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Perspective:

Technology Adds Depth to Three-Dimensional Learning

By Chad Dorsey

The Next Generation Science Standards (NGSS) and related "three-dimensional learning" approaches define a new paradigm in STEM teaching and learning that is refreshing, revolutionary, and research based. The science and engineering practices they espouse frame pedagogy in important new ways. However, shining the bright light of technology's potential on these practices reveals intriguing new possibilities—and uncovers a few glaring gaps.

As we implement three-dimensional learning, it is important to stay attuned to the many possibilities technology opens up. A close-up view of two of the NGSS science and engineering practices demonstrates how the introduction of technology's full potential can change their emphasis in subtle, but often critical ways.

Investigating investigations

When we imagine science education in action, the most common image that comes to mind is the science lab. The laboratory, we all know, is where students are supposed to experience real science. Pendulums swing, beakers bubble, students hunch over microscopes—the lab is where hands-on meets minds-on.

Well, maybe.

Despite what the posters in countless science labs might still have you believe, it's now widely accepted that the "scientific method" bears scant resemblance to the way true scientific discovery proceeds. As practicing scientists uncover new knowledge about our world, they do not consult checklists or follow a series of linear steps. The NGSS acknowledge this in several ways, most prominently by framing science as a set of related practices. "Planning and carrying out investigations" is one of these practices.

In many ways, the laboratory is the centerpiece of the scientific endeavor—science would be nothing without experiments. However, even the standards can be interpreted in ways that threaten to reduce this practice to the mere application of a generalized strategy, such as controlling variables. While this strategy is undeniably important, applying it too generally can create shallow experiences for learners, sidestepping opportunities to engage with the underlying conceptual model being investigated. Placing too heavy a focus on the generalized technique of controlling variables also risks mischaracterization and missed opportunity. Scientists in many major branches of science—geologists, field biologists, cosmologists—simply cannot run controlled experiments. Yet their techniques of comparative analysis hold just as much value and their contributions to science carry just as much import.

Our work in projects such as InquirySpace and InSPECT pushes these boundaries, redefining what technology-based investigation means for STEM learning. These projects integrate data collection directly into activities and house collected data within a data analysis tool, inviting learners to explore and examine continuously. They provide concrete representations of the data collection process, aiding learners' comprehension, and allow fine-grained command over automated data collection processes. They also provide programmable triggers, enabling learners to incorporate controlled external modules such as lights, pumps, and motors into their experiments. Equipped with these tools, learners can investigate otherwise inconceivable realms, and are empowered to ask new "What if?" questions.

Tools such as these also introduce meaningful personal agency to investigations, a subtle notion that can be stunning to observe in action. The first time a student lights up with an idea that might crack the question she's been working at all week, the moment when two disengaged students break into excited debate about what color of light to shine on their plant, the hour they then spend diving into their data to build, support, and refine original conjectures—moments of empowered learning such as these make technology's value starkly apparent. With new technology-based tools and approaches, our projects are forging novel ground, deepening student investigation across all STEM domains.

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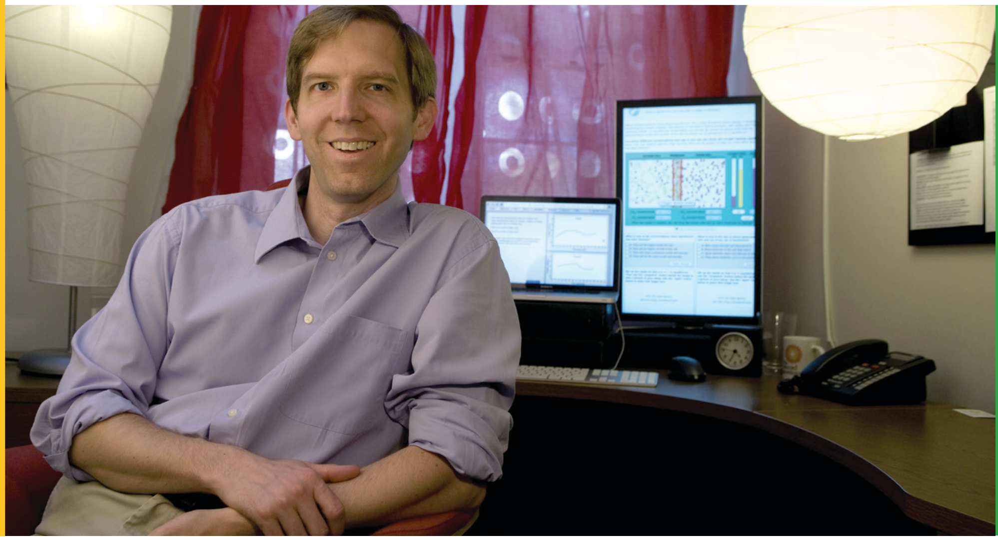

Analyzing analysis

Though all STEM practices are naturally interlinked, "analyzing and interpreting data" is perhaps one of the most intertwined of all. Practically all meaning-making in the science classroom centers on the analysis of data in one way or another. However, we need only look at the daily news to see the disconnect between "real" data and its classroom counterpart. News stories regularly tout the role of data in all corners of industry and everyday life, yet the real data they describe are entirely different from the over-simplified versions students encounter in a typical science class.

Real data are *messy*—multiple variables, heterogeneous data types, large datasets—and they harbor complex, multi-layered stories. Working with these messy datasets is a science in itself (so much so that it's called *data science*). But, despite the fact that it's practically impossible to imagine a major future occupation that won't touch on data science in some form, practically no place in our current STEM curricula builds these much-needed skills. STEM education must evolve to incorporate data science *education*.

The Concord Consortium has helped spearhead the field of data science education. A core aspect of this movement involves rethinking what's included in the practice of analyzing and interpreting data. *Data moves** are operations that re-structure, re-represent, and re-construct data in ways that help uncover hidden meaning. Though they represent core aspects of engaging with data, such moves need not be inherently complex—*filtering* a dataset to look at a subset and *reorganizing* a dataset to reflect inherent groupings are two key examples. However, they are rarely, if ever, emphasized in today's STEM learning.

Part of the reason is that it is nearly impossible to engage in activities resembling data science education in the absence of technology. Furthermore, the mere presence of technology alone is not sufficient in itself; many technologies allow students to enter data and create graphs, but provide no opportunity to engage in essential activities such as exploring a dataset or interacting with its structure. Data tools such as our Common Online Data Analysis Platform (CODAP) are designed from the ground up for *learning* about and with data. As such, they intentionally evoke exploration and deepen discovery, helping learners uncover new questions in the process of seeking answers. They highlight connections across different representations, permit learners to easily reorganize and filter data, and enable the rapid generation of multiple different graphs from a dataset. Through the design and application of such technology, we aim to enrich the practice of analyzing and interpreting data and bring data science education to learners worldwide.

The role of technology

These examples, viewed through the practices of "planning and carrying out investigations" and "analyzing and interpreting data," reflect the Concord Consortium's fundamental view of the world: technology used to its fullest extent can introduce critical new dimensions to STEM teaching and learning, deepening and expanding all science and engineering practices to reach topics or enable methods that might otherwise be unimaginable. At its core, technology makes *open exploration* possible across a huge diversity of STEM domains, whether the study of genetics or plate tectonics, the examination of individual chemical bonds, or the motion of everyday objects. Technology allows learners to explore concepts freely and broadly, pose their own questions, conduct original experiments, and make novel claims. At its most powerful, technology does what we all aim to do: bring students as close as possible to the process of truly *doing* science.

* See Tim Erickson's blog at https://bestcase.wordpress.com.

What Happens When Students Try to Work Collaboratively?

By Paul Horwitz

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The problem is deceptively simple. The simulation consists of a variable resistor and a voltmeter with which to measure the voltage drop across the resistor. The resistor forms part of a larger simulated circuit, connected in series to three other resistors and a battery. The battery sends the same current through all four resistors, resulting in a voltage drop across each. Ohm's Law states that those individual voltage drops can be calculated by multiplying each resistance by the current. The challenge for students: alter your resistance to achieve a specific goal voltage drop. Sounds simple, right?

To solve the problem, students click on their resistor, choose a new resistance from a drop-down list, check the voltage on the meter, then repeat until they get what they're looking for (Figure 1). But there's a catch. Those other resistors may not stay the same. Two of them are controlled by other electronics students, each of whom also has a goal voltage to attain and can alter his or her resistance to do so. The three must work as a team, each on their own computer and communicating only via a chat window. As described, their resistors are connected so that every time anyone changes their resistance, it affects the circuit as a whole and consequently changes the voltage drops of their teammates.

And what about the fourth resistance and the battery voltage? They cannot be altered by any member of the team, but they affect the behavior of the circuit. At early levels of the challenge, each team member is told the voltage and external resistance, while in later levels, they must compute them (Table 1). Each team member is provided with an online calculator and every calculation they perform, every circuit change, every measurement, and every chat message is monitored, logged, and analyzed by us.

Analyzing log data

The goal of the Teaching Teamwork project is to measure how effectively electronics students work in teams. We look for patterns in the data and try to answer questions, such as: do the team members collaborate or do they mostly work on their own? Are their actions coordinated or independent? Does a leader emerge to direct them? How does each member contribute to the ultimate success or failure of the team?

Take Team Birds, for example, three community college electronics students who attempted this challenge in March 2017. At Level A, we see from the log data that they succeed in achieving their goal voltage drops. Level A is the simplest: both the external voltage E and the external resistance R_0 are known to the team members and their goal voltage drops are the same and exactly one fourth of E, meaning that the goal voltage drops across all four resistors are exactly the same. Thus, if they're clever they can achieve their goal by simply setting all their resistors to be the same as R_0.

Team Birds makes a total of 28 resistor changes on the way to achieving its goals, and the team members chat with each other 24 times. They make no use of the online calculator. From this cursory analysis, it would appear that they are simply changing their resistors (perhaps at random) until they arrive at their collective goal. But these simple measures conceal a more complex process.

For one thing, those 28 resistor changes are not equally allocated across team members. Eagle made 20 resistor changes, Seagull made 7, and Hawk made only one change. That seems unusual, particularly when you realize that the problem is very tightly constrained: for each voltage drop to match its goal, its resistance must be set to one and only one value. Moreover, the first student to do this is not rewarded with instant success. His voltage drop is not yet at the goal since the other two members of the team still have their resistances set "wrong." In making only one change to the correct value, and then keeping it there, Hawk was either incredibly lucky or somehow knew what he was doing. What was going through his head?

We have only the log data to guide us. Hawk makes his momentous resistor change just over five minutes into the challenge. What does he know at that time? Everyone knows their own goal voltage drop, of course, and because this is Level A, everyone knows E and R_0. From the record of chats we see that by the time Hawk makes his resistor change he has told the others what his goal is, has asked them for theirs, and has received a reply from Seagull but not from Eagle. Nevertheless, even with incomplete information, Hawk appears to know what his resistor should be in order to achieve the goal. And sure enough, 40 seconds after setting his resistor, Hawk asks, "Eagle, is your goal voltage also 2 V?" Eagle replies, "Yes," and Hawk says, "So we all have equal voltages . . . so I think all of our resistors should be the same value as R_0."

Hawk has explicitly told the others what to do, but they ignore him and continue to make resistance changes intended to approach their goals, but—because they don't both arrive at their goal voltages at the same time—missing each time. Finally, Hawk again urges his teammates to match their resistances to R_0, and when, a minute later, Eagle finally does this, they achieve their goal.

At Level B the goal voltage drops for different students are all different, making the problem a bit harder, but Team Birds solves it in just over seven minutes. This time they make 23 resistor changes (again, only one by Hawk). They chat 14 times and make use of the online calculator 10 times.

Once again, Hawk seems to be the leader. He appears to know what his goal resistance should be, makes that one change, and then sticks with it, waiting for the others to catch up. Indeed, by analyzing his use of the online calculator, we can tell that he computes his goal resistance in a three-step process: he computes goalV_0 as E – goalV_1 – goalV_2 – goalV_3, then computes the goal current by dividing goalV_0 by R_0, and then finds his goal resistance by dividing his goal voltage by the goal current. This is basic Ohm's Law math.

Hawk changes his resistor and then communicates the goal current to the others. They ignore this information, however, and continue to change their resistors without knowledge of what each of their goals should be. This goes on for two minutes, after which Hawk reminds them, "Unless we all have our appropriate resistor value in, the correct voltage will not display, though. Just to keep that in mind." As it happens, he says this just

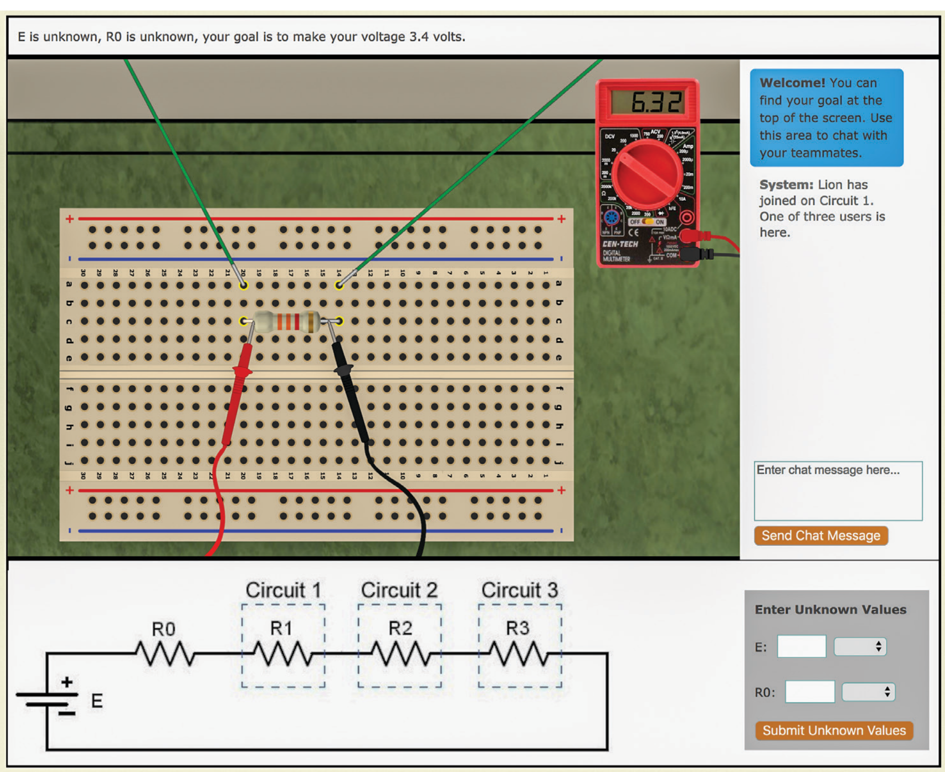


Figure 1. The three-resistor challenge (Level D), as seen by team member Lion on Circuit 1.

(continued on p. 6)

(continued from p.5)

as Eagle and Seagull converge to the correct resistance values—without actually calculating them. Then Hawk says, "Great job guys."

A picture is now emerging: Hawk knows how to solve the problem, but doesn't communicate that knowledge very effectively to his teammates, or perhaps he's trying to teach them how to solve the problem, rather than "spoon-feeding" them the answers. Does he see this as "cheating"?

Misconceptions emerge

By Level C, the Birds know the routine—they communicate their goal voltages within the first minute, a good first step and indicator that they have the shared information to solve the problem. Then, about one minute in, Eagle notices something: "It looks like the voltage will step down with each circuit." Let's be clear. For this case the (randomly chosen) goal voltage drops for R_1, R_2, and R_3 are, respectively, 4.11 V, 1.98 V, and 0.88 V. As Eagle points out, these happen to be in descending order. It's a total coincidence, but it fits into a well-known misconception: that as the current travels around the circuit, the voltage is "used up," so most of it ends up across the first resistor, leaving progressively less and less for the other two. There is no validity to this model, but it is pervasive among novice learners. In this case, it leads to disaster.

Eagle's "discovery" leads Hawk to comment, "Oh yeah, you're right. It halves down each time." Well, not exactly, because 1.98 is not half of 4.11, nor is 0.88 half of 1.98, but close enough for Hawk to continue, "Well, that should make this a little easier since there's a pattern." They've found a pattern where there isn't one and it will lead them astray for almost half an hour. After a few futile attempts at calculation, they fall back on a long, frustrating series of resistor changes interspersed with messages. At about 18 minutes, they achieve the goal—momentarily—but before they recognize and communicate that fact, one of them changes his resistor and they're off to the races again. They finally get back to the desired state almost 10 minutes later, but it is clear from the chats that they have no idea how they did it.

At Level C the team is also asked to find E, the external voltage, and here Hawk's expertise returns. He divides his voltage by his resistance to find the current, multiplies the current by R_0 (which is known to all the team members at this level) to find the voltage across the external resistance, adds that to the voltages across the other three resistances and voilà—the sum is E. The entire process takes less than half a minute!

Hawk is capable of using Ohm's Law in a relatively sophisticated strategy to find the external voltage. But having been led astray by a misleading pattern, all of his learning goes out the window when he tries to compute his goal resistance.

Finally, at Level D, the Birds are unable to attain the correct voltages at all. They try over and over with remarkable persistence, exchanging 98 chats and making 67 resistor changes (this time evenly distributed among the team members). Twenty-four minutes into the ordeal Hawk says, "Want to wrap this up?" Eagle replies, "Not yet. Let's keep trying! We can do this." Hawk, though, gives up on trying to get the right voltage and starts submitting various guesses for E, which he correctly surmises will be an integral value. After four tries, he guesses correctly. He then turns his attention to guessing R_0, but after eight incorrect guesses he gives up.

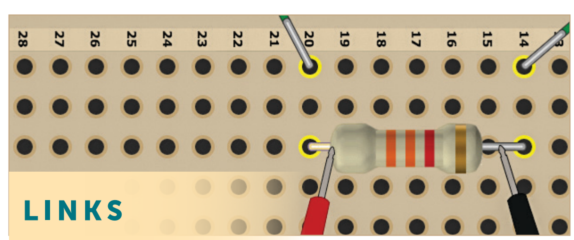
Human cognition and the challenge of automated scoring

Human cognition is complex. This case study emphasizes how students cannot usefully be characterized as "knowing" or "not knowing" something. Does Hawk (or Eagle or Seagull) "know" Ohm's Law? Clearly, context is everything. Team Birds is able to succeed at Level B in seven minutes, but struggles at Levels C and D where the voltage challenge is exactly the same. Hawk doesn't suddenly lose his knowledge of Ohm's Law at those levels, he just fails to apply it.

Imagine how difficult it would have been to automate the data analysis for this case. What would it take for a computer algorithm to detect the devastating and lasting effect of Hawk's fruitless pursuit of a perceived pattern in the data? How can such effects even be accounted for by an assessment methodology that scores item responses under the assumption that they are independent? Gleaning useful information from logs of student actions is more akin to analyzing video data than it is to scoring their answers on a test. For the time being at least, it is a task best left to humans.

Level	External Voltage	External Resistance	Goal Voltages
A	Known to team	Known to team	Same and equal to V_0
B	Known to team	Known to team	Different
C	To be found by team	Known to team	Different
D	To be found by team	To be found by team	Different

Table 1. The four levels of difficulty of the three-resistor challenge. All levels require that team members achieve the desired goal voltage drops across their respective resistors. In addition, at Level C they must measure or calculate the external voltage E; at Level D they must determine both E and R_0, the value of the external resistor.



Teaching Teamwork
https://concord.org/teaching-teamwork

Monday's Lesson:

Finding Median in R the Common Core Way

By Jie Chao

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Most data scientists regret that they didn't pick up R earlier. This top programming language offers data manipulation, graphics, simulations, and countless application packages. And it's free! The goal of our Computing with R for Mathematical Modeling (CodeR4MATH) project is to integrate R programming and computational thinking into high school math.

This sample activity demonstrates how programming in R can help strengthen students' math skills. Download R and RStudio, an integrated development environment for R, or create an account on STATS4STEM.org and use the web-based RStudio.

We'll use R to explore the concept of median, a measure of central tendency of a set of values. There is a built-in function `median()`, but it's a black box for students new to statistics. Instead, we're going to find median the Common Core way by emphasizing algorithmic thinking.

First, write down the steps to find the median of a given dataset. Now, find a partner to use your instructions on the following two datasets. If your partner gets stuck, modify your instructions.

DATASET 1: Kilowatt-hours of electricity used by a family in the past several months: 630, 580, 580, 600, 550, 630, 590, 590, 610

DATASET 2: Bowling scores for a group of friends: 110, 62, 80, 132, 126, 194, 95, 78

With so few data points, it's easy to find the median by hand, but what about datasets with a large number of values? Here's a dataset of yogurt prices:

2.09, 1.13, 1.69, 1.00, 2.00, 1.79, 2.09, 1.00, 1.00, 0.60, 1.00, 1.11, 1.79, 1.79, 1.79, 3.19, 1.69, 1.79, 1.99, 5.79, 3.69, 2.79, 2.79, 2.29, 0.59, 1.79, 1.99, 7.69, 1.19, 1.49, 4.49, 4.49, 4.09, 0.89, 0.89, 0.59, 1.99, 2.09, 1.79, 2.09, 2.09, 2.09, 3.99, 0.50, 1.00, 0.79, 1.00, 1.00, 1.59, 0.69, 0.69, 0.69, 0.69

R functions help you automate the steps.

Step 1. Use the `c()` function to combine all these values and store them in a vector (a sequence of data elements of the same type) called `yogurt_price`. Paste and run the following code in your R console:

```
yogurt_price = c(2.09, 1.13, 1.69,
1.00, 2.00, 1.79, 2.09, 1.00, 1.00,
0.60, 1.00, 1.11, 1.79, 1.79, 1.79, 3.19,
1.69, 1.79, 1.99, 5.79, 3.69, 2.79, 2.79,
2.29, 0.59, 1.79, 1.99, 7.69, 1.19, 1.49,
4.49, 4.49, 4.09, 0.89, 0.89, 0.59,
1.99, 2.09, 1.79, 2.09, 2.09, 2.09,
3.99, 0.50, 1.00, 0.79, 1.00, 1.00,
1.59, 0.69, 0.69, 0.69, 0.69)
```

Step 2. Use the `=` assignment operator to assign the dataset to a new vector `x`, so you can manipulate this copy without changing the original one. Type the following code in your R console:

```
x = yogurt_price
```

Step 3. Use the `sort()` function to sort the dataset, and then use the `=` assignment operator to overwrite vector `x` with the sorted data.

```
x = sort(x)
```

Step 4. Use the `length()` function to count the total number of values in the dataset and store it in a variable `n`.

```
n = length(x)
```

There are 53 yogurts. With an odd number of data points, the index of the median is (n+1)/2.

Step 5. Calculate the index `i` using arithmetic operators in R.

```
i = (n + 1) / 2
```

Step 6. Use the `[ ]` operator to select the median based on the index identified above.

```
x[i]
```

The median of the `yogurt_price` dataset is 1.79.

With R, students are encouraged to think computationally. The CodeR4MATH project is researching students' computational thinking and mathematical modeling competencies.

Note: View the online version of this article to find the median of an expanded dataset using R functions and operations.

LINKS

CodeR4MATH https://concord.org/computing-with-r

Online version of this article https://concord.org/2018-spring/mondays-lesson

R Project https://www.r-project.org

STATS4STEM http://www.stats4stem.org

RStudio https://www.rstudio.com

Paper Mechatronics:

A Case for Craft-based Engineering Education

By Sherry Hsi and Colin Dixon

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When artists select a medium with which to create their work, the medium is both the material and the tool used to express their idea. In improvisational dance, for example, the physical space, the dancer, and the dancer's movements together form the creative medium with which to design their performance. Malcolm McCullough argues in *Abstracting Craft* that computation, like traditional craft media, is a creative medium. Computation can be crafted and shaped by one's hands in a tangible way beyond typing into a computer keyboard.

Inspired by this notion of a computationally enabled medium, we are exploring a new learning medium that melds craft and computation. We use the term Paper Mechatronics to describe the integration of mechanical, computational, electronic, and artistic techniques with children's papercrafts. This emerging genre results from the blending of familiar craft materials with embedded sensors and computational elements. With Paper Mechatronics, children create objects that can be animated with light, motion, sounds, sensors, and cameras, using Arduinos and other microcontrollers. The goal is to engage children in creative design and engineering education.

Funded by the National Science Foundation, Paper Mechatronics aims to provide an extensible approach and kit that incorporates both "high" and "low" technological elements, along with learning resources that can meet the needs of novice designers and appeal to the interests and abilities of a wide range of learners. The design marries the inherent approachability and flexibility of everyday materials with graduated pathways into mechanical and computational complexity.

Simple craft materials—construction paper and scissors—provide familiar starting points for learners young and old. These materials can then be progressively augmented and enriched with a variety of "smart" computational and electronic elements. For example, a learner can cut paper or cardstock, use conductive tape to fasten an electric circuit to a motor and switch, then attach a small programmable chip to tell the motor to make the paper "come alive" (Figure 1). Paper Mechatronics is intended to span disciplines to allow learners to generate their own narratives about their work and themselves. Through tinkering with tools and materials, learners develop skills in designing, planning, and problem solving.

The process of creating objects with this medium, scaffolded by powerful but low-threshold design software, provides accessible entry points into engaging, personalized projects that place learners at the center of an engineering design process that deepens over time. Our research posits that the intentional design of inclusive pathways using Paper Mechatronics can support the development of adaptive expertise and provide inviting on-ramps to engineering practices and pursuits.

Rationale for paper and cardboard

Paper Mechatronics builds on a tradition of creative and expressive papercrafts. For well over a century, papercrafts have been a staple of children's constructive work with origins as early as the first century AD in

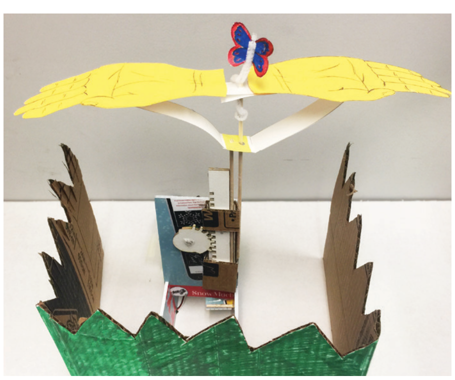


Figure 1. Sample project designed with mechanical movements using various papers and crafting methods.

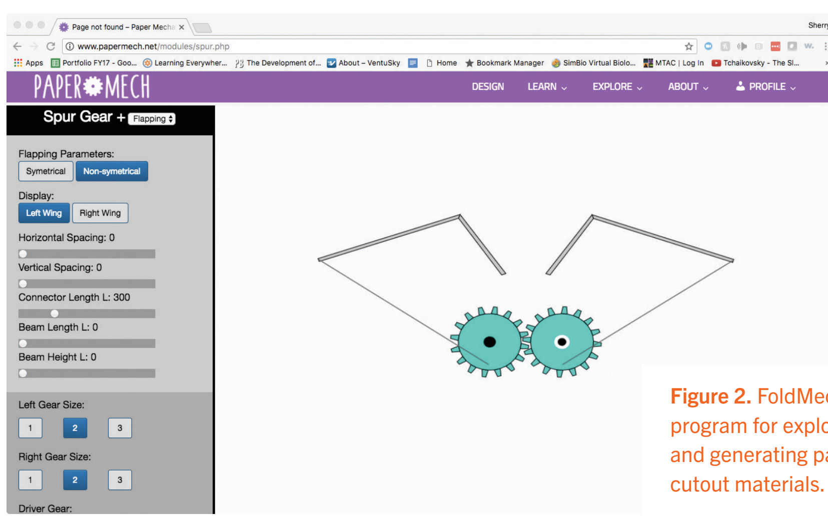


Figure 2. FoldMecha software program for exploring motions and generating papercraft cutout materials.

China and later Japan with paper folding and paper cutting. In the early 1800s, Friedrich Froebel included paper folding and cutting activities in his development of the kindergarten system; and even before Froebel, in the late 1700s, some children's books included flaps or cut-out pieces. In the last half-century this genre of work has blossomed in a variety of directions and educational domains.

Paper and cardboard are ubiquitous materials that can be cut, shaped, painted, and decorated. This craftability allows learners to use everyday materials to express an idea or tell a story, then build a tangible model of that idea. With the addition of robotic components, the model becomes interactive and animated.

One pathway for creating a Paper Mechatronics project begins with a web-based parametric design software tool called FoldMecha.* With this software, learners experiment with different motions and change sizes and relative lengths of various mechanisms (Figure 2). FoldMecha then generates a PDF blueprint ready for cutting. Younger learners who have difficulty handling tools can use plastic cutting knives and pre-cut gears. Small electronic pieces can be replaced with larger versions or with commercially available controllers and motors.

Paper Mechatronics aims to not only engage learners in constructing and assembling activities invented by others, but to use a design project as a context for teaching and learning the underlying principles involved in mechanical movements, coding, and electronics. Creative engineering can be supported by foregrounding or hiding aspects of the design and construction process from children. Instructors can choose to focus on aspects such as mechanical design, robotics and programming with sensor control and feedback loops, breadboarding electronics, artistic expression, or creative exploration.

Promoting equity

Though computational tools have become increasingly ubiquitous in both daily life and education, differences in where and how these tools are used persist. For example, while access is growing among groups of students, more affluent students are given greater opportunities to use high-tech tools more expressively and creatively, and STEM learning in schools remains disconnected from the interests and concerns of large numbers of students. Young women and students of color remain underrepresented in STEM fields in higher education and careers.

The high-low mix supported by Paper Mechatronics has the potential to address some of the factors that have contributed to these disparities. Paper Mechatronics can support a wide range of learners as they move from intuition, experience, and curiosity into disciplinary technologies and practices. The design projects appeal to all genders with an extraordinary variety of interests and backgrounds. In particular, three features foster more equitable learning:

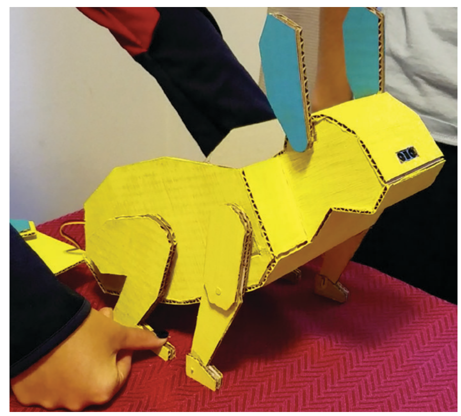
Materials are low cost and readily available. Barriers to using Paper Mechatronics in creative and personal ways are low: educators and youth do not need expensive equipment or specialized expertise to begin designing and building. This accessible entry allows learners to capitalize on what they already know and have at hand.

Tools are highly flexible. The tools straddle art studio and engineering lab and scale from playful experimentation to an in-depth exploration of computation and mechanical design. Combining paper with new computational media helps demystify blackboxed devices, provides an entrée into tinkering with tools and seeing how things work, and allows young people to build objects and stories that are creative and personal.

Artifacts are easily sharable. Learners' creations can be shared across settings and backgrounds, giving them a chance to display their products and growing expertise to parents, mentors, and peers, regardless of technological fluency or access.

In collaboration with the University of Colorado Boulder's Craft Technology Lab and the Children's Creativity Museum in San Francisco, we have begun designing a set of computational tools, learning resources, and materials, and testing them with youth, teachers, and adults with a range of backgrounds in design (Figure 3). Capturing a spirit of play and tinkering, our workshops engaged learners who had no previous experience in mechanics and electronics. The activities allowed learners to build passionate and personal stories from their own strengths and interests.

* FoldMecha was designed by HyunJoo Oh, a Ph.D. candidate at the University of Colorado Boulder.



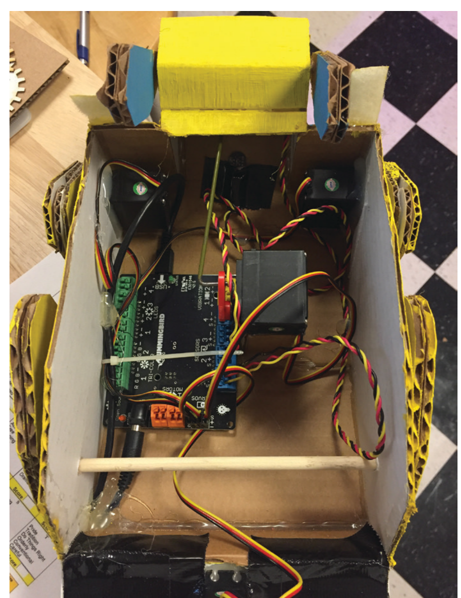


Figure 3. A responsive hare that stands up when a hand moves close to its nose, created with hand-cut cardboard and components from a Hummingbird Robotics Kit provided by Tom Lauwers, founder of BirdBrain Technologies and advisor on the project.

LINKS

Paper Mechatronics
https://concord.org/paper-mechatronics

Developing Watershed Stewards

By Nanette Dietrich, Steve Kerlin, and Carolyn Staudt

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Everyone lives in a watershed, which makes us all watershed stewards. The Teaching Environmental Sustainability: Model My Watershed project—a collaboration funded by the National Science Foundation between the Concord Consortium, Millersville University, and Stroud Water Research Center—has developed a weeklong curriculum unit to help high school students understand the impact of human actions on the watershed. The curriculum incorporates innovative technologies that provide students with access to real data and real tools in actual places to make authentic decisions.

Students explore and evaluate local watershed conditions using probeware, simulations, and a scientifically valid online watershed modeling application. They simulate runoff from a storm event, collect data from their schoolyard, analyze local data from national databases, and model changes in land cover and conservation practices. Finally, they create scenarios to improve their local watersheds.

Probes and simulations for student learning

Using the animated Runoff Simulation, students learn how different types of land cover and hydrologic soils influence the distribution of evapotranspiration, runoff, and infiltration amounts after a 24-hour storm event. Students can see the effect of changes they make to variables in the model for different precipitation levels, 12 choices of land cover (from highly developed to wetlands, grassland, crops, and more), and four types of soil (Figure 1).

Students also collect data using low-cost environmental monitoring devices from Texas Instruments called SensorTags, which act as watershed trackers on their smartphones or mobile devices. With these Bluetooth-enabled devices, students collect relative humidity, temperature, and light measurements in different areas, and upload their sensor data to the Innovative Technology in Science Inquiry (ITSI) portal, where the data can be viewed in graphical form, saved in snapshots, and shared with other students and teachers.

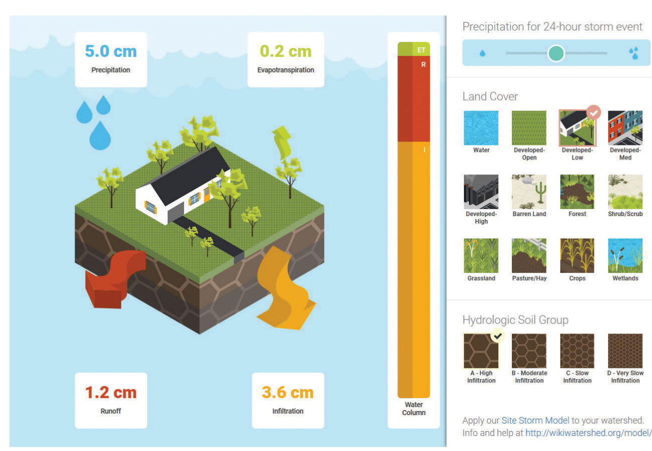
For example, to examine the ways in which vegetation and land cover affect the water that evaporates or is taken up by the plants, students might compare an area with one conservation practice such as a rain garden with another area such as a grassy playground without a planned conservation practice. This helps them identify the evapotranspiration from areas where runoff would be greater. Students use small stakes or markers to identify the four corners and center of two nine-square-meter study sites. At each site's five marked locations, students hang or tape a SensorTag on a stick one meter above the ground. They then enter the resulting data into the ITSI portal, and an average reading is calculated for each study site for temperature, relative humidity, and light (Figure 2).

After the sensor data is collected, students compare their study sites' data and discuss how sites that are porous and have high infiltration rates are different from those that are impervious and have high runoff rates. The sites with a large amount of vegetation will have high infiltration and evapotranspiration rates.

In the final activity of the curriculum unit, students use a scientific modeling tool called Model My Watershed (MMW) to create scenarios for improving their local watershed. MMW is a watershed-modeling web geographic information systems (GIS) app that includes USGS, USDA, and other scientific datasets for watershed modeling across the entire lower 48 states.

It enables citizens, conservation practitioners, municipal decision-makers, educators, and students to analyze real land use, soil, and additional data in their neighborhoods and watersheds; model stormwater runoff and water quality impacts using professional-grade models; and compare how different conservation or development scenarios could impact runoff and water quality.

Figure 1. Runoff Simulation.



STUDY SITE #1: Conservation Practice in Place

Location	Temp. (°C)	Relative Humidity (%)	Light (lux)
Corner 1	20	65	30
Corner 2	21	60	25
Corner 3	20	60	30
Corner 4	19	70	25
Center	20	65	25
Average	20	64	27

STUDY SITE #2: Conservation Practice Needed

Location	Temp. (°C)	Relative Humidity (%)	Light (lux)
Corner 1	25	30	85
Corner 2	25	35	80
Corner 3	30	40	75
Corner 4	27	35	80
Center	30	30	80
Average	27.4	34	80

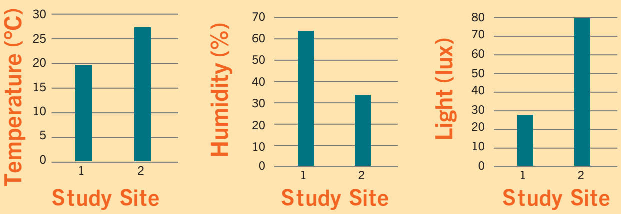


Figure 2. Sample data from the SensorTag while students are investigating around their school.

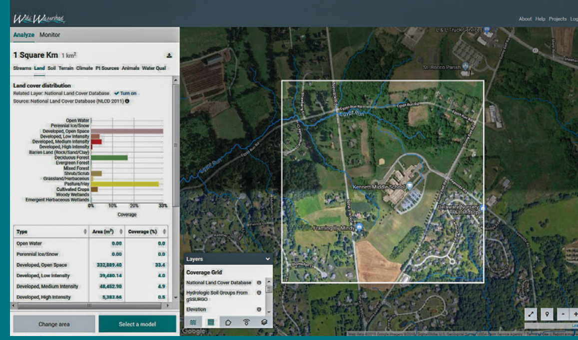


Figure 3. Model My Watershed allows students to select an area of study and analyze watershed data for that site.

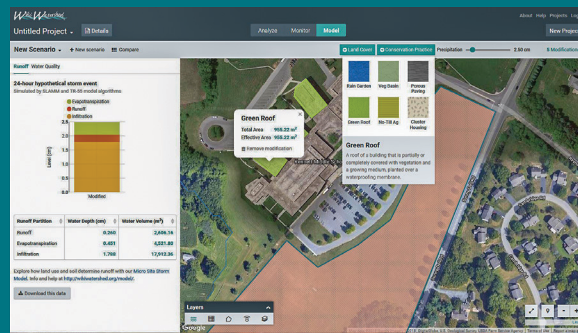


Figure 4. Students create scenarios in Model My Watershed to model changes in land cover types and conservation practices.

Using MMW, students select an area of study and analyze watershed data for that site. By running the site storm model of a 24-hour storm event, they can view the runoff and water quality results under current conditions (Figure 3). Next, students create scenarios to model changes in land cover types and conservation practices using the same 12 land cover choices in the Runoff Simulation, along with six conservation practice choices. Students can view multiple scenarios side-by-side to compare results (Figure 4).

Making activities relevant to local contexts

The curriculum unit was designed for students to learn systems thinking and geospatial analysis skills in the context of place-based watershed science problem solving. It includes five activities that can be easily customized in the ITSI portal. Teachers can modify activities and tailor them to their instructional objectives, student abilities and prior knowledge, and school context. For instance, teachers can include a discussion or activity to introduce their students to foundational understandings of watershed concepts. An extensive teacher's guide includes vocabulary for the unit.

Authentic data motivates students to take action

The barrier between students' conceptual understanding of watershed content and their real-world actions can be bridged by providing students with access to scientific tools and authentic data to make informed decisions about their local watershed. Focusing on the students' "home turf" provides context and relevance that enhances engagement and promotes meaningful learning.

Our research with 37 teachers and 1,546 students in 7 states shows that MMW students made statistically significant gains in their knowledge of actions that can improve the health of their watersheds. Many students identified actions that can positively impact their watershed such as installing a rain barrel, creating a backyard habitat, and taking care of a stream.

My neighborhood and I can build a rain garden at the end of our street and the street is slanted so all the run off water runs down there then into the river. If we put a rain garden there we can stop all the trash that the water picks up on the way down to the river and we would have a healthy watershed if everyone helps out. ~ Grade 7, Colorado

We can implement porous paving in various areas in my neighborhood to reduce the amount of run off water. Right now a lot of water goes straight into the streets and is being wasted when we could be using porous pavings or rain gardens to reduce that amount. ~ Grade 7, Colorado

I am really interested in adding a rain garden or vegetated infiltration basin to my house. It would be helping my watershed by cleaning and allowing the runoff (that possibly carries pollution) to get infiltrated into the ground. ~ Grade 12, California

The Teaching Environmental Sustainability: Model My Watershed curriculum helps students take on the critical roles of responsible citizens and watershed stewards.

LINKS

Teaching Environmental Sustainability: Model My Watershed
https://concord.org/tes-mmw

Runoff Simulation https://runoff.app.wikiwatershed.org

Model My Watershed https://app.wikiwatershed.org

ITSI
https://itsi.portal.concord.org/itsi#high-school-environmental-science

Connecting Genetics and Evolution with 3D Learning

Frieda Reichsman
(freichsman@concord.org)
is a senior research scientist.

By Frieda Reichsman

Allele, gene, heterozygous, phenotype, polygenic trait, recessive, dominant . . . The list of terms—and facts that go with them—goes on and on. Much of traditional biology has been taught and learned as a giant vocabulary lesson along with a history of discoveries to be memorized. And as scientific research progresses, more discoveries and vocabulary are added. Is it any wonder that biology textbooks have expanded to over 1,000 pages? In this formulation, biology lessons come to resemble a lifeless catalog more than a science brimming with scenarios for investigation.

The Connected Biology project, a collaboration funded by the National Science Foundation between Michigan State University (MSU) and the Concord Consortium, is developing a technology-enhanced curriculum aligned to Next Generation Science Standards (NGSS) designed to teach high school biology as a coherent set of interlinked and powerful reasoning scenarios. Our goal is to help students explore biological mechanisms, as opposed to memorizing facts and terms coined from past discoveries.

An understanding of biological mechanisms is fundamental to being able to reason about biological phenomena. For example, consider the mechanism underlying the influence of genes on traits. Genes are molecular-level instructions for building large, complex molecules (proteins and RNA) that play an important role in cells. Cells carry out specific functions based on the proteins produced by a subset of the organism's genome. Depending on the information encoded in the genetic instructions, those complex molecules may function well, poorly, not at all, or simply differently. Over eons of time, these ongoing, varied results produce the myriad life forms on our planet. The underlying mechanisms are key in being able to reason about important topics—from the diversity of life to addressing genetic diseases to meeting ecological challenges.

Such mechanisms play out in and across every level of biology from molecules to populations. In fact, many subfields of biology were originally defined by different levels of scale: microbiology, genetics, molecular biology, behavioral biology, ecology, population biology, phylogenetics, and more. The cause and effect relationships throughout these levels have great explanatory power and form a framework for thinking and reasoning about biology that has led to a blending of these subfields. This same framework can be used in the classroom so that students, too, can experience biology as a coherent field rather than a set of topics investigated in isolation.

Integrative cases

A series of "Evo-Ed" cases, developed originally at MSU for undergraduate-level teaching, provide compelling real-world examples of how genetic and evolutionary processes are interlinked. Six different phenomena—from lactose metabolism in humans to toxin resistance in clams, to variations in mouse fur color, and more—were chosen based on the research that has illuminated the phenomena across levels. We understand the mechanism at each level of these cases, which trace the emergence of new phenotypes from their origination in a DNA mutation to the production of different proteins to the effects on cells and finally to the development of stable, alternate macroscopic traits in reproductively isolated populations.

Using these cases, the Connected Biology project is currently developing a Multi-level Model (MLM) to help high school students connect both visible and invisible events into a causative chain across levels—with the ability to "zoom" in and out of the population, organism, cell, and molecular levels. Students start with an observable phenomenon such as an organism's trait at the visible level and view the trait alongside the "next level down," a representative cell that produces the trait or a central aspect of the trait. They can also view one level up to see how different versions of the trait affect a population of individuals, or how a changing environment can influence the expression of a trait.

In the case of the beach mouse, for instance, students explore the multiple, linked levels underlying the phenomenon of differing fur colors (Figure 1), and are

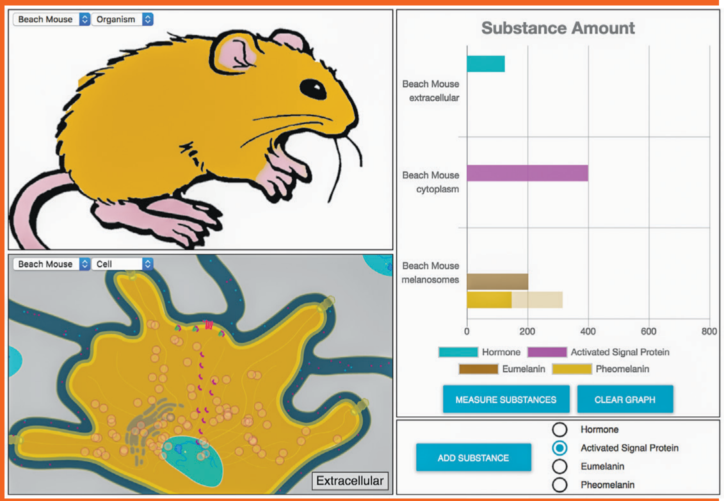


Figure 1.
Multi-level Model view of the beach mouse showing both the organism level (top left) and the cell level (bottom left). Students experiment by adding four substances (right) to different areas in the cell. The effects they produce in the cell are shown at the same time on the mouse. In this snapshot of the model, an added substance has resulted in a temporary darkening of the beach mouse's cell and fur color.

Alignment to Next Generation Science Standards for the beach mouse case

- **HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
- **HS-LS3-1.** Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
- **HS-LS3-2.** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
    - LP 1. Investigate the MLM to identify how changes at the cell level determine phenotype.
    - LP 2. Create a model showing how changes within an interacting system (hormone, transmembrane receptor, g-protein, eumelanin) can result in changes in the phenotype.
    - LP 3. Explore and explain a model of receptor/ligand interaction and how this interaction affects cell function.
    - LP 4. Identify the gene involved in coat color variation in beach mice and defend your claim.
    - LP 5. Determine whether a specific change in a nucleotide will change the coding instructions for a particular protein and predict the phenotypic outcome.

Table 1.
Three Performance Expectations (PEs) selected for the unit on cell and molecular biology of mouse fur color form a "bundle" that the Connected Biology lessons work toward. Learning Performances (LPs) are created by the project team to assess student progress toward the disciplinary core ideas, practices, and crosscutting concepts as expressed in the bundle of PEs.

challenged to deduce the events that produce variation in fur color. Fur colors of several beach mouse subspecies in the southeastern United States range from light to very dark and are correlated with the color of each subspecies' environs. At the cell level, students discover that the fur-producing cells make two different shades of the pigment melanin and that various substances can affect the balance between them. Looking at the molecular level, they find that in the mice with light fur, the signal to make dark melanin is not received by the fur-making cells, due to a non-functional protein receptor. Comparing the gene for the receptor in the two types of mice, they find a mutation that changes the protein so that it no longer transmits the signal in the light-colored mice. As we follow the fur color differences into the population level of the MLM, students explore the dependence of fur color variation on genetic inheritance of the mutation, and examine how over long periods of time, predation leads to the separation of subspecies via natural selection.

The integrative approach of this case enables students and teachers to focus on one phenomenon via the mechanisms that produce it across multiple, linked levels. In addition to the NGSS disciplinary core ideas and performance expectations outlined in Table 1, students engage in the practices of analyzing and interpreting data and constructing scientific explanations in the context of the crosscutting concepts of patterns and cause and effect. The MLM's computer-based simulations make invisible events accessible and explorable, and allow students to view or control a phenomenon at one level and observe the outcome on another level, in order to integrate understanding across levels.

Research

We are exploring how materials designed to support three-dimensional learning can promote growing complexity in student understanding of the linked ideas of evolution, traits, and their underlying molecular mechanisms. Our research hypothesis is that multiple representations of phenomena will help students connect observable phenomena to both causative and resulting events occurring on widely varying scales—from sub-microscopic to population level—and help them develop an understanding of the scientific concepts underlying each phenomenon.

We hope that delving into the chains of causation across multiple real-world phenomena explored through interesting cases will increase students' familiarity with each level of the chain of events, and that as they reason their way through these mechanisms, they will learn to recognize the interlinked levels at work in all of biology.

LINKS

Evo-Ed
http://www.evo-ed.org

Connected Biology
http://connectedbio.org

Under the Hood:

Localizations with POEditor

By Kirk Swenson

Kirk Swenson
(kswenson@concord.org)
is a senior software engineer.

At the Concord Consortium our goal is to increase the impact of our work so that more students in more places can engage in STEM inquiry. One way to do that is to translate our free STEM models and activities into different languages, an adaptation that's called localization.

Years ago, I helped localize Fathom, our desktop application for data analysis and statistics. At that time the localization process involved emailing files of English strings to our translation partners and receiving files of translated strings in return, which were then manually merged back into the code base. As development proceeded, new English strings were added and existing strings were changed, which meant additional email exchanges. It was a time-consuming and error-prone process. Invariably, some localizations would become outdated. Managing the process was a significant amount of work.

Since then, a number of online translation services have significantly simplified the localization process, allowing users to import English strings files, manage the process online, and download the translated strings files to incorporate back into the code base. We chose POEditor for its features and UI, as well as its generous support of open-source software like those we develop.

With POEditor, each collection of strings is represented by a project. Translators are added to the project and POEditor manages email communications with translators and developers. The site tracks the translation progress and notifies translators when new strings are added or existing strings are changed.

To make use of POEditor, we started with three Concord Consortium projects—SageModeler, CODAP (Common Online Data Analysis Platform), and the Cloud File Manager. First, we converted each project's strings file from CoffeeScript/JavaScript to JSON. Then, we wrote a few short scripts to simplify the process of automating the upload/download of strings files using POEditor's web APIs. At this point, we ran into an issue with POEditor's handling of Unicode escape characters. We use Unicode escapes to represent Unicode characters in ASCII source code files, e.g., `\u2212`, the Unicode MINUS SIGN. On upload, POEditor automatically converts these to the Unicode character. Since JSON files and JavaScript both support Unicode characters, this generally isn't a problem, but there are some cases where the Unicode escape character is preferable in source code.

Furthermore, sometimes the correct translation for a particular string is the empty string—when that string isn't needed for a specific localization, for example.

If a translated string is left blank, POEditor assumes that it just hasn't been translated yet, and flags it as incomplete. Thus, we need a way to represent a string that is *effectively* empty, but not *actually* empty, for which the Unicode character `\u200b`, the ZERO WIDTH SPACE, is ideally suited. Since POEditor doesn't maintain Unicode escapes, we adopted the convention that `[u200b]` represents a Unicode escape character, and then modified our scripts to convert them to their canonical form on download. The resulting bash scripts use the `curl` utility to upload/download the strings files and the `sed` utility to convert the Unicode escapes.

In our software development, developers modify the English strings file. Whenever the file is changed, a script is run that uploads the strings to POEditor, which flags strings that have been added or changed in each translation and notifies the appropriate translators automatically. When translators have made the corresponding changes, a script is run that downloads the translated strings files where they can be built into the application. In short, POEditor allows us to automate much of the localization process so that developers can focus on developing and translators on translating.

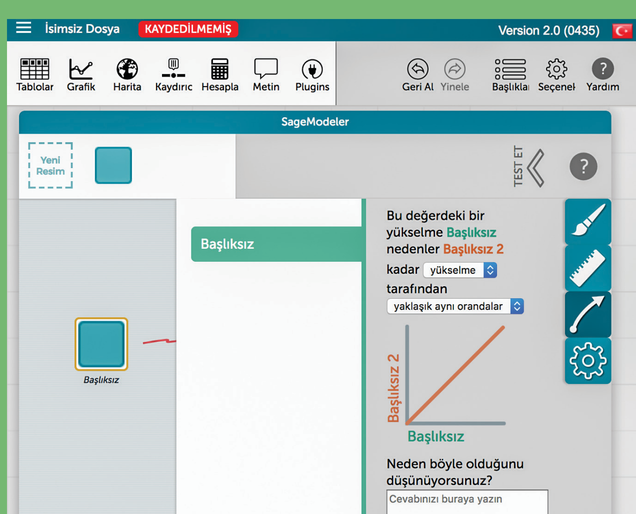


Figure 1. SageModeler systems modeling tool translated into Turkish. Users can switch languages using the flag icon in the upper right.

LINKS

Fathom
https://fathom.concord.org

SageModeler
https://learn.concord.org/building-models

CODAP
https://codap.concord.org

POEditor
https://poeditor.com

Innovator Interview:

Hee-Sun Lee
hlee@concord.org

"The Korean curriculum at that time.... There was nothing about creating experiments, none of the inquiry stuff the Concord Consortium is doing."

Hee-Sun's interest in science blossomed early, when she was only six years old, while watching an animated movie about robots saving the Earth. She became fascinated by space—by how small she was when she looked up to the sky—and in middle school she decided she wanted to work for NASA. Since she excelled in science, she thought to herself, "Think big!"

With the support of her parents, Hee-Sun graduated from Seoul National University in 1990 and taught science in middle school. In 1992, she was accepted to a Ph.D. program in physics at the University of Michigan. In Korea, she had memorized facts and provided answers to predetermined problems, even in college. "The Korean curriculum at that time—that's the way students were evaluated in science. There was nothing about creating experiments, none of the inquiry stuff the Concord Consortium is doing," she explains.

So Michigan was a jolt. When her thesis advisor in physics asked what she wanted to investigate, she thought, "What kind of question is that? Why do you want me to come up with my own question?" Ultimately, they both agreed that Ph.D. training was not for her, and she received a master's degree. She laughs about it now, but at the time, she wondered if that was the end of her education.

While reflecting on why a Ph.D. in physics hadn't worked out, she applied to the science education Ph.D. program at Michigan, and decided to do the opposite of her first advanced degree in physics. "I started talking even though my English wasn't that good, I actively asked questions even though they were not well formulated, and I volunteered for research work even though I didn't know how," she says. This turned out to be a critical moment in her path to a career in educational research.

Inspired to figure out how learning works, she saw everything from the perspective of her experience—cultural issues, science education, technology, problem solving. "I cannot blame myself that it didn't work out the way I intended in physics. It's not because of me failing. There were systemic issues, curriculum issues, and social-cultural problems."

Hee-Sun credits Dr. Nancy Songer currently at Drexel University, Dr. Marcia Linn at the University of California, Berkeley, and the late Dr. Robert Tinker at the Concord Consortium with giving her the opportunity to do research and wait for an idea to blossom. It paid off. Hee-Sun's postdoctoral research described knowledge integration—the idea that learners explain a particular phenomenon using and connecting knowledge pieces. After reviewing thousands of student responses, looking for knowledge units is now a habit for her.

At the Concord Consortium, Hee-Sun's insights influenced principal investigator Amy Pallant's High-Adventure Science project. The project brings frontier Earth and environmental science into the classroom, where uncertainty is part of the curriculum because the answers to questions scientists are currently studying are unknown.

High-Adventure Science students wrestle with uncertainty as they use computational models and explore real-world data. But the work is not about students doubting themselves; it's about making a transition from personal knowledge to thinking scientifically. And students are showing gains in pre-post measures. New research with automated scoring and feedback has increased the gains threefold. "We are not done yet!" Hee-Sun says, "The most difficult part of uncertainty is thinking about the limitations of the materials students are working with and how that limits the strength of the evidence and claim."

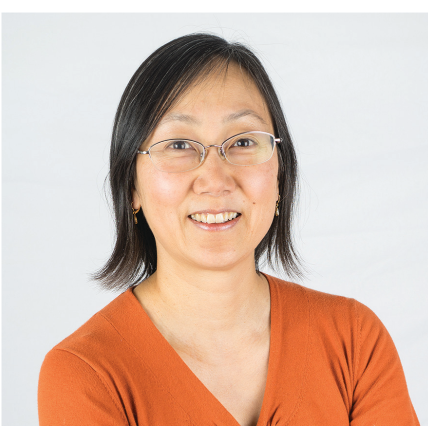
Hee-Sun is thinking about how to pursue the idea of uncertainty in the InquirySpace project where students engage in real-world investigations, and encounter uncertainty as they collect data and try to generalize to broader systems. Hee-Sun's original idea continues to bring excitement to her research.

The Concord Consortium
25 Love Lane, Concord, MA 01742

Sherry Hsi, New Executive Vice President

As a graduate student at UC Berkeley in 1996, Sherry Hsi accompanied Professor Marcia Linn to a learning technology center planning meeting at SRI International where she met Robert (Bob) Tinker, creator of the same probeware Marcia was using in her Apple computer-enabled research classroom and founder of the then two-year-old Concord Consortium. This would prove to be a decisive moment in Sherry's career path.

At the time, probeware was controversial. Many teachers believed that plotting points by hand and labeling graphs on paper was necessary to do meaningful science, rather than letting the computer plot points so students could focus on understanding data trends. Bob Tinker was ahead of his time, and Sherry was hooked by his enthusiasm and innovative ideas. She joined the Concord Consortium in 1997 as a virtual postdoc, doing research on mobile learning and teaching with the Virtual High School.



She went on to build collaborative knowledge communities at several nonprofits, develop ways to support deeper engagement in science with technology and new media at the Exploratorium, and create open-access STEAM digital libraries and high-low tech materials for engineering education at the Lawrence Hall of Science. In 2016, she returned to the Concord Consortium to lead three Innovation Lab projects: InSPECT, Learning Everywhere, and Paper Mechatronics.

Sherry was recently appointed Executive Vice President of the Concord Consortium. She says, "I am excited about accelerating our research and impact on technology-enabled inquiry learning and teaching. Our goal is to ensure teachers are empowered to use technology effectively to support content-rich STEM inquiry, foster collaborative problem solving, and engage in critical sense-making."

Inventing New Tools for Tomorrow's Students

Bob Tinker was enlightened by a vision of the future, blazing the trail to a transformative era in education. At the Concord Consortium, we continue to experiment with novel ideas, using new technologies to support classroom inquiry in STEM, and research the effects on learning. We draw from the future as we invent new tools for tomorrow's learners.

This spring, we are convening a group of thought leaders in a two-day summit to envision learning of the future, and then map the steps needed for this vision to become reality. Led by the Concord Consortium and co-hosted by Dynamicland with generous support from the Gordon and Betty Moore Foundation, Designing 2030 represents a diverse, future-looking community, poised to take full advantage of current convergences in educational technology.

We will consider the growing maturity of open technology resources for STEM learning, notable advances in learning sciences research, new possibilities arising from the streams of data generated as learners interact with educational technology, and the growing potential of learning analytics and data mining to shed new light on teaching and learning. We'll honor Bob's legacy by dreaming big and exploring what learning and teaching should look like in 2030. How can technology transform the way we teach and learn science and broaden participation by more learners?

Robert F. Tinker Scholarship and Fellows Program

At the AERA 2018 joint SIG business meeting of Learning Sciences and Advanced Technologies for Learning, we were delighted to announce the Robert F. Tinker Scholarship for emerging scholars. The scholarship will be awarded annually to a graduate student or postdoc who is a member of the Learning Sciences and/or Advanced Technologies for Learning SIG and has an accepted presentation at AERA with research in one of the following themes: tools for inquiry, learning and collaboration, data explorations, sustainability and the environment, tinkering with models, playful experimentation, online learning, or learning everywhere. We are also creating a Robert F. Tinker Fellows Program at the Concord Consortium. Look for additional details on our website soon.

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