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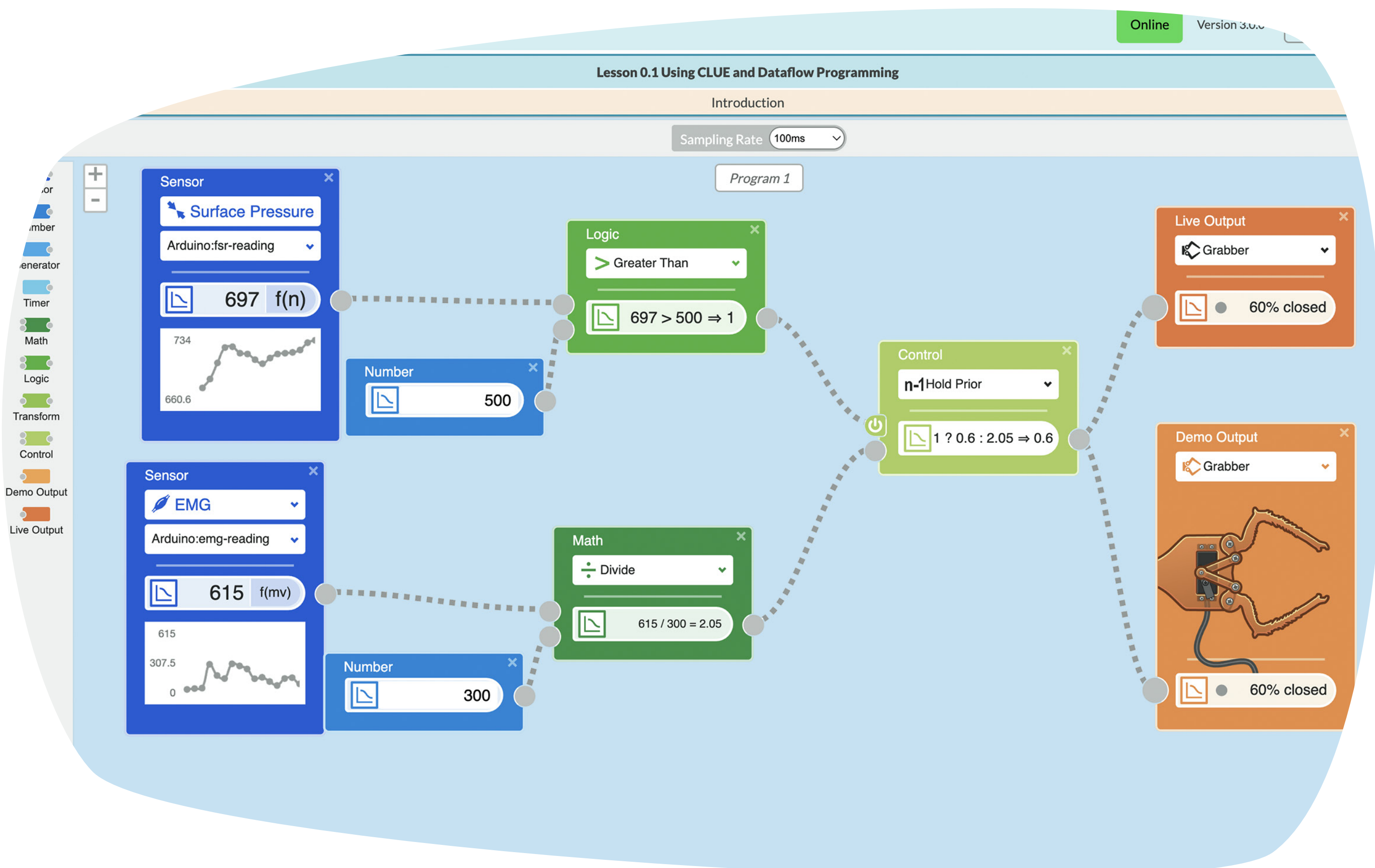

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Perspective:
Taking Pandemic Lessons Learned into the Future

By Chad Dorsey

For many schools, teachers, and students, this fall marks the return of a degree of normalcy after almost three years. However, even as we embrace the welcome familiarity, we recognize that everything has changed. While education faces many challenges as it rebounds from the pandemic, new perspectives also make space for new opportunities. There may be no better moment to consider the potential technology holds to transform education.

One of the undeniable effects of the pandemic was to demonstrate technology's central role in connecting us across time and space. And though remote connection is not the ideal mode for furthering rich, long-term teaching and learning, our recent societal "grand experiment" firmly established technology's power to enable flexibility, foster collaboration, and open up new educational possibilities. Whether by choice or circumstance, the pandemic introduced us to new apps, new perspectives, and wholly new approaches to teaching and learning.

While I fully acknowledge the need for us all to reset and recover, we also need to guard against slipping back into the comfort of timeworn habits. Even as we settle into a more normal year, we must keep our recent realizations front and center, both about technology's potential and about how flexible our world can actually be.

One way to avoid backsliding is to take a fresh look at that world. Across society, commerce, and culture, we find technology at the core. Our daily interactions play out across a vast network of computers of all sizes and types. Computational data, much of it from smart devices and sensors, forms the basis for critical decisions across all sectors of society. Artificial intelligence and machine learning algorithms work as silent partners in smartphone apps and smart grid infrastructures. And countless new innovations await in areas ranging from robotics to quantum computing and beyond.

Knowing this, we can tap into everything we've just learned about the flexibility of the status quo to consider embarking on a grand new experiment. What would education look like if we were truly starting fresh? How might learning play out if we embraced our society's inextricable connection to technology?

Educating with computing at the core. Children today live in a world where AI algorithms generate art seemingly from thin air, extend single sentences into complete short stories, drive our cars, and control our city infrastructures. It's hard to imagine what comes next, but one thing is clear: The jobs these children will someday take up will bear titles not yet imagined.

But comparing the curriculum that youth encounter in school today with modern reality reveals a harrowing mismatch. If we were designing an education suitable for a world in which computers inspire engineers with original, interactive 3D models, in which we can track the global movement of shipping containers and Arctic Terns to the nearest meter in real time, what would our elementary school children spend their time learning? I'm willing to bet it wouldn't be long division.

Instead, children might begin with the basics of modeling the world around them. They would learn how to wield data to illuminate their understanding. They would almost certainly accept as natural the key role of computational simulation in solving problems across topics and scales.

And what would we discover in the process of creating curricula anew? We would certainly expose today's subject area silos as outdated and irrelevant—not a big surprise, given that they were created in 1892. We would also undoubtedly cast aside the current emphasis on memorizing details and mastering facts to make space for learners to develop key habits of mind and exercise the vital practices of questioning, investigation, and evidence-based argument to solve relevant, unique problems.

Technology for authentic learning. Rather than make learning experiences fit stale paradigms and rigid categories, we would instead push aside longstanding boundaries and ask how

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An education that acknowledges technology's fundamental role would place authentic models and simulations at the core of the curriculum.

technology can transform our paradigms. In the process, I'm certain we would find at least one answer cropping up regularly—technology's ability to support more authentic learning opportunities.

While most domains can benefit, Earth science provides a particularly salient example. Observing a traditional Earth science lesson, one could easily be forgiven for coming away with the view that Earth is a static mass and that geologists spend their time memorizing the stages of the rock cycle, only taking occasional breaks to run scratch tests on minerals they pull from a dusty cardboard box.

We want our students to see the Earth wholly differently, as a dynamic, shifting entity, and to view each rock as a miniature chapter in the Earth's grand, ever-evolving story. We want them to recognize that geologists are some of the most artful systems thinkers around, and to know that scientists today are even more likely to unlock the Earth's mysteries by clicking a mouse than by pounding a rock hammer. Students should see Earth science as a lab science, where computers serve as active aids to help them understand the Earth as a system and provide an active, accessible proving ground for testing ideas and making original discoveries.

An education that acknowledges technology's fundamental role would place authentic models and simulations at the core of the curriculum. We're creating precisely such learning environments for students around the globe, holding them up as examples to show the world how computing can pave new paths.

Transdisciplinary transformation. Though the topic of Earth science education is in particular need of radical change, truly rethinking education means going deeper. In particular, it means recognizing that almost nothing in life involves only one topic in isolation. And while we recognize that approaches that combine disciplines don't fit easily into the container of traditional school, we choose to see that as an opportunity rather than a barrier.

At the Concord Consortium we're helping students take part in authentic, transdisciplinary experiences around key topics such as data science. Working side by side with teachers, we're co-designing and researching engaging, project-based learning opportunities using innovative new tools and learning approaches. By fostering computational thinking throughout the curriculum and allowing students to connect with community members around issues relevant to their individual cultures and backgrounds, we're creating experiences that put students in the driver's seat and place their lives and concerns front and center.

Making it happen. So, what would we do if we could rewrite everything? In short, we would design an education that treats technology as the partner it has become in our everyday lives, preparing learners to take full advantage of technology's potential. We would provide space for doing so, embracing curricular integration and flexibility, and borrowing from current movements rethinking the transcript and questioning the Carnegie unit. We would focus relentlessly on providing all learners with the foundational ability to control, design, and move technology forward as an evolving tool for addressing humanity's greatest needs.

In a year when achieving normal may feel like a high bar already, thoughts about this level of change may feel grand and complex. But if there's one important take-away from our collective pandemic experience, it's the realization that we can do things differently, and that technology must be a transformative part of the process. Even in a moment when we may simply feel like seeking familiarity, we must keep the big picture in view. Our goal—and the goal of every educator—is to build the best possible path toward the brightest possible future. Let's get started today.

How Do Teachers in Networks Use Digital Resources?

By project researchers at Michigan State University and the Concord Consortium

The Concord Consortium and Michigan State University are developing the Collaborative Learning User Environment (CLUE), a multi-featured digital platform designed to support groups of students working together to solve mathematical problems. Teachers have access to an embedded teacher guide and an additional suite of features for planning, teaching, and reflecting on their instructional practice. In a new project designed to facilitate collaboration among teachers in the same building or district, we're adding teacher networking supports and features so they can share their successes and struggles, engage in ongoing professional learning, and participate in collaborative teacher inquiry.

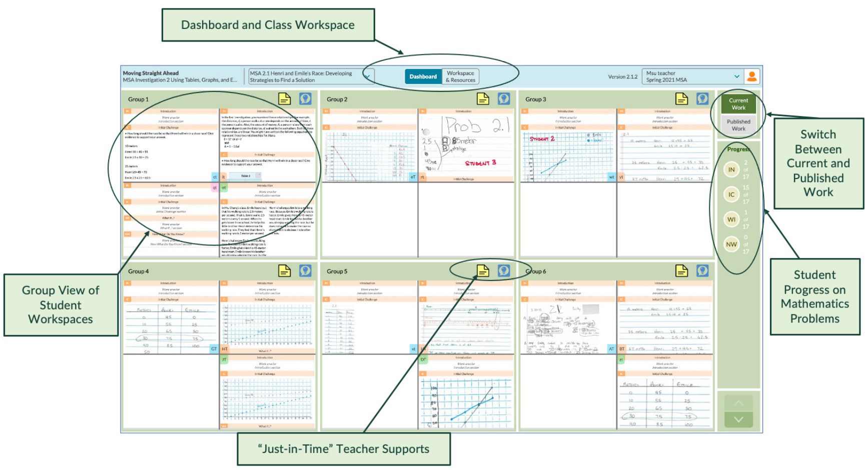


Figure 1. Teacher dashboard features in CLUE.

We have embedded three seventh grade units and teacher guides from the Connected Mathematics Project (CMP) curriculum into CLUE. Students use the software tools to create graphs, text, images, and drawings and to share or co-develop their mathematical thinking with their small group and larger classroom community. Teachers can view students' individual and group work through a dashboard that monitors student thinking across a class (Figure 1). New network features allow teachers to see student work or work created by teaching colleagues (Figure 2) and discuss it using threaded discussions that are linked to the shared documents.

The CLUE platform provides a unique opportunity to study how teachers prepare for teaching, implement the CMP curriculum in their classroom, and reflect on student learning. We are studying how teachers access, generate, share, and use digital resources to assess its usability, flexibility, and effectiveness in bringing this problem-based learning curriculum to life in the classroom. We are also interested in understanding how teachers interpret the embedded resources. This study focuses on how teachers in small networks interact with CLUE teacher resources and their collaboration and communication using the digital platform.

Framing the study

Digital tools provide new opportunities for detailed study of teachers' use of online resources. As teachers use the platform, we're able to capture a trail of "events" that provides insights into what resources they visit and their interaction with them. While these log files are an important source of data for this study, they show only what was done, but not necessarily the teachers' motivation or the conclusions they drew. Additional data come from an electronic survey that asked teachers about their planning, teaching, and reflection practices prior to implementing CLUE. Finally, we conducted semi-structured, follow-up interviews about teachers' experiences for each CMP unit.

Here we look at the work of two of the five networks of seventh grade teachers from the 2021-22 school year. We selected these networks because they illustrate contrasting approaches to using, sharing, and co-developing digital teaching resources. Network A consists of four teachers and one mathematics coach and Network D consists of two teachers and no coaches. The communication frequencies differed between networks (Figure 3). Network A shared synchronous planning time every other week, while for Network D, such synchronous planning time occurred daily. Teachers in both networks engaged students in using CLUE for multiple problems across three CMP units.

We reviewed data log files that record every teacher (and student) action in CLUE. Log files include a detailed record of when and how teachers viewed or acted on various tools and documents, such as accessing problems in the student edition or a problem solution from the teacher guide or adding or responding to a comment on a colleague's document. We looked across all log events to identify similarities and differences in the ways teacher networks used CLUE. Our analysis focused on how teachers use digital resources as they examine existing materials through "viewing" events or develop or edit materials through "action" events. Survey responses and interviews helped us learn more about teachers' practices when not using the digital platform and allowed us to make additional comparisons of the two networks.

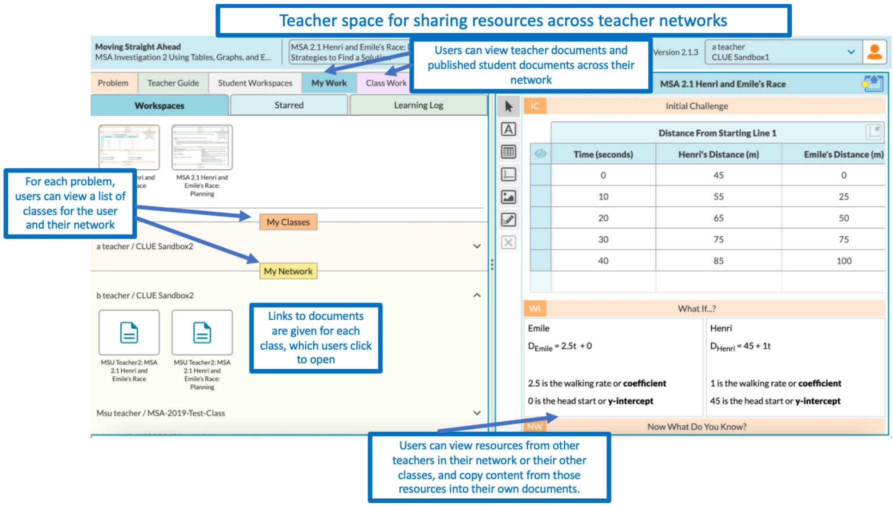
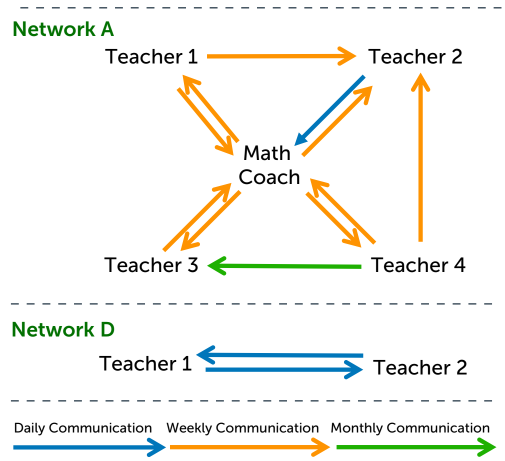


Figure 2. Teacher workspace features for accessing student/colleague work in CLUE.

Figure 3. Structure and communications for the two networks.



Unit	Network A	Network D
Stretching and Shrinking	6 problems 558 events	9 problems 4275 events
Comparing and Scaling	6 problems 455 events	3 problems 528 events
Moving Straight Ahead	4 problems 572 events	5 problems 2980 events
Total	16 problems 1585 events	17 problems 7783 events

Table 1. CLUE use across all units for Networks A and D.

Results

Analysis of the digital events showed varying degrees of resource use for both networks (Table 1). Teachers in both networks engaged with a similar variety of variety of problems and units in CLUE, although Network D engaged with the platform to a greater extent, including teaching multiple classes of students and viewing digital resources during daily shared planning time. Network A's platform usage varied greatly by unit and by user (teachers and coach), while Network D's usage was more consistent between the two teachers.

Digital Materials as Resources

Both networks used a variety of digital materials as resources for planning, teaching, and reflecting on mathematics problems (Table 2). Interactions with teaching documents (e.g., generating graphs and tables, creating documents for students) are the most common, accounting for approximately 41% of Network A events and 77% of Network D events. Both networks also frequently accessed student edition resources. However, the networks showed different overall patterns of resource use. Although Network A accessed resources with less frequency, they accessed resources in different categories with similar consistency. Network D accessed the platform frequently, but their access focused primarily on resources for students. We found a statistically significant difference between networks for frequency of access and use across nine resource categories (Table 2). The only exception was the embedded problem solutions, which both networks used with similar frequency. These differences are not indicative of instructional quality or student learning but show that the two networks differed in how they took advantage of digital resources.

Resource Category	Percentage of Total Network A Events (n)	Percentage of Total Network D Events (n)	p-value from Hypothesis Test*
Student Edition	8.8% (140)	12.6% (984)	.00003**
Teacher Guide	7.1% (112)	0.2% (17)	.00000**
Teacher Guide: Problem solutions	1.7% (27)	2.0% (153)	.55309
Planning documents	0.6% (9)	0.1% (3)	.00001**
Teaching documents	41.0% (650)	77.2% (6009)	.00000**
Learning logs	2.3% (37)	1.1% (88)	.00023**
Student work	20.8% (329)	1.5% (117)	.00000**
Colleagues' documents	1.7% (27)	0.4% (34)	.00000**
Collaborative discussions	2.0% (31)	0.1% (4)	.00000**
Other platform navigation	14.0% (223)	4.8% (374)	.00000**
Total	**100% (1585)**	**100% (7783)**	

* If $n<5$ for either network we used Fisher's exact test; otherwise, we used Pearson's chi-squared test (all tests with 1 degree of freedom).
** We reject the null hypothesis with $p<0.05$ level of significance and conclude that networks interact with that resource category in different proportions.

Table 2. Statistical comparison of the prevalence of each resource category in Networks A and D.

Although the networks differed in the extent to which they used each resource category, both networks appreciated the affordances of the platform for viewing multiple resources in sequence or side by side. When compared to traditional paper-and-pencil environments, one Network D teacher observed, "It was nice to

(continued on p.6)

(continued from p. 5)

have [materials] all condensed, so we can switch and use them quickly." Teachers in Network A were able to view student edition problems, teacher guide resources, and digital student work throughout instructional time. Teachers in Network D focused most heavily on the student edition, viewing multiple parts of the problem during planning and implementation. This flexibility and ease of connection between resources in the CLUE platform made it possible for teachers to use the resources differently according to their needs and way of working.

In order to understand what their students would experience, teachers explored the student edition when planning lessons, prior to making any modifications. In the words of one Network D teacher, this was to ensure "it's displayed in a way that I find kid-friendly for the kids in my classroom." Teachers in both networks focused on the initial challenge section of the problem, which engages students in developing multiple strategies and mathematical reasoning. According to one Network A teacher, that initial challenge is "the heart of a lesson or the idea that I think is the most important." For teachers in both networks, their decisions about which curricular resources to view were shaped by their formative assessments of their students and the key mathematical concepts they wanted to foreground.

	Network A		Network D	
Units	Action Events	Viewing Events	Action Events	Viewing Events
Stretching and Shrinking	**142**/558 (25.45%)	**416**/558 (74.55%)	**3279**/4275 (76.70%)	**996**/4275 (23.30%)
Comparing and Scaling	**45**/455 (9.89%)	**410**/455 (90.11%)	**323**/528 (61.17%)	**205**/528 (38.83%)
Moving Straight Ahead	**349**/572 (61.01%)	**223**/572 (38.99%)	**2563**/2980 (86.01%)	**417**/2980 (13.99%)

Table 3. Action and viewing events across all units for Networks A and D.

How Teachers Use Digital Materials: Viewing and Action Events

In addition to teachers' choices about which digital resources to view, they also made instructional decisions about how to interpret and "re-source" those existing materials to support student learning and their own teaching practices. Across all categories, the action events involved interacting with resources, such as creating, copying, or moving tiles; changing graphs, drawings, or tables; publishing documents; creating learning logs or notes to students; and adding or responding to teacher comments. As shown in Table 3, Network D teachers performed a much higher percentage of action events for each unit. While viewing problems, they explored the platform from a student's perspective by utilizing action tools, which is consistent with their focus on the student edition problems. A large portion of both networks' events involved editing specific content (e.g., graphs, tables).

Both networks' digital activity generally aligned with initial surveys on teachers' resource use when planning without the digital platform (Table 4). Network A indicated daily use of the teacher guide and weekly use of the student edition, and log analytics confirm this general use pattern. Network D indicated daily use of the student edition and weekly use of the teacher guide, and this also aligns with the log analytics. In initial surveys both networks reported using student work only weekly or monthly, but this

Resource Category from Initial Survey	Average survey response for Network A	Average survey response for Network D
Student Edition	weekly	daily
Teacher Guide	daily	weekly
Teacher Guide: Problem Solutions	weekly	daily
Their planning documents from previous years	weekly	weekly
Their student work	weekly or monthly	monthly
Colleagues' planning documents from previous years	monthly	daily
Student work from colleagues	rarely	monthly
District planning or pacing guide	daily or weekly	N/A

Table 4. Network initial survey responses about resource use for planning when not using the digital platform.

tended to happen more frequently in the digital platform, particularly for Network A. In contrast, for other resource categories such as colleagues' documents and planning documents, teacher responses to initial surveys indicated frequent use (often weekly or daily) but digital activity was less frequent. These resources appear less in log files overall, potentially because of their later development timeline.

In both networks, teachers continued to plan and work together outside of the digital platform, although their attempts to use the new digital resources for teacher collaboration and planning showed some differences between networks. Network A, with more members and less common planning time, interacted with collaborative features of the digital platform to a greater extent than Network D, who collaborated daily during shared planning time. The digital resources were used as a complement to each network's existing ways of planning and working together, rather than a replacement.

Conclusion

Teachers have new opportunities to select and adapt digital resources for their classrooms. Digital platforms offer both increased access to student work and new possibilities for how teachers plan, teach, and reflect on student learning, including as part of networks. Not surprisingly, teachers use digital resources in their classrooms in a variety of ways. We are enhancing features for collaboration, planning, and reflection and studying how teachers and instructional coaches use the rich set of digital tools for student and teacher collaboration.

Research was conducted by Taren Going (goingtar@msu.edu), Alden J. Edson, Ashley Fabry, Sunyoung Park, and Kristen N. Bieda at Michigan State University, and Nathan Kimball and Chad Dorsey at the Concord Consortium.

LINKS

Teacher Networks
concord.org/teacher-networks

Monday's Lesson:

When It Rains, Does It Always Pour?

By Kevin Waterman, Brian Fitzgerald, Emily Fagan, and Bill Finzer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Brian Fitzgerald (bfitzgerald@mountwashington.org) is a science educator at Mount Washington Observatory.


Emily Fagan (efagan@edc.org) is a curriculum developer at Education Development Center.


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

After months of drought in the Boston area, a sudden rainstorm dumped a large amount of rain in a short time, flooding parking lots and roadways (and one of our basements). The intensity was incredible, but was the weather event itself "extreme"? Climate scientists define extreme as a measurement within the top or bottom 5% or 10% of all records for that date.

In this activity, students search for evidence of extreme precipitation at a location they choose using CODAP's NOAA Weather plugin.

1 Get Data

Launch CODAP at **https://codap.concord.org/** and create a new document.

- **Choose your weather station.** Select NOAA Weather from the Plugins menu. Under "Station Location," enter your city/state or ZIP code. A drop-down list appears with stations that match your entry. You can also click "Near Me" or use the "Station Map" button to find a station.
- **Choose your date range.** Select "monthly." The date range by the name of the station indicates the time frame for which NOAA has weather data. Choose all or part of that range—the longer the time frame you select, the more likely it will find outliers.
- **Get data.** Click the "Get Data" button. CODAP pulls the data from the NOAA database and creates a table.

2 Analyze Data

- **Create a graph.** Click the Graph button. A new graph appears with the data points randomly drawn on the grid. To organize the data, drag "precip (in)" from the table header to the y-axis and "when" to the x-axis (Figure 1). Now that the data is organized to show the amount of precipitation over time, do you see any outliers?

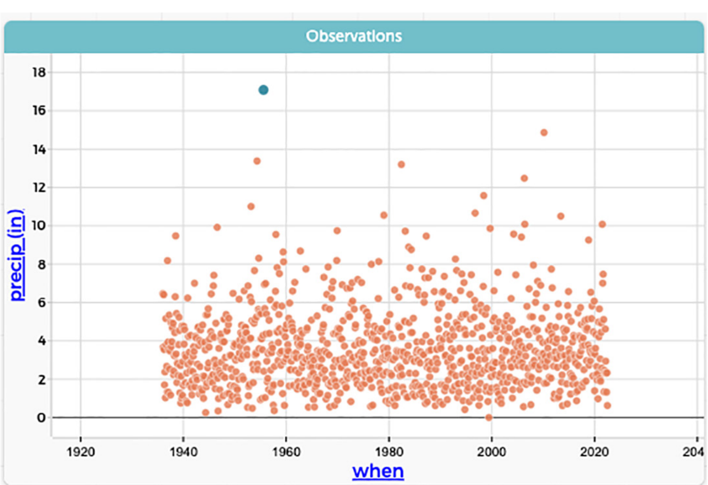

Figure 1. Monthly accumulated precipitation (inches) in Boston for the last century.

- **Analyze graph.** Click on a point near the top of the graph for amount of precipitation (e.g., the blue dot in Figure 1). The data associated with that point highlights in the data table. What do you think is going on?

3 Investigate

- Do a web search to check the weather on that date (e.g., "August 1955 Boston weather").
- Read articles that describe the event you found in your data (Figure 2).

4 Dig deeper

- Examine the hourly data for the day or date range of the weather event. Do other variables give you more information about the weather that happened that day? What patterns do you notice that can help you understand more about the event?
- Investigate another location. Can you find an extreme precipitation event in the dataset?

The National Science Foundation-funded WeatherX project has developed two weather units for middle school students, one focused on exploring local weather data and one on weather at Mount Washington Observatory.

WeatherX team members also include Jo Louie, Pam Buffington, and Brianna Roche at Education Development Center; Asli Sezen-Barrie at the University of Maine; and Deb Morrison at the University of Washington.

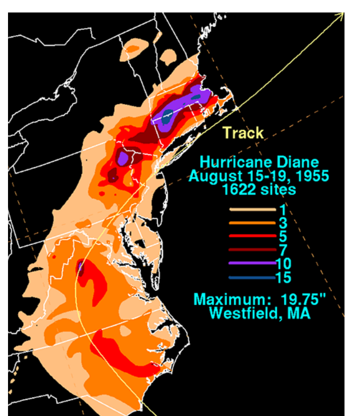

Figure 2. Monthly historic flooding in Massachusetts in August 1955. Image from https://www.wpc.ncep.noaa.gov/tropical/rain/diane1955filledrainblk.gif

LINKS

WeatherX – https://www.edc.org/weatherx

K-12 Data Science Education:
A Recipe for Success

By Chad Dorsey

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is the President and CEO of the Concord Consortium.

Data is at the heart of decisions made across all sectors of society, and K-12 education is beginning to take notice. While ensuring that all students learn to work with data fluently is crucial, the path to doing so is unclear, and many open questions exist. Answering them demands cutting-edge research, extensive testing and implementation, and collaboration across many different groups. The Concord Consortium is proud to be at the center of this work with several new initiatives and research projects.

Data science education is a feast of both the familiar and the new, combining traditional statistics instruction and research with intriguing new software tools, data wrangling and management techniques, and interdisciplinary context.

Perfecting any good recipe involves many skills: identifying key ingredients and their optimal ratios, refining the processes of combination, and anticipating ideal conditions. In the field of K-12 data science education, everyone's still hard at work in the test kitchen assessing essential components—from key competencies to datasets to technology tools and affordances. What pedagogical techniques and curricular treatments can and should be combined? What different educational conditions and settings are needed to pull it all together? We're seeking answers to these questions and more.

Finding the fundamentals. Datasets are perhaps the central ingredient of data science education. Much more than raw numbers, datasets have order, meaning, and structure. At the heart of any dataset is an object, or "case." Multiple examples of this case, with one or more associated attributes, comprise a dataset. A lab experiment may capture the state of a system at points in time as its individual cases, with attributes of temperature or position measured for each. Other datasets may choose vastly differing cases—households in a census or individual police stops in a social justice dataset—but the overall "case-value" relationship holds universally.

Although the case-value relationship may seem practically invisible in a two-column table, add one more layer and bigger issues pop into view. What if a lab dataset contains multiple experimental runs? What if a census dataset includes multiple households? Our cases suddenly nest within larger categories. Real-world datasets exhibit such hierarchies all the time, in ways that may shift depending upon the perspective. (Do we group experimental runs by student or control condition? Do we aggregate census households into counties or income bands?) In a new research project, Multidimensional Data, we're taking a close look at these core components, asking foundational questions about how learners interpret hierarchical data and exploring how novel, technology-based affordances can help deepen understanding and sensemaking (Figure 1).

Another question concerns the fundamental types of data, especially one family—data that vary in space and time. From virus tracking to climate change and environmental racism, our understanding hinges on analyzing and tracking patterns in spatiotemporal data. But until the past decade the complexities of doing so have thwarted even science and industry.

Recent advances in computing power and algorithms offer intriguing promise. Yet cognitive and learning sciences still understand little about how learners approach these data or how technology-based tools might help. In our new Data in Space and Time project, we're joining with leading spatial thinking researchers at Northwestern University and James Madison University to take some of the first steps toward foundational understanding in this crucial new area of study.

These projects offer help navigating ongoing questions about data's fundamental ingredients. One key lesson we've learned: students should understand that data is far more than simply numbers. In our ongoing StoryQ project students learn to view and analyze text and its features as data, demonstrating how data education can help students better engage with the written word—and how doing so can bring data science learning into English classrooms.

Pedagogy and processes. The StoryQ example presages another set of open questions in K-12 data science education, namely where and how we teach about data. These are questions about the processes we use to blend our data ingredients. What does high-quality teaching and learning involving data look like? What experiences are most important? How can we ensure students engage in them effectively?

Some new projects home in on what may be data science education's largest dilemma. Although many people instinctively place data under the mathematics umbrella, true data science is

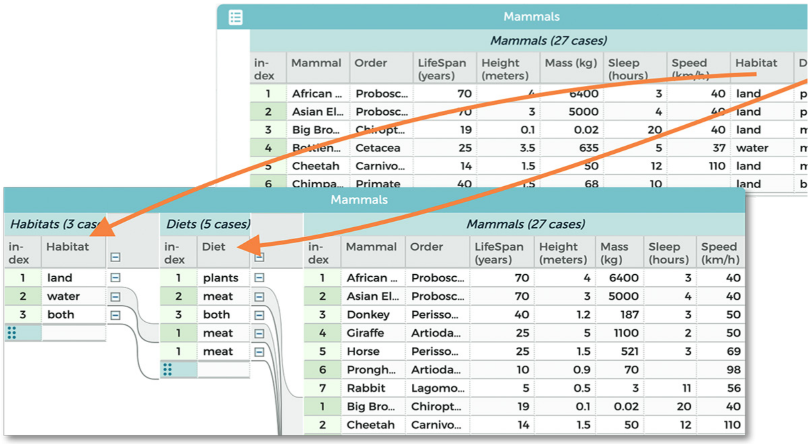

Figure 1. Multidimensional data represented hierarchically in CODAP. Attributes with repeated data values have been dragged to the left to group the data.

the *interdisciplinary application* of data to ask and answer questions within domains. This distinction is critical—data experiences that lack context misrepresent how and why we work with data. Even worse, by hiding data's relevance to learners' lives they may turn many, often those already most underrepresented, away from gaining an interest.

Our new DataPBL project is working to correct this bias and investigate how interdisciplinary approaches can help middle school students identify as data-focused learners. By co-designing project-based learning experiences with teachers, in partnership with EL Education, University of Colorado researchers, and UCLA data science curriculum designers, we're identifying how authentic, high-quality data science education experiences can bridge multiple disciplines.

While data may indeed be everywhere in our world today, very little exists in forms useful for K-12 education. Through initial funding from the Hewlett Foundation, our Open Datasets for Learning project is exploring how datasets can be sourced, prepared, and made broadly available in formats—and with accompanying pedagogical supports—appropriate for use across topics and levels from elementary through high school.

Of course, even the best recipes amount to little in the hands of a chef without sufficient training or experience. In our new ESTEEM II project, we're building on successful work with North Carolina State University designed to ensure that new teachers become fully prepared to help students gain fluency in working with data. Adopting a systems view, we're refining and expanding on models developed over years of partnership to develop a network of faculty, organizations, initiatives, and projects focused on transforming undergraduate teacher preparation in data education.

Understanding the conditions. Even the best chefs must be able to work under a variety of conditions. After all, if one is cooking with only an oven, a recipe designed for the stovetop is irrelevant. The difference between formal and informal settings can be equally stark, yet both have promising roles to play in K-12 data science education.

Our new Isles of Ilkmaar project uses the power of games to create a fantasy word with shared experiences in which data plays a critical role (Figure 2). As players—in this project, primarily Latina girls—encounter the game's scenarios, they come to discover that the key to progress lies in generating, sharing, and analyzing data about its creatures and ecosystems. By purposely making data central to solving problems they find relevant, the game will allow youth to make discoveries together and gain recognition and value for specialized knowledge and skills. By investigating both "game-only" learners and players also involved in after school coding clubs, we will develop a nuanced understanding of how different informal learning settings can interweave to help learners develop identities around reasoning with data.

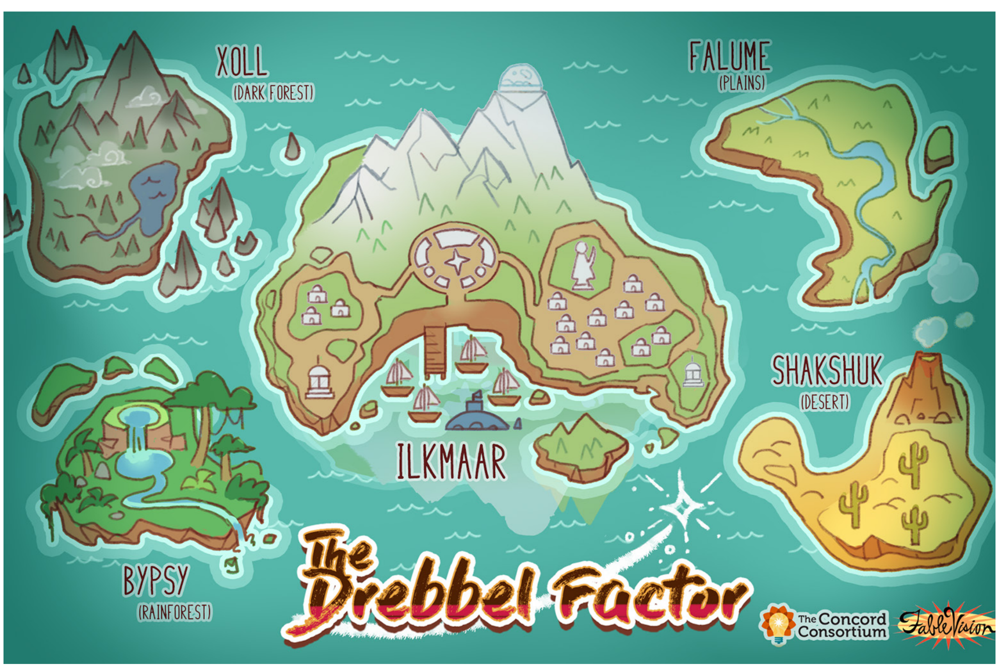

Figure 2. The Isles of Ilkmaar game art.

Aiming for the horizon. Together these projects represent a substantial addition to the growing momentum of K-12 data science education research and development. We are proud to add these projects to the extensive body of work we've engaged in over many years, including developing tools, convening thought leaders, and building research capacity nationwide. We're excited to be part of the collective efforts of many data science "chefs" working together to produce a shared result—data science education for all K-12 students.

Developing a Modeling **Orientation to Science**

Dan Damelin
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is a senior scientist.

By Dan Damelin

When I first heard the phrase "developing a modeling orientation to science," it struck me as a little odd. As a former high school science teacher for over 20 years, it felt redundant, like suggesting that someone in a pool should "develop a water-based orientation to swimming." One might argue that the primary activity of doing science is creating models to explain and make predictions about natural phenomena. However, given how difficult it has been to transform science education from courses that "cover" lots of content to inquiry-based investigations of phenomena using both the tools and practices of scientists, perhaps "developing a modeling orientation to science" is not so peculiar. The Concord Consortium is excited to join project leads from the Gulf of Maine Research Institute (GMRI), Vanderbilt University, and Bowdoin College to work toward this goal.

The Developing a Modeling Orientation to Science (DMOS) project, funded by the National Science Foundation, aims to engage middle school students in utilizing several modeling approaches to understand various ecosystems. Project research is studying to what extent teachers' comfort and ability to use a modeling approach affects students' modeling experiences and understanding of ecosystems.

Collaborative research on ecosystems

The work has focused on systems under study in GMRI's Ecosystem Investigation Network (EIN), which supports field-based, collaborative research into the climate-driven changes happening in the Gulf of Maine and its watershed. Through EIN community science projects, students learn about particular ecosystems by contributing to growing datasets while helping ecosystem scientists, too. As a companion to the data collection efforts of these projects, DMOS has developed curricular portals for teachers and students that build from existing resources on GMRI's Learning Resource Hub.

To help students develop a modeling orientation to science, DMOS curriculum modules provide opportunities for teachers to integrate modeling in multiple forms throughout an investigation of a scientific phenomenon. Students might:

- Create a physical microcosm of the system (e.g., a tank with crabs, prey, and other components of the intertidal zone) (Figure 1). Such a physical model is dynamic and living, making it possible to ask and explore questions about the system.
- Explore a simulation or act out a "game," which involves playing the roles of components of an interacting system (e.g., the *Crabs! / Oh Deer Invasive Species Modeling* game).
- Dive into data, where exploring relationships between variables in a system is a form of mathematical modeling (e.g., CODAP document exploring crab data submitted by many students and classes through the EIN) (Figure 2).
- Develop a computational model of the system using the SageModeler system modeling tool (e.g., SageModeler model of invasive crab impact) (Figure 3).

Figure 1. Physical microcosm with crabs, prey, and other components of the intertidal zone.*

Our goal is to engage students in multiple ways of learning through models, allowing them to see how various types of models provide different ways to learn about an ecosystem. Students also learn how each modeling approach has strengths and limitations. Used together, they can provide a more comprehensive view into the scientific phenomenon under study and engage different ways of knowing.

Modeling as a science practice

Learning in science class is more than learning about content. It is also learning what it means to build knowledge through science practices, both learning about and participating in how scientists do science. In the Next Generation Science Standards (NGSS), the science practices are integrated with disciplinary core ideas and crosscutting concepts. Modeling is a particularly powerful practice because it can be an umbrella for engaging students in all the other practices: asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information.

In order for teachers and project researchers to know that students are developing a modeling orientation to science, we have created guides and learning goals linked to specific activities:

- Students understand models as representations that help them investigate the world.
- Students see the system under study as being made of component parts, interactions, and functions.
- Students understand that models are constructed through a series of intentional choices about what to represent and how to represent it.
- Students see all models as incomplete representations of the system/phenomenon and evaluate models for their usefulness in highlighting certain aspects of the system.
- Students recognize data as one type of model, which involves making choices about what attributes to represent and how to represent them when producing that data.
- Students construct and interrogate models as representations of the system to help them understand the system and to communicate that understanding.
- Students are comfortable working in a complex system with both knowns and unknowns and with there not being a single, correct model.
- Students build understanding by integrating learnings from multiple sources and across multiple models of the system.
- Students understand science as a process of making choices about what parts to investigate and how to investigate them through modeling and data.

Supporting teachers

In addition to designing classroom resources, DMOS is supporting teachers to make this new pedagogical approach possible. For three years, we have been working with a dozen middle school teachers to build capacity and confidence in using a modeling-based pedagogical approach. DMOS has offered several supports for teachers, including: 1) teacher guides around modular lessons that can be used to explore various ecosystems, 2) a professional learning program that includes three-day, in-person summer institutes, bi-monthly virtual meetings, and a Google Classroom in which the teachers are enrolled as students for information sharing between the DMOS team and teachers, as well as peer sharing between teachers, 3) in-class researcher support for one-on-one planning and reflection, and 4) virtual learning sessions around modeling tools such as SageModeler and CODAP, and planning and reflection discussions around how to best use these tools.

In our 2022 summer institute, teachers had the opportunity to work alongside GMRI scientists to study a blue mussel ecological system and experience participating in a research study firsthand. In order to facilitate teachers staying in "researcher" role, rather than switching to "teacher" role, we chose a system they were not planning to teach during the upcoming school year. We wanted them to be immersed in a mini-research study for most of the three days with reflection at the end when they could discuss how to bring their experiences back to the classroom.

Teachers developed an understanding of the role of modeling practices in a professional ecological investigation, identified aspects of modeling that are central to student learning experiences, and developed ideas to approximate those modeling practices in their classrooms. For teachers to be able to facilitate developing a modeling orientation to science for their students, it is critical that they embody this perspective themselves and feel comfortable using modeling tools and leading discussions that go beyond the content and help students understand the why and how of doing science.

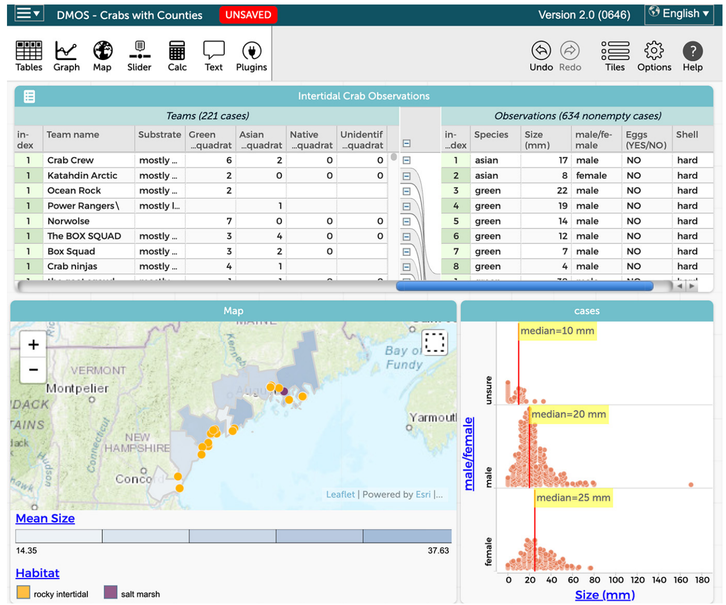

Figure 2. CODAP document exploring crab data submitted by many students and classes through the EIN. http://short.concord.org/lri

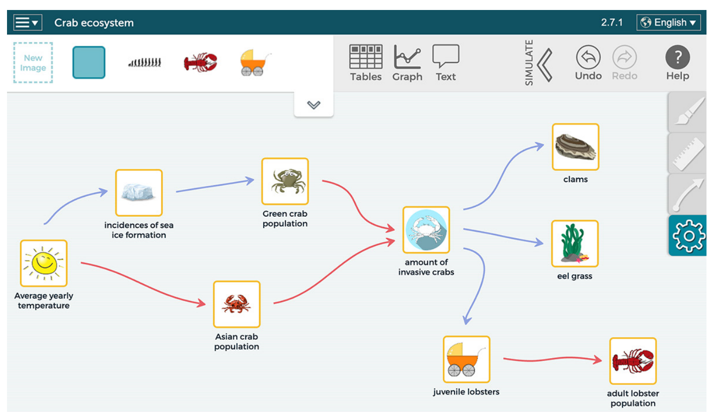

Figure 3. SageModeler model of invasive crab impact. http://short.concord.org/lrj

* Dickes, A., Wisittanawat, P., & Lehrer, R. (2022, June). Physical microcosms: Potentials for enriching classroom ecological investigations. In C. Chinn, E. Tan, C. Chan, & K. Yael (Eds.), *Proceedings of the 16th International Conference of the Learning Sciences* (pp. 2098–2099).

LINKS

GMRI's Ecosystem Investigation Network
https://investigate.gmri.org/project/

GMRI's Learning Resource Hub
https://teach.gmri.org/find-content/community-science/

Crabs! / Oh Deer Invasive Species Modeling game
https://teach.gmri.org/curriculum/activity/8-crabs-oh-deer-invasive-species-modeling/

Math Modeling with M2Studio

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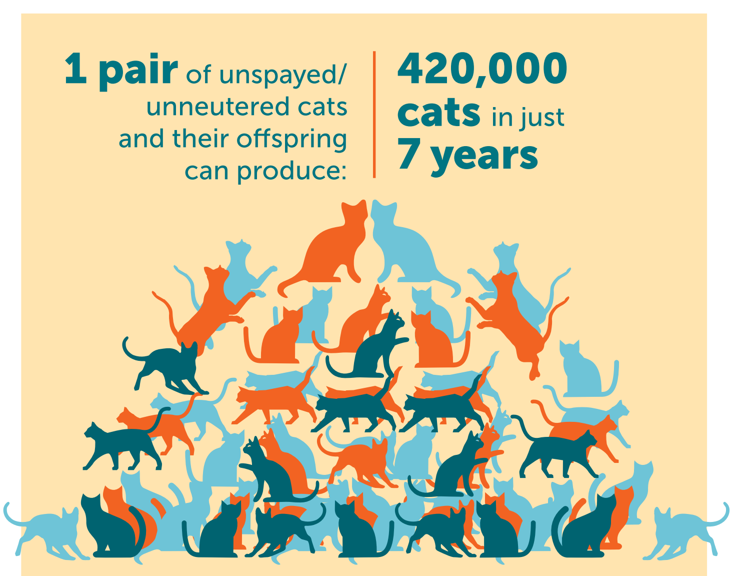
By Jie Chao and Ben Galluzzo

If nothing else can cheer Lila up, cats always do. One day, while scrolling through cat photos online, the ninth grader stumbles onto a poster with a shocking message: "One pair of unspayed/unneutered cats and their offspring can produce **420,000** cats in just **seven years.**" Lila's mind is racing with questions: Is that possible? How did they come up with that number? Did they assume unlimited food for all the cats to survive? She grabs a piece of paper and jots down some ideas: number of kittens in a litter, number of litters in a year, when cats are mature enough to have kittens… Before long, the paper is filled with notes on cat reproduction facts, drawings of cat family trees, and lots of calculations.

Lila is a budding mathematical modeler. She uses mathematics to represent and analyze a real-world phenomenon and make predictions about it. Problems like this are distinct from typical word problems. Mathematical modeling problems are often open-ended and ill-structured. Their goals can be vague and the information they provide may be incomplete. A single problem may have multiple solutions that can be evaluated by various criteria under different circumstances. Mathematical modeling is thus challenging to learn and teach.

Our M2Studio project is creating tools, materials, and opportunities for young people like Lila to develop mathematical modeling competencies that are necessary for solving real-world problems using mathematics. In this article, we introduce M2Studio, a web-based learning environment featuring a semi-structured workspace and dynamically linked representations.



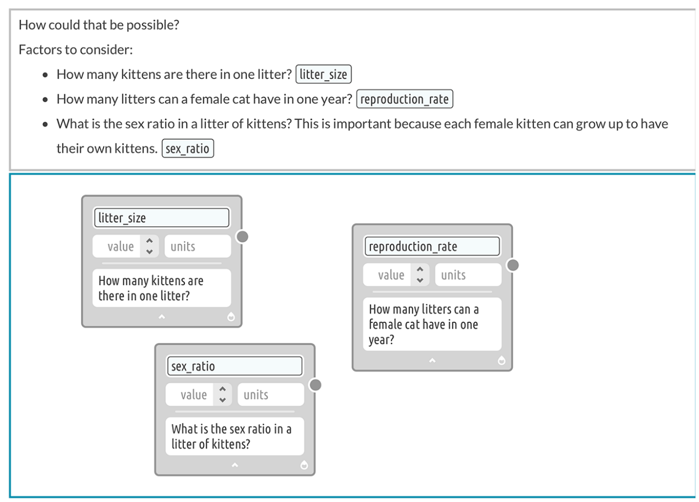


Figure 1. Text (top) and diagramming tiles (bottom) in M2Studio.

Identifying and defining variables and relationships

M2Studio includes a suite of tools, including a rich text editor, a drawing tool, and a diagrammatic programming tool. Using these tools, students can create multiple "tiles" to express their ideas and arrange these tiles based on their flow of ideas or presentation needs.

Like Lila, when we see the cat poster, a lot of ideas and questions come to mind. We can use the text editor to record them. How many kittens are there in one litter? How many litters can a female cat have in one year? What is the sex ratio in a litter of kittens?

All of these are useful questions that include within them factors that have numerical values. By selecting the text and opening the variable editor, we can create variables inside the text editor. The newly created variables appear in the text editor as "chips" and in the diagramming area as "cards" (Figure 1). The chip and card point to the same variable so that if we make a change to one, the other instantly updates.

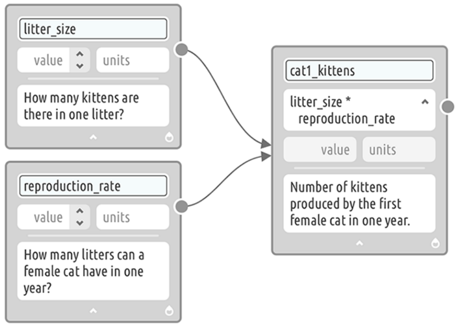


Figure 2. Connecting two input variable cards to an output variable card in M2Studio.

Using [litter_size] and [reproduction_rate], we can determine the number of kittens produced by the first female cat in one year. We can add a variable card for [cat1_kittens], connect the two cards to it, and write an expression: [litter_size] * [reproduction_rate] (Figure 2).

With a quick Internet search, we find that cat litter size ranges from 1 to 5 with an average of 3.7 for street cats, and that the reproduction rate ranges from 1 to 3 litters per year with an average of 2 to 2.5. To simplify, we assume the litter size is 4 kittens/litter and the reproduction rate is 2 litters/year. Once we set these values and units in the cards, the value and unit for [cat1_kittens] is calculated. We can then report it in the text editor by inserting the [cat1_kittens] variable, where we see the value 8, the result of 4 * 2.

Realizing that the total amount of time can also be a variable, we turn "7 years" into the variable [total_time] and create another variable [cat1_kittens_total]. Finally, we change [cat1_kittens] to [cat1_kittens_annual] for clarity (Figure 3).

So far, we have only looked at the offspring of the first female cat. What about the female kittens in each litter? They will also have their own offspring. Next, we consider how long it takes for female kittens to have their own kittens. According to our source, cats start having kittens from 4 to 18 months old. Since we want to see if it's possible to reach the number in the poster, let's assume the shortest time.

We use a drawing to visualize cat family trees where big circles are mature cats and small circles are newborn kittens and where red are female and white are male (Figure 4). Assuming the sex ratio is 1:1, there will be two female kittens (cat2 and cat3) in the first litter from the first pair of cats. The kittens will take 4 months to mature and start having their own kittens. So, the total amount of time for them will be 4 months shorter than 7 years. We can label our drawing with these variables to make the relationships clear. Because we are using variables, we can test different scenarios. What about 9 years? If we change [total_time] to 9 years in the diagram, the amount of time for cat2 changes accordingly and the total number of kittens produced by the first female cat [cat1_kittens_total] also increases to 72.

Although we haven't yet determined if it's possible for one pair of unspayed/unneutered cats and their offspring to produce 420,000 cats in seven years, we are on our way. Note that our partial solution is based on many assumptions we made earlier. There are more variables and assumptions we could incorporate into our cat reproduction model.

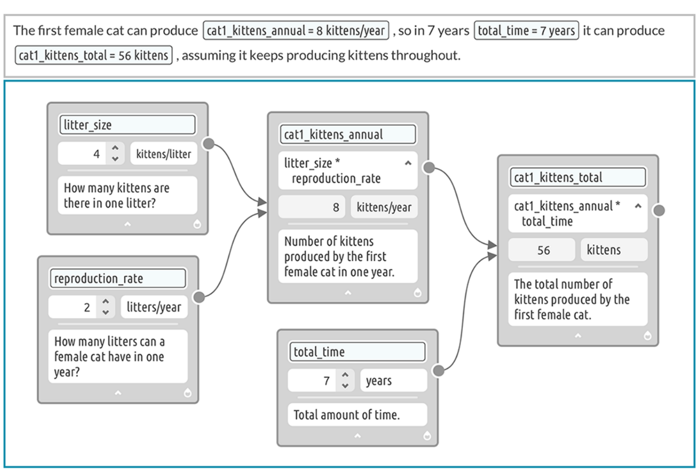


Figure 3. Building models in M2Studio.

Supporting mathematical modeling competencies

M2Studio is designed to support students in developing mathematical modeling competencies, allowing them to express their ideas in multiple representations and highlighting the connections among representations. By presenting variables and relationships as easy-to-manipulate digital objects and placing them at center stage, M2Studio embodies the key practices of building, testing, and iteratively refining models.

If you are interested in piloting our M2Studio math modeling lessons in your high school classroom, please contact us at m2studio@concord.org.

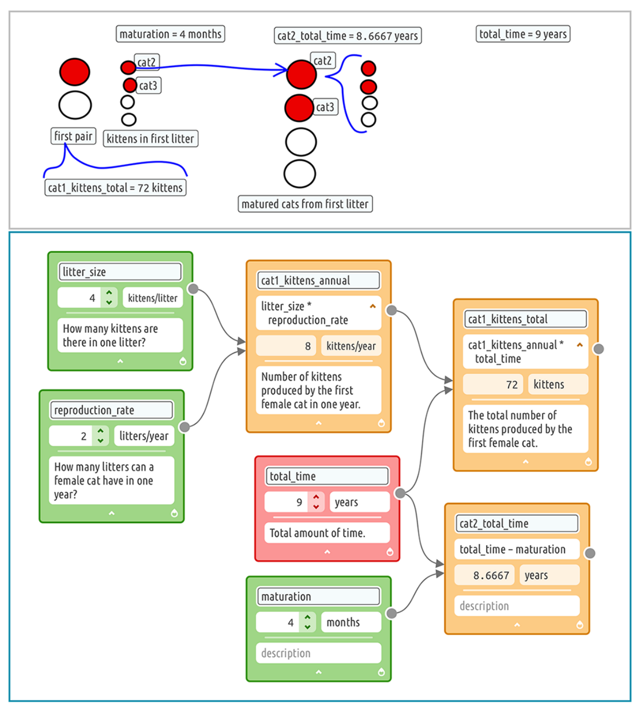


Figure 4. A growing mathematical model in M2Studio with variables linked across representations.

* Little, S. E. (2011). Female reproduction. *The Cat: Clinical Medicine and Management*, 1192–1227. https://doi.org/10.1016/B978-1-4377-0660-4.00040-5

LINKS

Mathematical Modeling with M2Studio
concord.org/m2studio

Under the Hood:

Using Brain Signals in a Block Programming Environment

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By Joe Bacal and Teale Fristoe

It's a hot late August day and your neighbor's kids have set up a lemonade stand. After paying your quarter, you reach for a cup. As you lift it, you sense the paper cup is thin, so you tip it gingerly and take a sip—delicious! But how did the idea of picking something up become motion in your arms and fingers? And how did you know to grasp the cup just enough so it wouldn't be crushed or slip out of your hand?

Electricity is the answer. Your brain's motor cortex sends electrical signals through motor neurons to contract muscles in your arm and hand. At the same time, nerves in your fingers send electrical signals back to your brain with information about how the object feels in your hand.

In collaboration with the University of Connecticut, we're designing activities for high school biology students that engage them in computational thinking as they learn how to use electrical signals from their brains to control virtual and real mechanical devices. We were inspired by Backyard Brains whose Arduino-based hardware kits allow students to attach an electrode to their arm, then tense their muscles and use the electricity created to make a robotic-like Grabber open and close (Figure 1). We wanted to provide students with components to program this process on their own, using Backyard Brains hardware in combination with an accessible, drag-and-drop programming environment.

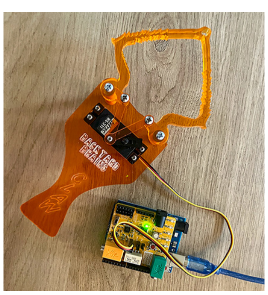


Figure 1. The Backyard Brains Claw and Muscle Spiker connect to an Arduino microcontroller.

We started by importing our Dataflow visual programming software into a new tool tile in CLUE, our Collaborative Learning User Environment. Using Dataflow, students can write programs that consume, process, and output data by connecting blocks, similar to Legos. It's the perfect environment for simulating how electrical signals traverse a system (Figure 2).

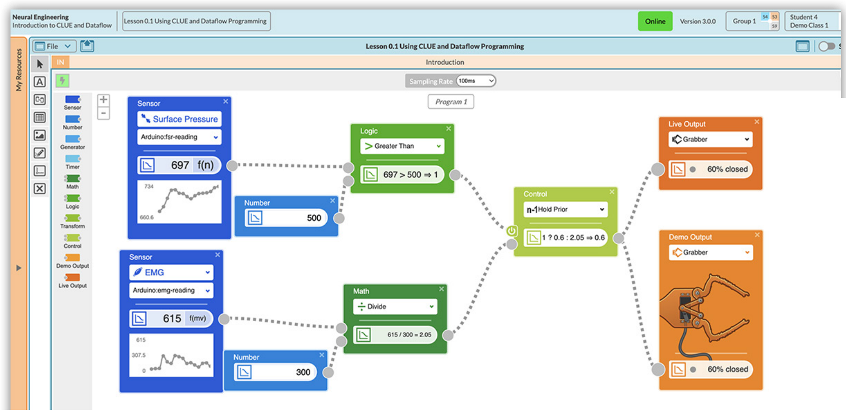


Figure 2. A Dataflow program to control the Grabber.

We updated Dataflow's existing Sensor block to take a measurement from an EMG sensor or surface pressure sensor connected to the Backyard Brains Muscle Spiker and bring it into Dataflow. We also added three new blocks. The Demo Output block takes a number created in Dataflow and animates a virtual version of the Grabber. The Live Output block passes a number from Dataflow to the physical device, which opens or closes to the percentage specified by the number calculated from the Logic and Math blocks. The Control block adds the ability to turn the flow of data on or off.

To make the Live Output and Sensor blocks work, we had to manage communication between the Arduino (the microprocessor that handles sensor input and controls Grabber motion) and Dataflow. For example, to get sensor data into Dataflow, first the Arduino program takes sensor readings and sends them to the serial output.

```
emgReading = analogRead(A0);
fsrReading = analogRead(A1);
emgStringOut = String(emgId + : + emgReading);
fsrStringOut = String(fsrId + : + fsrReading);

Serial.println(emgStringOut);
Serial.println(fsrStringOut);
```

Meanwhile, Dataflow takes the reading from the serial port and brings it into the program on a dedicated "channel" for each block.

```
if (targetChannel){
  targetChannel.value = parseInt(numValue, 10);
}
```

Figure 2 illustrates the use of all four blocks to approximate the cup of lemonade scenario. One Sensor block takes an EMG reading and sends it through some arithmetic blocks to create a value to close or open the Grabber, while another Sensor block keeps track of the pressure on the cup. If it's too high, the Control block prevents the close message from getting to the Output block.

Now that students can program a path of blocks to open a Grabber using their own brainwaves, we hope that Dataflow opens up additional new areas of neuroscience exploration.

LINKS

Dataflow repo
github.com/concord-consortium/collaborative-learning

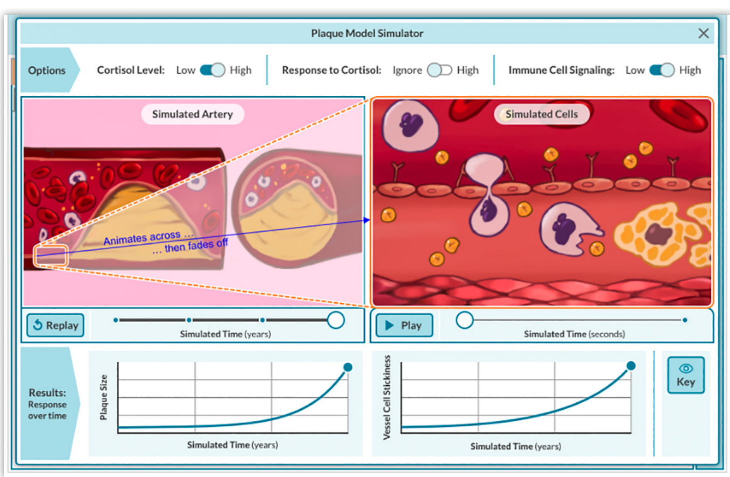
Teacher Innovator Interview:
Jessica Sudah

Middle school science teacher
New Brunswick, New Jersey

Jessica Sudah is a self-described introvert, but she says, "I found my voice in the classroom. I found myself in the classroom." When Jessica discovered that the goal of the Bio4Community curriculum was to honor student voices and experiences, she wanted to learn more. At the first curriculum design meeting, she witnessed seventh grade students talking to project researchers from Rutgers University, the University of North Carolina at Greensboro, and the Concord Consortium. She was hooked. "I loved that interaction. They always tell you to use student voice to change your curriculum. This was an actual, tangible way to see it backed by research."

Before becoming a teacher, Jessica studied microbiology and conducted research in neurology, so the Bio4Community curriculum on the biological and physiological mechanisms of stress appealed to her. The unit, co-designed by researchers, teachers, and students, aims to engage middle school students in an inquiry-based biology learning environment where they develop their ideas and decide what is relevant and what counts as "valid" knowledge. As part of the curriculum design team, Jessica describes learning to see different points of view and the importance of getting to common ground. The key, she says, is putting students first.

When she implemented the curriculum in her classroom last spring, she was thrilled with the connections she made with her students. Because she teaches grades six through eight, she felt that she already knew the seventh graders—"their personalities, their fears, their ideas"—but she credits the Bio4Community curriculum for deepening that relationship. "The first thing the curriculum did was to build connections," Jessica notes. From the outset, a storyboard allowed both Jessica and her students to share their life stories. According to Jessica, the relationships that resulted from that experience helped her learn about stress in her students' lives, both at school and at home—from deadlines for school assignments to the responsibility of caring for siblings. This led her to rethink her approach to homework.



As part of the curriculum, students drew models of the body under both short-term and chronic stress. Although Jessica led the class through the first model-building experience, her students took charge of the second session. They developed a consensus model of chronic stress, integrating all the body systems based on case studies they had examined in groups. "The kids were very involved and engaged in the science," she reflects. "They were excited and proud of their work." As was Jessica. When the principal visited the classroom and asked about the role of the brain in stress, one student described how the prefrontal cortex is responsible for focus and regulation and how stress affects neurological connections. Jessica recalls how the rest of her students "were surprised by their own classmate saying all these big words. It was a big deal. They all clapped!"

Jessica believes Bio4Community was successful because the curriculum was culturally responsive; she says the design team "knew the community, the stressful events, and some of the culture." But she admits that it's also a difficult curriculum because it brings up issues of social justice. For example, Bio4Community considers causes of stress, such as racial discrimination. "That's the more sensitive part of the curriculum," Jessica explains. "I wasn't sure how to deal with it myself at first and I realized the kids had the same feeling as me." But seeing both a community elder and another teacher modeling how to talk about such stresses in their lives helped open the door for students to express themselves.

For Jessica, it's all about incorporating students' voices into the curriculum. She wants her students to find their voices in the classroom, just as she has.

In the Bio4Community model simulator, students choose different levels of stress hormones and related body chemistry and observe short- and long-term changes in organs and cells.

The Concord Consortium

25 Love Lane, Concord, MA 01742

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

Mobile Design Studio

We're partnering with the University at Buffalo to enable students in grades 7-10 to collaboratively problem scope, generate, and evaluate engineering design ideas. Students explore environmental and Earth science problems that include science, engineering, and social/community factors, such as access to clean water and increasing biodiversity loss in local communities. We will transform our Collaborative Learning User Environment (CLUE) into a front-end design platform called the Mobile Design Studio (MODS). Students will work in small groups on front-end design challenges in MODS, exploring potential solutions by considering both stakeholders and context. An artificial intelligent design mentor will guide students through an exploration of ideas and "learn" from students' design processes to scaffold their ideation through a pedagogically framed creativity tool called Design Heuristics. We will examine students' perceptions of science and engineering, their ability to integrate academic and personal or community knowledge, their confidence for engaging in engineering, and their design thinking abilities.

Investigating Mathematics Learning in a Digital Environment Over Time

A new project with Michigan State University is developing and embedding learning analytics into digital notebooks to provide middle school students with information on their engagement and learning of mathematics and to support reflection on big mathematical ideas across an entire year. We will embed the seventh grade Connected Mathematics Project (CMP) curriculum into CLUE, which automatically logs every student action and sequence of events, then create learning analytics based on these log data. Just as students have access to fitness data on smartwatches and app usage on smartphones, they will be able to use a dashboard of analytics about their work in CLUE to consider questions such as: "Do I modify or build on the work of others? Do I use previous work to make sense of unfamiliar problems and mathematics?" Project research will explore the use of dashboard visualizations on collaborative engagement and mathematics learning.

Data Science Foundations with Mathematical Logic for Rural High School Students

Data science is revolutionizing science and industry. The current job market has shown a strong demand for a workforce fluent in data science. However, rural students are less likely to choose a STEM major and have far less access to advanced STEM courses taught by highly qualified teachers. We're partnering with Texas Tech University to develop a new curriculum for the Florida Virtual Schools to introduce high school students, including in rural communities, to data science concepts and careers. The novel LogicDataScience (LogicDS) curriculum will unify foundations of data science in computing, mathematics, and statistics through mathematical logic. Project research will study the impacts of the curriculum on students' learning of computing, mathematics, and statistics.

Developing Simulations with Noise to Investigate Students' Understanding in Experimental Physics

Understanding measurement uncertainty is critical for evaluating experimental data and conclusions made from those data, but studies show that students in introductory undergraduate physics lab classes do not attain these learning goals. To improve students' conceptual knowledge of and views about measurement uncertainty, we're working with the University of Colorado at Boulder to add sources of randomness (noise) to a selection of Physics Education Technology (PhET) interactive simulations of common introductory lab experiments. These noise-enhanced simulations will be integrated with CODAP so that students can study the effect of the noise and quantify the resulting uncertainty. We will study the impact of the use of this integrated platform on students' understanding of measurement uncertainty and how students view measurements in experimental science in a clinical setting and in the classrooms of diverse institutions. We will develop strategies and associated curricular materials for implementing this new platform in undergraduate lab courses to help students reason better about and make decisions with data in their future studies and careers.

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