learning experiences designed to make sense of a phenomenon or solve a real-world problem.

The units provide opportunities for students to engage in the NGSS science and engineering practice of *Developing and Using Models* and the crosscutting concept of *Systems and System Models*, plus content-specific disciplinary core ideas related to the phenomenon or system being modeled. Figure 4 shows how students engage in iterative cycles of model revision, including studying an aspect of the phenomenon, revising the model based on new information, discussing the model with peers, and revising again. This loop happens several times throughout the unit as students both expand and hone their model on their way to becoming true system thinkers.

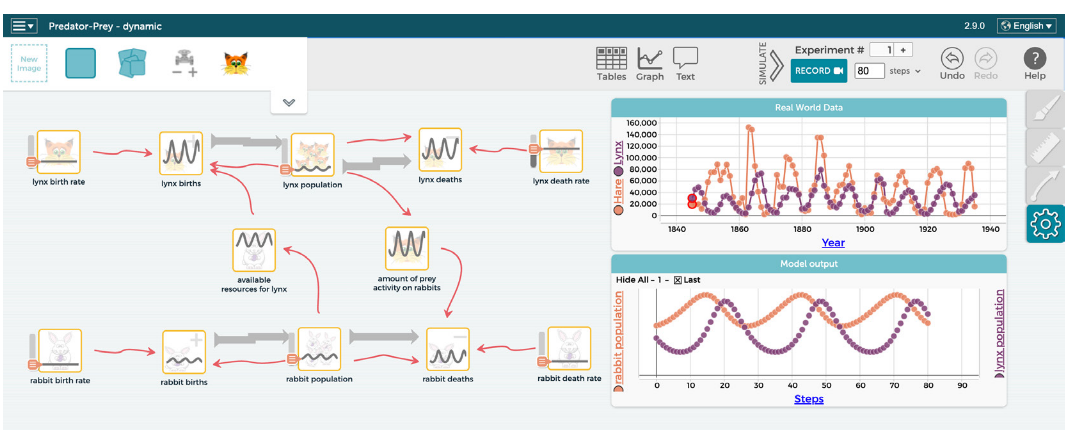

Figure 3. A predator-prey model showing how the populations of lynx and rabbit change over time. Feedback in the system causes a periodic pattern with both populations rising and falling as first one species dominates and then the other. The top graph represents real-world data and the bottom graph depicts model simulation output.

LINKS

SageModeler—sagemodeler.concord.org/

SageModeler curriculum units learn.concord.org/building-models

Multilevel Computational Modeling—concord.org/mcm

Data Stories

and Interdisciplinary Project-Based Learning

By Joe Polman, Trang Tran, and Kate Miller

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When eighth grade teacher Rae Kennedy prepared for a curriculum module that centers around the book *Farewell to Manzanar,* she knew she needed to make it personal for her students. The book is a memoir by Jeanne Wakatsuki Houston about her experience in a Japanese American internment camp during World War II. Rae's students had already explored storytelling and writing informative and argumentative essays. So when she introduced CODAP to her class—something her students may have expected in a math class, but not humanities—she assured them that using data to craft stories is another genre of authentic storytelling.

The DataPBL project enlisted a team of teachers, data science educators, and researchers to co-design data experiences for the eighth grade Japanese American Internment curriculum module developed by EL Education. In the DataPBL version of the interdisciplinary project-based module, students analyze and visualize data in CODAP. Project research is studying how students tell stories with data and how this data storytelling contributes to students' data agency and identity.

Rae focused on the stories of Japanese American internees before, during, and after incarceration. To humanize data, she organized gallery walks and held discussions to elicit examples of data in students' daily lives. She also introduced reasons why working with a dataset was important and helped students make connections with their prior experiences writing stories and essays.

Students were then tasked with creating an informative story using their insights from CODAP as well their opinions. They explored several datasets, including one with information from the WRA (War Relocation Authority) and the FAR (Final Accountability Records) about the people incarcerated at the Manzanar internment camp during World War II. Rae stressed that it was very important that her students "see the people that were incarcerated as human beings" and that they ascribe "meaningfulness in the stories [and] data." In other words, students should be aware that the dots in CODAP, which represent a point on a graph or a row in a data table, are real people.

Narration with data

Telling stories that are meant to be empirically true requires sometimes contradictory discursive modes: narrative and logico-scientific. Narrative discourse involves creating a coherent storyline by including certain events and excluding others. Logico-scientific discourse involves making claims based on argumentative norms from the disciplines involved (e.g., science, history) and appeals to data. In interdisciplinary accounts, both narrative and logico-scientific discourses may contribute to a story's action. Telling a story with data requires using both of these discursive modes. The CODAP Story Builder plugin supports students in making choices about which data to highlight.

Rae's students used Story Builder to create data stories. Story Builder allows students to create a presentation of their data explorations, with each interactive slide capturing the state of the CODAP document at a given time, plus text annotations, images, and more. The DataPBL research team employed Joshua Radinsky's idea* that narration with and around data can take four modes: (1) telling a story about oneself working with data, (2) animating a data representation, (3) incorporating data into extant narratives, and (4) narrating oneself into a data-represented world. The four modes were then mapped onto the stories narrated by the students to better understand how they transformed the data into stories.

Using Story Builder to tell a story

One student's inquiry and data story exemplified the incorporation of all four of Radinsky's modes of data narratives. Taylor (a pseudonym) prepared five slides in Story Builder that included graphs and text about her guiding questions, data examination and analysis processes, results, and interpretation.

Slide 1. Taylor's guiding question was "How did being at incarceration camps for different periods of time affect how many people died?" Her first slide began with mode 3, incorporating data on how many people died into an extant narrative she had read about in *Farewell to Manzanar* and learned about in class sessions on the

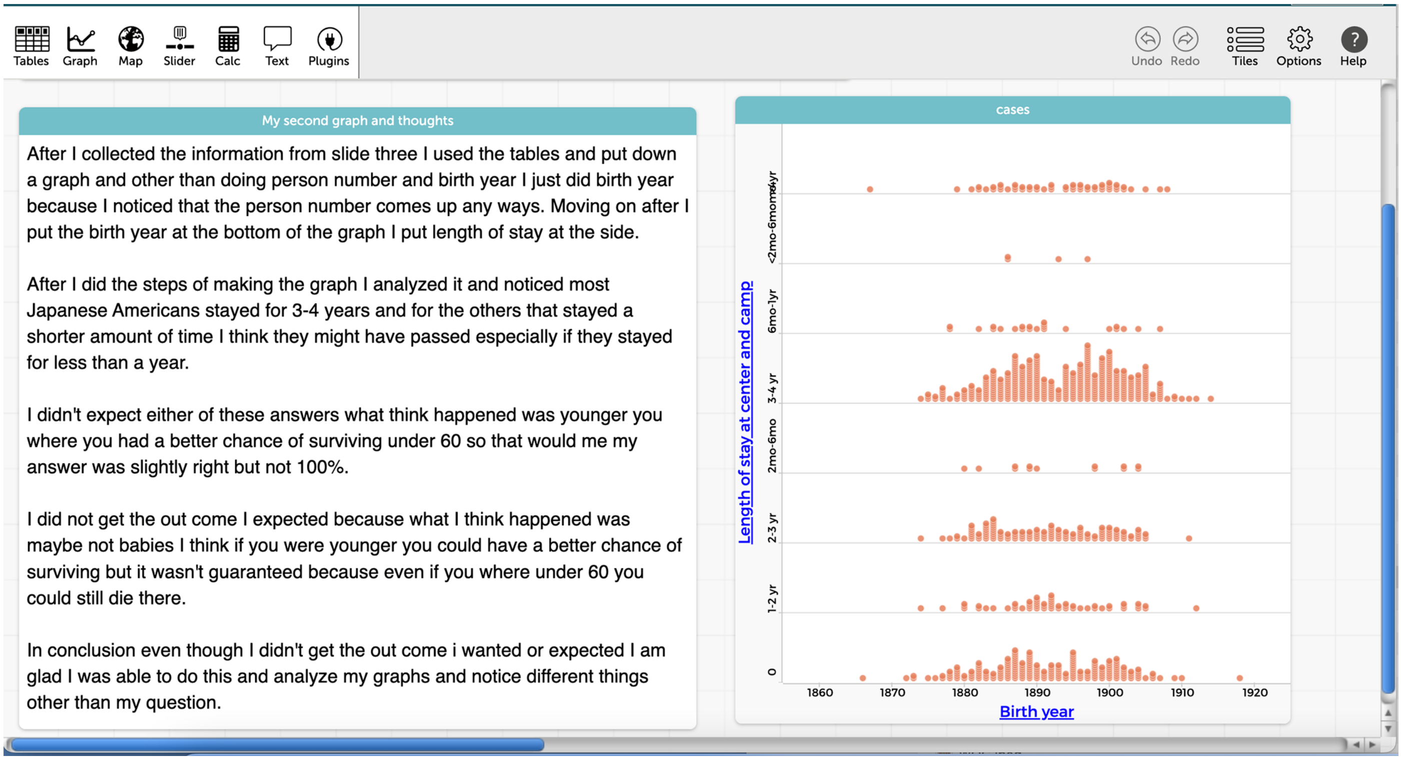

Figure 1. Slide 4 of Taylor's data story built in the CODAP Story Builder.

history of the Japanese American internment. Next, she used mode 1—narrating her own investigation—when she explicitly explained the origin of her idea: "I chose this topic because in class we read about people dying at incarceration camps, and I wondered how old the people were [when they] died."

Slide 2. Taylor continued in mode 1, describing how and why she selected particular attributes from datasets to test her prediction about children born in incarceration camps.

Slide 3. Taylor remained in mode 1, describing her steps in making a graph. She then switched to mode 2—animating a data representation—saying, "The graph is about what year they were born." She made an inference about the data collection: "I didn't expect this outcome [that the data doesn't include babies]. What I think happened is when they collected this data they weren't able to collect data from babies at this time."

Slide 4. She continued with mode 2 by animating her data representations, noting, "After I did the steps of making the graph I analyzed it and noticed most Japanese Americans stayed for 3-4 years and others stayed a shorter amount of time." To make sense of differences in the length of stay among the internees, Taylor connected "length of stay" and age, inferring "I think they might have passed, especially if they stayed for less than a year."

Slide 5. In the final slide, Taylor switched to mode 4 by narrating herself into a data-represented world and reflecting on her takeaways working with the data: "Even though I didn't get the outcome I wanted or expected, I am glad I was able to do this and analyze my graphs and notice different things other than my question." Finally, she returned to mode 3, connecting to the extant narrative of "what we learned in class about forced Japanese American incarceration." She said that her story "shows how old they were along with how long they were [in the camp] … I think the littler they stay in incarceration was the more likely they passed. Being in incarceration could and did kill innocent people."

Taylor's story incorporates both narrative and logico-scientific discourses by both choosing which attributes within the dataset to analyze and then using that data to support her story. She related to the experiences of marginalization based on identity and, by connecting her own identity and experiences in the contemporary United States to those of Japanese Americans, including Jeanne Wakatsuki Houston, she achieved mode 4 of data storytelling.

Conclusion

Data storytelling provides a means for students to connect to extant narratives, build their own stories of inquiring into meaningful questions with data, and ideally narrate themselves into data-represented worlds. Such skills can serve them well as they navigate our increasingly data-saturated world. In addition, opportunities to respond to their own questions through storytelling activities with well-curated data, teacher guidance, and collaborative work with peers enables students to connect emerging data agency and data identities with their existing intersectional identities. Taylor did so by engaging her identity and commitment to issues of justice. She manifested agency in calling for audience actions to "make sure this will not happen again."

* Radinsky, J. (2020). Mobilities of data narratives. *Cognition and Instruction, 38*(3), 374–406.

LINKS

DataPBL–concord.org/datapbl

Under the Hood:
DataCard Deck

Joe Bacal
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By Joe Bacal

The MothEd project aims to foster students' ability to develop their own systems for organizing and making sense of the data they collect about moths in their local area. We developed a new online tool for our Collaborative Learning User Environment (CLUE) called the DataCard Deck to give students a just-structured-enough platform for collecting and sorting their moth data, discovering relevant attributes, and refining their data structure on the fly.

In the physical world, a box of index cards is a useful data collection and organization tool. For example, imagine that you have collected a number of moth specimens in the field and have created a card for each. You might label each card with the date, the moth's length, color, and other attributes. Later, as you collect more cards, you might try to make sense of your data by sorting and resorting by various attributes. However, with enough cards, repeated sorting and editing can become tedious.

We designed the DataCard Deck to replicate this functionality and add some computer-powered conveniences: students need to be able to quickly and automatically sort by any attribute, readily add attributes, and have the ability to change values by dragging a card from one group to another. For example, if a student enters the values "small" and "large" for the size attribute, but mistypes some as "smll" or "Small," the DataCard Deck will sort these different values into separate piles. The student should be able to simply drag the mistyped cards to the correct "small" group and not have to retype "small" in the "size" field.

Our first development goal was to create a card-like experience, where students can create cards, and at any time add a new characteristic or attribute to a card, change its value and name, and have that reflected in every card in the deck. Given this flexibility, we also wanted to help students maintain the integrity of their data by reminding them not to create duplicate attributes.

By using our existing dataset API, we are able to check that the underlying dataset does not already have an attribute with the same name before allowing a student to save it.

```
const handleCompleteName = () => {
  if (labelCandidate !== getLabel()) {
    const names = content.existingAttributesWithNames().map(a => a.attrName);
    if (!names.includes(labelCandidate)){
      caseId && content.setAttName(attrKey, labelCandidate);
    } else {
      showRequireUniqueAlert();
    }
  }
};
```

Our second goal was to allow students to quickly sort and resort their cards by any attribute, allowing them to find patterns in their data.

```
<div className="sort-area-grid">
  {uniqueOrderedValues.length > 0 && sortById &&
   uniqueOrderedValues.map((value, i) => {
    return (
     <SortStack
      key={`${sortById}-${value}`}
      id={`${sortById}-${value}`}
      model={model}
      stackValue={value}
      inAttributeId={sortById}
      draggingActive={sortDragActive}
     />
    );
   })
  }
  {renderPlaceholderCells()}
 </div>
```

To accomplish this, we again leveraged the dataset API and added a basic sort state view. We call on one of our React components to display a stack of cards with a title that shows what attribute and value the cards have in common (Figure 1).

Finally, we needed to be able to allow students to not only see their sort groups but to move cards between them, rewriting the relevant data on the cards when they change groups. We leveraged the DnDKit library and again called on our dataset API to do the heavy lifting and change the underlying data.

```
onDragEnd: (e) => {
  if (e.active.data.current?.sortDrag) {
    const draggingId = e.active?.data?.current?.caseId;
    const attrId = e.active?.data?.current?.sortedByAttrId;
    const draggedToValue = e.over?.data?.current?.stackValue;
    draggedToValue && content.setAttValue(draggingId, attrId, draggedToValue);
    setSortDragActive(false);
  }
}
```

Structuring, analyzing, and interpreting data are key scientific practices. With DataCard Decks, elementary and middle school students can collaboratively and iteratively organize the data they collect in ways that make sense to them as they develop and refine their investigations. We're currently studying how students use these data cards so we can add new features to make their investigations even more productive and exciting.

Figure 1. Users can sort moths based on attributes, such as color or where the moths were trapped.

LINKS

MothEd—concord.org/mothed

GitHub for DataCard Decks
github.com/concord-consortium/collaborative-learning/tree/master/src/plugins/data-card

Teacher Innovator Interview:
Renee Green

Elementary and middle school teacher,
Hooper Bay, Alaska

As a Yup'ik Native, Renee Green's goal throughout college was to return to her community and work for and with the people in Hooper Bay. A graduate of the University of Alaska Fairbanks, she has been teaching first through eighth grades in the Lower Yukon School District for 20 years. Since 2019, she has been an elementary and middle school teacher at the Hooper Bay Charter School, the first charter school fully initiated and developed by an Alaska Native tribe.

Hooper Bay Charter School is pioneering the Innovative Technology in Science Inquiry for Yup'ik Students project, funded by the U.S. Department of Education to adapt Concord Consortium's STEM resources by including local phenomena and Universal Design for Learning (UDL) features. The goal is to create dual-language, place-based STEM curricula that both support the needs of English language learners and provide a means for students to learn in their Yugtun Alaska Native language.

The innovative curriculum units called TREKS extend the traditional 5E learning approach to include two additional E's—Environment and Elder Conversations—which are critical parts of Indigenous ways of knowing. The TREKS instructional model is thematic and based on local science phenomena. In a word, Renee describes them as holistic. "As a Yup'ik person," she says, "we tend to see things holistically. Everything is related."

When the school develops TREKS, they invite the community and Elders in for storytelling. "We want them to be as broad as possible, which can give us more ideas where we can go with the science, math, and reading." Renee notes, "I really enjoy the TREKS because the kids are sticking to one subject but at the same time they're branching out to different subject areas." TREKS include English Language Arts, science, math, and more, but in her class, the subjects flow into each other. "Some days go by quickly because we're connecting information. Kids aren't going from one subject to another and another."

For Renee and her colleagues, it's all about place. While TREKS focus on Alaska, they also "go outward" as students learn about other parts of the world. However, the most important thing is that students "learn about who they are in their community."

During one TREK, students and teachers gather different species of plants, then sort them, categorizing medicinal plants and how they're used in the community as well as poisonous plants. In another, students test the local water, including ponds where the kids swim and those where villagers get their drinking water. According to Renee, students feel empowered because they're the ones collecting and sharing the information on whether or not the water is safe. Renee also notes that her students, like children everywhere, enjoy being outdoors. "It's good for them emotionally and mentally."

In addition to outdoor activities, students use Concord Consortium's online activities, which include interactive simulations, sensors, embedded questions, videos with Elders, a glossary in both English and Yugtun, and both speech-to-text and text-to-speech capabilities (Figure 1). Each TREK includes a career connection and concludes with a presentation about important community issues such as erosion and conservation where students showcase for parents, Elders, and others what they have learned.

While Renee typically teaches fourth and fifth graders, teachers rotate among grades. When she recently met with a group of eighth graders who have been doing TREKS for the past three years, she beamed with pride. She described telling them, "You really know how to be involved in your learning and how to extend the lessons. I can see that you're learning and taking responsibility for your learning." Renee is also proud of her role at Hooper Bay Charter School. "I'm familiar with this area, know subsistence activities, know Yup'ik sayings and the wisdom I've heard." She is now passing on that wisdom.

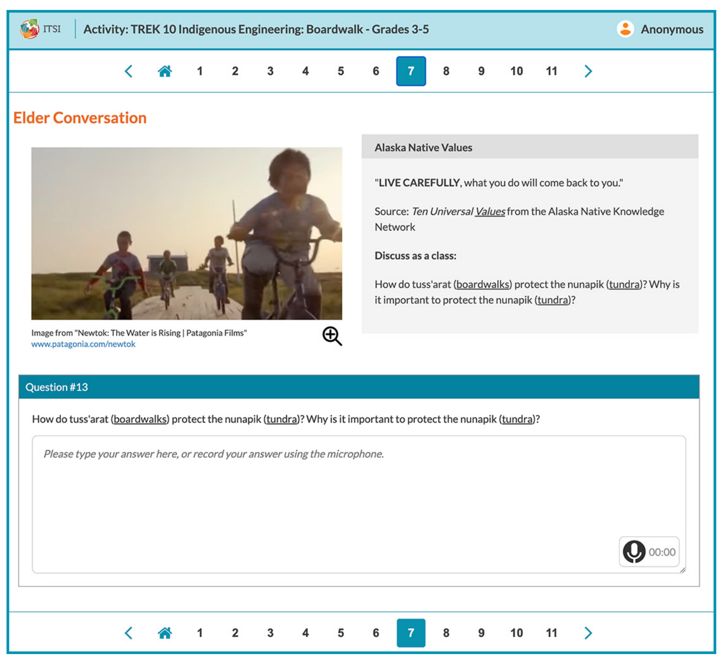

Figure 1. Elder conversation page in the Indigenous Engineering Boardwalk TREK.

The Concord Consortium
25 Love Lane, Concord, MA 01742

Data science research conference

K–12 data science education is a crucial and growing education research field. However, as practitioners move quickly forward, there is little research-based guidance about what learners need to know and be able to do with data, and when, within the course of their learning, these skills and competencies are appropriate. With funding from the National Science Foundation and the Valhalla Foundation, the Concord Consortium is proud to host a conference of 30 diverse researchers, educators, data scientists, policymakers, curriculum developers and more to develop a research-based framework for learning progressions in data science education. The conference committee is seeking broad input to help review and refine the framework into formats valuable for the field. For more information or to volunteer, contact Kate Miller (kmiller@concord.org).

New project brings geoscience practices to middle school students

Earthquakes can wreak havoc on infrastructure, cause casualties, and disrupt vital services. To identify vulnerable communities and assess earthquake likelihood and impacts, computational geoscientists use sophisticated instruments such as remote sensing satellites, land stations, and seismic and GPS stations to collect and analyze large-scale seismic, geographical, and socioeconomic datasets. As data from these instruments become more robust and computers become more powerful, the rise of computational practices in geoscience research and careers is also accelerating.

Our new National Science Foundation-funded YouthQuake project aims to bring this important work to middle school students in an urban California district. We are partnering with the EarthScope Consortium, the San Joaquin County Office of Education FabLab, and the University of South Florida to design a curriculum for students to engage in authentic science practices and explore earthquake hazards, risks, and preparedness in the context of their own communities.

YouthQuake is developing materials that are situated in the community context as students explore their neighborhood's likelihood of experiencing a damaging earthquake and related preparedness, investigate GPS data and use computational models of land motion along the faults around their community, and create computational visualizations of earthquake hazard maps. Project research is studying how students engage in authentic computational geoscience investigations of earthquake hazards and whether these activities increase their interest in, and identity with, computational geoscience careers.

Partnering for environmental literacy

We are delighted to partner with Ten Strands to create environmental literacy curriculum units for K–12. The Concord Consortium is providing resources and support to the middle and high school curriculum writing teams. Our goal is to help students build habits of mind around data and engage in modeling, which are critical skills for understanding and developing solutions for complex problems.

Data collection and exploration is a cornerstone of each curriculum unit. Students use CODAP to examine data from atmospheric sensors across the state of California and explore inequities regarding the environmental impact of air quality on different populations; investigate Census data for impacts of different environmental characteristics on different racial and ethnic populations found in California; and study data on subsidence (decreasing altitudes) of land in the Central Valley as a result of ground water extraction for agriculture.

Each curriculum unit also incorporates a key modeling activity. While examining how climate change is causing the electricity to go out more often, students could express their understanding of the links between climate change and power by building a system model in SageModeler. Students are also studying the dynamics of water flow into and out of aquifers used to support agriculture. By experimenting with different water policies and environmental circumstances, they can see how projections into the future of water availability might be adjusted to promote sustainability. Through these and other activities, students are learning to become stewards of the local and global environment.

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 Valhalla Foundation, the George Lucas Educational Foundation, Ten Strands, the U.S. Department of Education (S356A210002), and the National Science Foundation under several grants (DRL-2101382, DRL-1813737, DRL-1842035, DRL-2200887, DRL-2100990, DRL-2325871, and DRL-2241021).