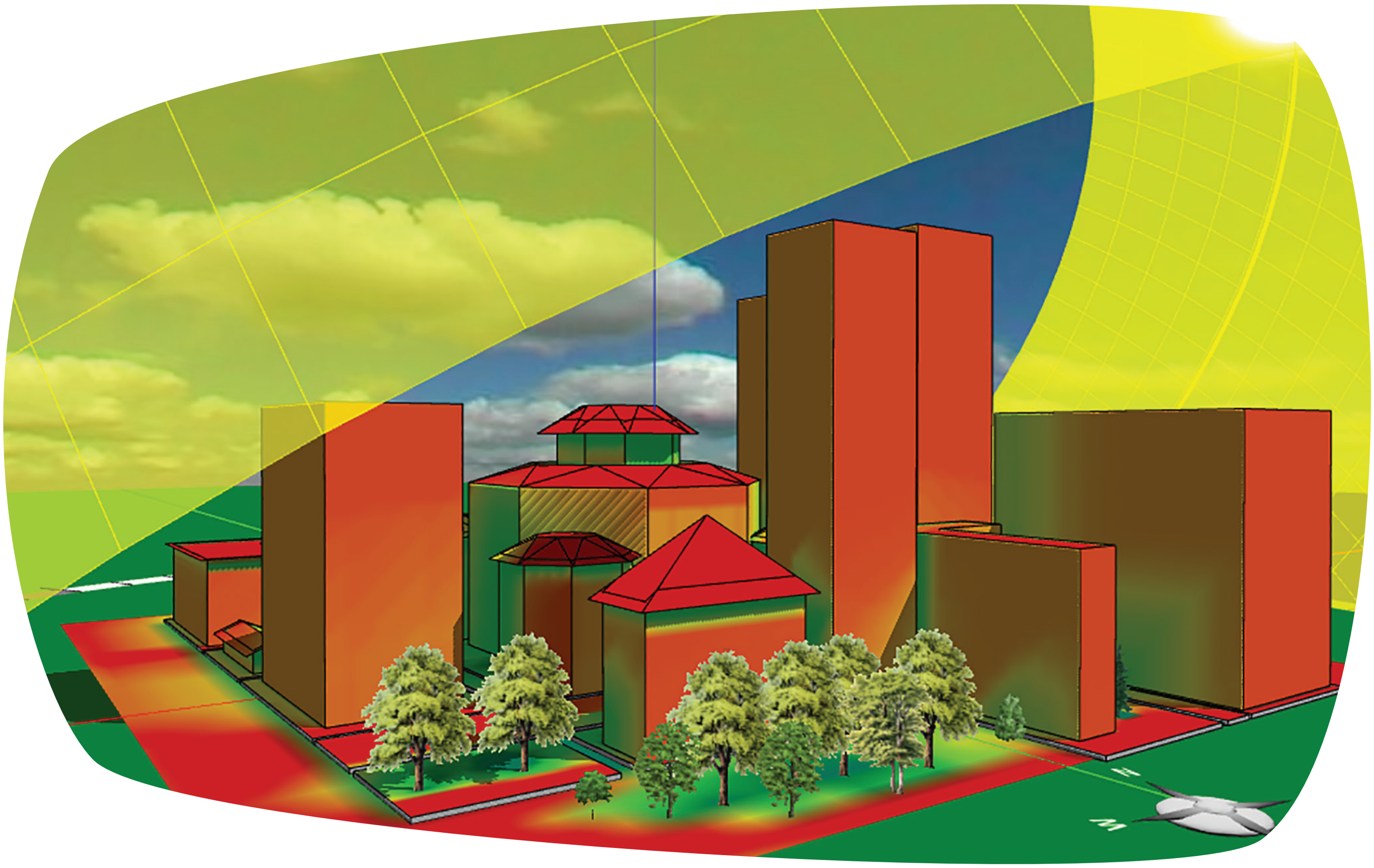
# @CONCORD

vol. 21 • no. 1 • Spring 2017



The Concord Consortium
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# Perspective:

## Preparing Learners for the Future

*By Chad Dorsey*

We live in an interconnected world of accelerating complexity. As populations expand and people, economies, and nations become inextricably intertwined, even seemingly simple problems reveal intricate subtleties. And the issues of our time are far from simple. Preparing for and defending against disease. Assessing global energy needs. Taking a principled stand on major political causes. All are rife with complication. How can we prepare today's children to live and work productively in a future defined by complexity?

The notion that accelerating interconnectedness is an inescapable aspect of modern life could be disheartening, particularly for those of us in education. However, we see things differently from our vantage point at the Concord Consortium. Rather than become buried in the problems of the present, our tools, approaches, and research are rising to the challenge of the future, enabling learners to investigate elaborate problems and to build the skills necessary to navigate a complexity-rich world.

**Dealing with the data deluge.** Some of the most imposing aspects of this rapidly approaching future appear in the guise of data. "Big data" now permeate all aspects of life. In less than a decade, data science has grown into a high-demand profession, and education has not kept pace. Our children are in danger of being stranded without proper preparation. Across varied projects with multiple partners, we at the Concord Consortium are responding by spearheading the new field of data science education and forming and refining its requisite tools, networks, and pedagogies.

To fuel this new field, we are developing the Common Online Data Analysis Platform (CODAP), a data exploration tool designed to enable more learners to use more data in more places. We envision a future where hundreds of curricula, thousands of classrooms, and millions of students worldwide engage in data exploration with ease and sophistication. To realize this vision, we are collaborating with others to define data science education, provide examples to further it in classrooms from kindergarten to college, and establish essential research networks to guide our work.

**Comprehending complex systems.** One of the biggest issues is the need to grapple with the dynamics of complex systems. As the number of interconnections within systems increase, they assume an entirely new nature. Actions involving tiny elements on a system's periphery can elicit significant effects throughout. These effects may arise with surprising immediacy or emerge only following mysterious dormancies or delays. In other cases, feedback loops dampen or amplify effects.

Most large problems involve such complex systems and their effects. In fact, most actually involve multiple, interlinked complex systems. Such situations, often called "wicked problems," are defined by their almost inscrutable causalities. Learning the ins and outs of such systems is a new educational challenge that demands wholly new tools and approaches. Our SageModeler software is one such innovative tool, a dynamic technology environment aimed to make concepts of system modeling accessible for students as young as middle school. Representing quantities through custom icons and connections through easy-to-understand arrows, SageModeler permits learners to quickly sketch intricate systems of their own making. Once learners have depicted a system's basic components and connections, they can specify the nature of the interdependencies and run dynamic simulations to explore the system's behavior. Further, students can compare their model output with real-world data. This ability—to move from concept to near-instant results—makes cause and effect visible in dynamic detail and transforms complexities and abstract musings into immediately testable hypotheses.

Though such a modeling environment is already transformative, combining technologies in cutting-edge ways can provide even more powerful views into systems. Agent-based simulations, in which individual entities such as ants or people operate independently, each following simple sets of rules, have long helped both learners and professionals visualize important aspects of complex phenomena. Technologies such as MIT's StarLogo—with its intuitive block programming approach—make it possible for learners to create systems and examine their emergent behaviors (e.g., population curves or flocking) with relative ease. This ease of use has a

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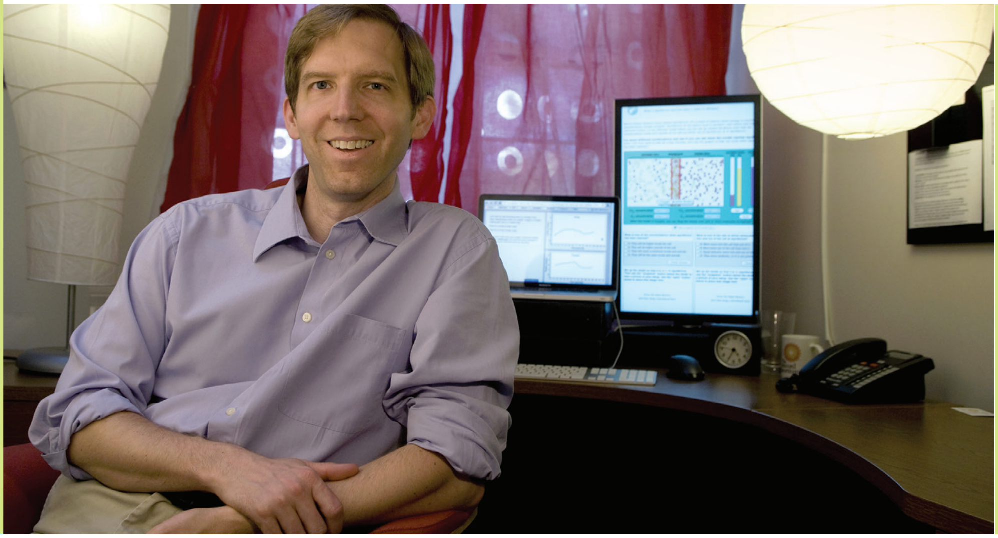

flip side, however. The block programs underlying these simulations can rapidly become difficult to parse. This presents a dilemma: Should we provide learners with access to the details of complex systems and risk muddling the big picture in ungainly coding or forego the coding for a conceptual view and risk losing learners in high-level abstraction?

We are currently merging the two into a whole greater than the sum of its parts—an example of *linked-hybrid modeling*. It will seamlessly fuse high-level system diagrams with detailed agent-based simulations, permitting learners to move smoothly back and forth between the two. This new technology, patterned after similar approaches used by practicing complexity theorists, will open new possibilities for systems learning, facilitating broad, inclusive perspectives and fostering previously inaccessible connections.

**Experimenting seamlessly.** When confronting nuanced problems and large datasets, even tiny points of friction in the inquiry and exploration process can quickly become substantial barriers to learning. We're addressing this by integrating proven tools with new ones in ways that can make essential scientific practices seamless. These tools allow learners to use wireless probes to collect data easily and quickly and make exploring and analyzing data seamless and engaging. And we're crafting approaches that scaffold learners' use of these tools, allowing them to compare real-world data with predictions from both theory and computational models.

Our research seeks to understand how these tools and approaches redefine the very nature of learning through experimentation. This work sheds new light on the familiar—highlighting the fundamental importance of "messing around" with parameters and experimental setups and defining the nature and trajectory of "parameter space reasoning" critical for operating in a world drenched in data. In the process, we're creating learners with the skills and tenacity needed to undertake extended, independent investigations into open-ended problems.

**Collaborating amid complexity.** We don't expect learners to approach tomorrow's complicated world alone. On the contrary, we must prepare them for a future of creative, technology-based collaboration centered on highly interdisciplinary problems. Our groundbreaking work is creating and researching tools and patterns that foster productive collaboration. We're building innovative technology environments that can enable seamless cooperation around simulations, experiments, and shared datasets. We're identifying curricular approaches that inspire collaborative work and make the best possible uses of technology. And we're researching new ways to use analytics to monitor collaboration in real time and provide meaningful feedback.

As students work on technology-based challenges in classroom groups, our systems will aid them while simultaneously providing vital information and guidance to their teachers. Such tools may steer teachers toward the students most in need of assistance, supplying real-time background notes and suggestions. A dynamic, whole-class overview can enable teachers to "be everywhere," allowing them to observe a busy collaborative classroom while saving targeted artifacts of student work for later use in large-group conversations.

The world's increasing complexity can feel overwhelming. We see it as an open call for experimentation and invention. We also find it deeply inspiring. As we develop and research transformative approaches to learning, we're not merely helping to solve today's problems, we're equipping entire future generations of youth with the skills to solve complex problems in innovative new ways.

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# Artificial Intelligence research for engineering design

By Charles Xie

Imagine a high school classroom in 2030. Students are challenged to design an engineering system that meets the needs of their community. They work with advanced computer-aided design (CAD) software that leverages the power of scientific simulation, mixed reality, and cloud computing. Every cool tool needed to complete an engineering design project is seamlessly integrated into the CAD platform to streamline the learning process. But the most striking capability of the software is its ability to act like a mentor who has all the knowledge about the design project to answer questions, learns from all the successful or unsuccessful solutions ever attempted by human designers or computer agents, adapts to the needs of each student based on experience interacting with all sorts of designers, inspires students to explore creative ideas, and, most importantly, remains responsive all the time without ever running out of steam. Such an ideal mentor does not exist in humans and a robot capable of doing such a job is still in the realm of science fiction. But the rapid development in artificial intelligence (AI) in recent years is bringing this science fiction closer to reality. At last, we can see a path to it.

AI is one of the three most promising areas for which Bill Gates said earlier this year he would drop out of college *again* if he were a young student today. The victory of Google's AlphaGo against a top human Go player in 2016 was a landmark in the history of AI. The game of Go is considered a difficult challenge because the number of legal positions on a 19×19 grid is estimated to be $2\times10^{170}$, far more than the total number of atoms in the observable universe combined ($10^{82}$). While AlphaGo may be only a type of weak AI that plays Go at present, scientists believe that its development will engender technologies that eventually find applications in other fields.

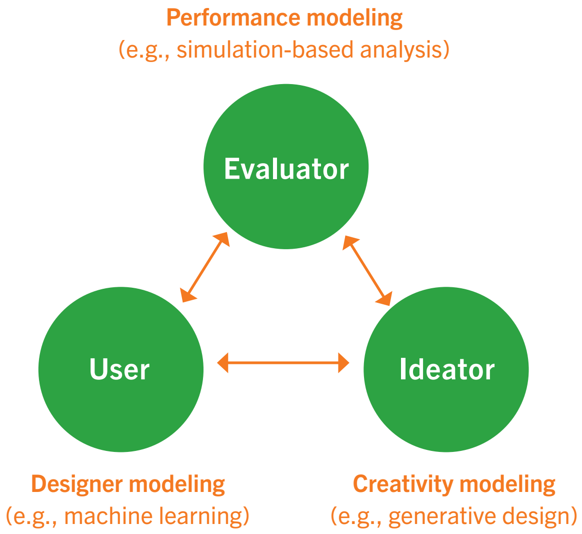

**Figure 1.** Three different sources of intelligence based on computational modeling provide the pillars to support the development of three types of intelligent agents—evaluator, ideator, and user—to assist students in engineering design projects with Energy3D.

## The challenge of engineering design

One field that excites us is engineering design. In this frontier, however, we face a much greater challenge than winning a Go game. If you are shocked by the number $2\times10^{170}$, prepare to be awed. The vastness of the solution space of a complex design problem is far beyond what language can describe. To comprehend its magnitude, consider these two facts: 1) an open-ended design project is not limited to 19×19 grid points and 2) the possibilities for each point are not limited to three choices (empty, black, or white). Finding an optimal design in such a gigantic solution space is like looking for a needle in a haystack or, to put it more aptly for many engineering projects, like searching for an electron in the universe.

Given the sheer difficulty of the task, people have developed—as in the case of Go—many techniques, strategies, styles, and cultures in the practice of engineering to find satisfactory solutions that approximate optima. The development of AI based on this foundational work will eventually lead to a paradigm shift of engineering practice and education. In this article, I introduce our work as a humble step towards this grand vision.

## Computer-aided design and artificial intelligence

In workplaces, engineering design is supported by modern CAD tools capable of virtual prototyping—a full-cycle process to explore a product on the computer before it is actually built, demonstrated by the remarkable success in designing the Boeing 777 aircraft during 1989-1992. Here we use a more inclusive definition of CAD to encompass simulation, analysis, automation, documentation, and communication, in addition to 3D modeling typically used to represent CAD. In classrooms, CAD tools allow students to take on a design challenge without regard to the expense, hazard, or scale. They provide valuable tools for teaching and learning engineering, because a significant part of scientific reasoning and design thinking is abstract and generic, can be learned through designing computer models that work in cyberspace, and is transferable to real-world situations. Due to its pivotal importance in engineering, CAD provides an ideal platform to support the research on design AI.

The study of AI focuses on intelligent agents that perceive changes in their environments and take actions to maximize their chances of success in achieving certain goals. An intelligent agent for engineering design must demonstrate the ability to 1) mimic basic skills of a human designer for attaining a goal and 2) improve those skills through learning from new design solutions and their contributors. Computational science provides sources of intelligence for developing three types of intelligent agents (Figure 1), defined below.

## The evaluator agent

The analytical capabilities of CAD tools based on numerically solving fundamental equations in science can be used to evaluate the performance of a design artifact (Figure 2). Through a simulation-based analysis, a CAD tool can calculate and collect a variety of performance indicators that can be used as *percepts* for an Evaluator, an agent that simulates the role of a human instructor who provides feedback to the designer based on evaluating the design artifacts. For example, the percepts of performance for a zero-energy building under design may be the predicted net energy consumption, the total cost for constructing it, the size of the usable space in it, and so on. A more knowledgeable agent may even draw upon details such as the energy usage of each room, the electricity output of each solar panel, and the cost of each part.

The Evaluator monitors and processes percepts to generate instruction. A *simple reflex evaluator* is powered by an event-condition-action rule engine that triggers an action based on a rule when a condition for the rule is detected in an event (Figure 3). For instance, the Evaluator will respond with a red flag when the total construction cost of a building under design exceeds the budget limit. A shortcoming of the simple reflex evaluator is its memoryless Markov property—when the agent only takes current percepts into account to figure out its next suggestion, the result is less systematic instruction. A smarter agent to prevent a design process from degrading into the chaos of Brownian motion is the *model-based reflex evaluator*, driven by an internal model based on the history of percepts such as a high-order additive Markov chain model. For example, a linear trajectory of continuous improvements in building performance with the budget under control may indicate systematic optimization. A trajectory of fluctuating performance, on the other hand, suggests the possibility of a divergent-convergent loop in which the designer experiments with various ideas. When the design goals are factored into the model, the agent becomes a *goal-directed evaluator* that can guide the designer with a "positioning system" capable of telling how far the designer is from accomplishing the goals and whether the designer is zeroing in towards the goals or going astray.

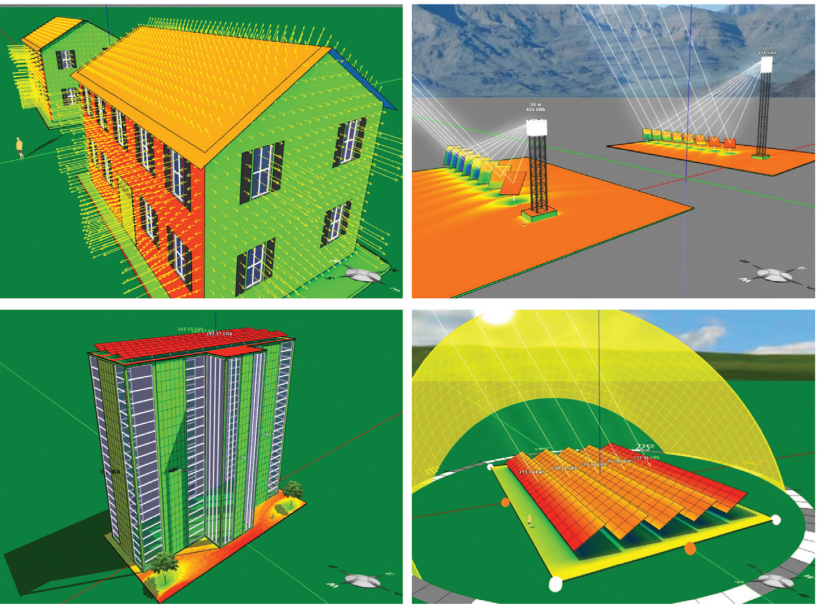

**Figure 2.** Modeling and simulation in Energy3D provide salient, dynamic visualization of science concepts and engineering principles that can inform the designer at each step if necessary.

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(continued from p.5)

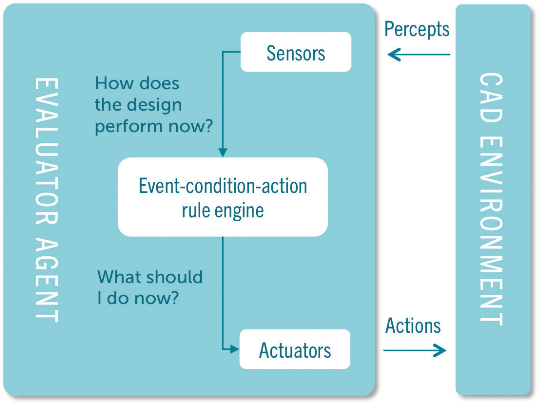

**Figure 3.** A simple reflex evaluator that observes a change in design performance caused by a designer's action through "sensors" and reacts accordingly through "actuators."

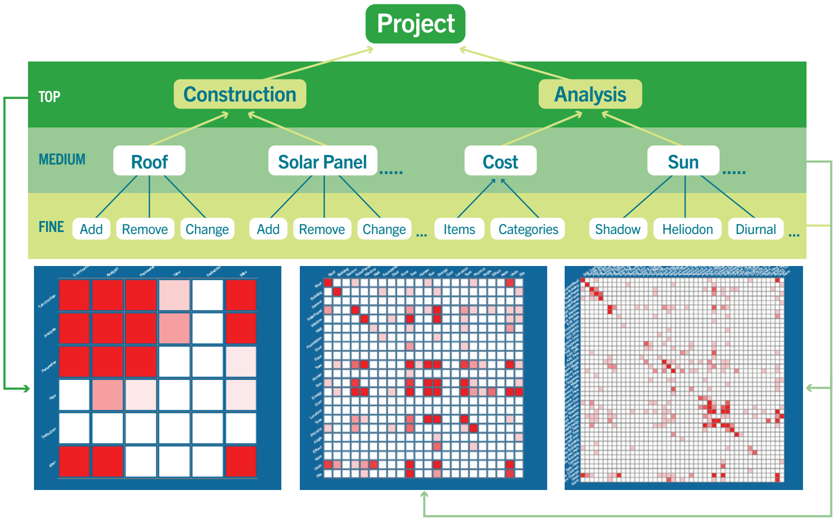

**Figure 4.** Created using our Visual Process Analytics, the heat map visualizations of task transitions across different zones in a multi-level knowledge graph, which represents the zero-energy building design project, provide a computational means for the User agent to learn about designers from their design behaviors logged by Energy3D.

## The ideator agent

The intimidating massiveness of the open-ended design space, nevertheless, gives us hope that there is always a better solution to be found somewhere in the intellectual universe. Given the fact that an exhaustive search is unrealistic, designers need to try many ideas. The parametric and generative design capabilities of CAD tools can spur ideation by suggesting permutations and variations of design elements interactively and evolutionarily, equivalent to teaming designers up with *computer co-designers* capable of helping them see new possibilities. This capacity of computational design allows us to develop the Ideator, an agent for generating new designs automatically through autonomous search or semi-automatically with human intervention. By storing and sorting all the designs that have been generated in such ways, the Ideator can also learn from itself and humans to advance its knowledge base.

## The user agent

The above two types of agents can be augmented by the User agent that can learn about designers by analyzing their process data. Logging capabilities can be easily added to CAD tools to collect large quantities of fine-grained process data from users in real time, the data can be mined to characterize user behavior and performance, and the results can be used to automatically compile formative feedback to students or create infographic dashboards for teachers (Figure 4).

## Fostering engineering education

CAD software enhanced by the AI described above has the potential to boost designer productivity and creativity. If you are familiar with simulation-based engineering, however, you may wonder about the difference between the current approach and the AI-based approach, and the reason AI is needed to aid the design process. A challenge of engineering analysis to the designer is to make sense of the numerous data produced in a simulation and the possibilities that they represent. In a conventional CAD environment, the designer must wade through this sea of data to find clues for the next move. As in the case of playing Go, this expertise takes years of training and practice to acquire. But young students have yet to develop abstract mental models and design thinking to help them imagine and reason about engineering systems they are challenged to design. They frequently need instructional support such as formative feedback and creativity stimuli such as generative design to help them forge their mental models and shape their design thinking. These essential elements for engineering education are often insufficiently provided in real classrooms as they require tremendous efforts from teachers for individual students. When students are solving complex design problems, the workloads for teachers would escalate to such a high level that it would be impossible for teachers to guide every student through the design process. In many complicated situations, even though teachers are available, accurate evaluation of students' subtle design decisions and effective instruction for their next steps may be possible only through computational analyses of design artifacts and designer states using the supporting CAD software. These difficult areas of design learning are exactly where AI can demonstrate its extraordinary value as a powerful teaching assistant.

## Afterword

The three types of intelligent agents will be available in our Energy3D software, a CAD tool for sustainable architecture and renewable energy engineering that serves as an open research platform for design computing and engineering education. The vital subject of energy, in which Energy3D specializes, is also one of the three areas in which Bill Gates would pursue a career. If his vision heralds impending waves of innovations, our research today at the intersection of AI, energy, and engineering would turn out to be strategically important to the economy of tomorrow.

### LINKS

Energy3D
http://energy3d.concord.org

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is a curriculum developer.

# Monday's Lesson:

## Exploring Data with the Ramp Game

*By Tom Farmer*

The Next Generation Science Standards promote learning science by doing science. Our new InquirySpace II project guides students in independent investigation by providing curricular and pedagogical scaffolds to support the exploration of phenomena. A game we are continuing to develop focuses on a classic physics experiment—rolling a car down a ramp. Students investigate the difference between dependent and independent variables and learn to work with data in our Common Online Data Analysis Platform (CODAP).

### Try the Ramp Game

Open the Ramp Game in CODAP: http://concord.org/codap/ramp-game

In the Ramp Game (Figure 1), your job is to place a virtual car at the right height so it lands close to the center of a target. There are five challenges with multiple levels for each challenge. To start an experimental run:

① Click "Start" to see how far the car rolls.

② Click "Analyze data" to see the result.

③ Click "Set up new run" to try again.

With each run, drag your car up or down the ramp to change the starting height and try to hit the target more accurately. Keep trying until you score enough points to advance to the next level. Note that the target gets smaller at each level!

Be sure to discuss experimental variables with your students after their initial success at landing on the target. The independent variable is the variable being changed (the car's starting height). The dependent variable is the parameter being affected (distance the car moves). Other variables are held constant (friction, mass of the car, etc.).

Do you notice a pattern in the table or graph? Use CODAP to analyze your data, determine the relationship between the starting height of the car and the distance it travels, and get better at the game. To make predictions from your graph, add a fit line and related linear equation:

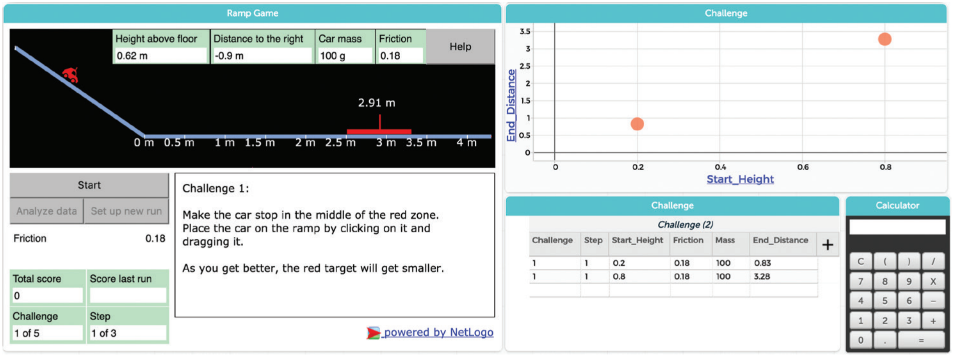
① Click on the graph. A set of tools appears to the right (Figure 2).

② Select the Measure tool, then "Movable Line" and "Intercept Locked." A line and equation appear on the graph.

③ Rotate the line by hovering over the upper right and dragging up or down.

Each new challenge changes a variable affecting the car-ramp phenomenon. The final challenge changes the independent variable from height of the car to friction.

**Figure 1.** The Ramp Game.



Height above floor: 0.62 m
Distance to the right: -0.9 m
Car mass: 100 g
Friction: 0.18

Friction 0.18

Total score: 0
Score last run:
Challenge: 1 of 5
Step: 1 of 3

Challenge 1:

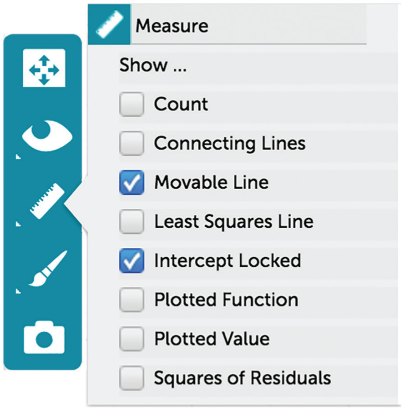
Make the car stop in the middle of the red zone. Place the car on the ramp by clicking on it and dragging it.

As you get better, the red target will get smaller.

*Challenge (2)*

| Challenge | Step | Start_Height | Friction | Mass | End_Distance |
|---|---|---|---|---|---|
| 1 | 1 | 0.2 | 0.18 | 100 | 0.83 |
| 1 | 1 | 0.8 | 0.18 | 100 | 3.28 |

**Figure 2.** CODAP's graph tools.



Measure
Show ...
☐ Count
☐ Connecting Lines
☑ Movable Line
☐ Least Squares Line
☑ Intercept Locked
☐ Plotted Function
☐ Plotted Value
☐ Squares of Residuals

Experiment with friction while holding the car's height constant. To excel at the game, create a new graph, then add the independent and dependent variables by clicking the label on the x and y axes and selecting variable names. You can also drag a table column header to a graph axis. To hide data from previous challenges, select data rows in the table, then click in the graph's header. Choose the eye icon and "Hide Selected Cases."

In our first InquirySpace project we used logs of student data and a sophisticated model analysis algorithm to group students into broad categories of problem solvers (see "Analytics and Student Learning: An Example from InquirySpace" in the Spring 2015 *@Concord*). Did they make reasoned guesses from the animation? Did they use the table, graph, or equation? This research is now helping us develop increasingly sophisticated games to move students toward data and data visualization literacy.

**LINKS**

InquirySpace II
https://concord.org/inquiryspace

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is a technology and curriculum developer.

# Using Technology to Enhance NGSS-Aligned Assessment Tasks for Classroom Formative Use

*By Dan Damelin*

**The Next Generation Science Standards (NGSS) are written as Performance Expectations that integrate the three dimensions of each standard: disciplinary core ideas, crosscutting concepts, and science and engineering practices. To measure student progress toward achieving proficiency in any standard, an assessment task must include all three dimensions. One of the major challenges in NGSS-aligned assessment design is creating tasks that include science and engineering practices. Technology is a uniquely adept tool for designing and delivering tasks that can meaningfully include the practices. Without technology, many performance tasks would be difficult or impossible to implement in any other way.**

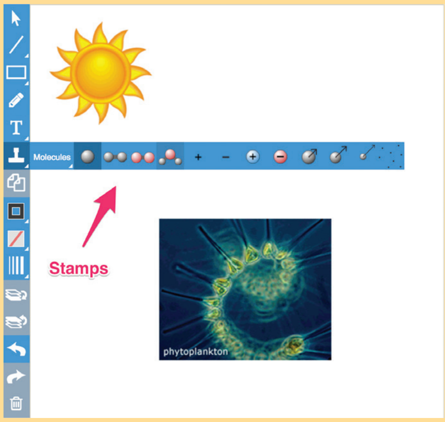
The Next Generation Science Assessment project is a collaboration between the University of Illinois at Chicago, Michigan State University, SRI International, and the Concord Consortium, with funding from the National Science Foundation and the Moore Foundation. We are currently developing technology-enhanced assessments for classroom formative use that address middle school physical and life science NGSS Performance Expectations. The Concord Consortium's online delivery platform allows us to take advantage of web-based tools and simulations that benefit students and teachers, as well as researchers on our team working to validate and improve the assessment tasks.

## Student benefits

Designing assessments to gauge student progress toward the NGSS science and engineering practices of "developing and using models" and "planning and carrying out investigations" poses the biggest challenge. These science practices are inextricably linked with the other six practices, but they are the most difficult to design assessment tasks for without the special affordances of technology.

Our task authoring system allows us to integrate computational models, which students can manipulate to explore phenomena, to generate data for a scientific argument, or to carry out an experiment they have planned or designed. An embedded drawing tool permits students to express their ideas using scaffolded background images, stamps, and manipulable objects (Figures 1 and 2).

**Figure 1.** Draw tool with custom background and molecule/atom stamps. See the task: https://authoring.concord.org/activities/6731



For example, Performance Expectation MS-PS3-4 states: *Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass and the change in the average kinetic energy of the particles as measured by the temperature of the sample.* In one of our assessment tasks, students must determine how much thermal energy to transfer to a sample of oil with a particular mass to heat it to a specific temperature. To answer the question the student must design an experiment using a simulation and carry out that investigation (Figure 3). Through analyzing the data generated by the computational model, the student can determine the proper amount of thermal energy to add to any amount of oil.

In other tasks students are asked to develop models, as in Performance Expectation MS-LS2-3: *Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.* Using the drawing tool or other custom interactive component, students can develop a model in response to assessment tasks that address this Performance Expectation.

## Teacher benefits

Through an online portal, teachers can easily set up classes, assign specific tasks, and generate collated reports of student work, making the tasks ideal for formative use. Teacher reports are updated in real time, allowing for close monitoring of student progress. Teachers can share and highlight student work just minutes after students have completed the tasks, including developing their own models and other artifacts. Student work can be used to drive classroom instruction or to adjust pedagogical strategies for the next class.

Rubrics linked to each task will soon be available to help teachers understand which aspects of student work are progressing toward mastery of the Performance Expectation and which need reinforcement. Teachers can provide online feedback to individual students within the portal.

## Researcher benefits

To develop the assessment tasks, our team employs a rigorous multi-step process (Figure 4). First, we identify a Performance Expectation (PE) or related cluster of PEs. Then we perform a *domain analysis* to unpack the relevant NGSS dimensions (disciplinary core ideas, practices, and crosscutting concepts), from which we create an integrated dimension map of the unpacked components. Using this map we link sub-components from each dimension to construct a three-dimensional construct we call a Learning Performance (LP), which is a smaller grain size than the PE. Several LPs are generated for each PE. Together they provide guidance at a more detailed level about student progress toward the Performance Expectations.

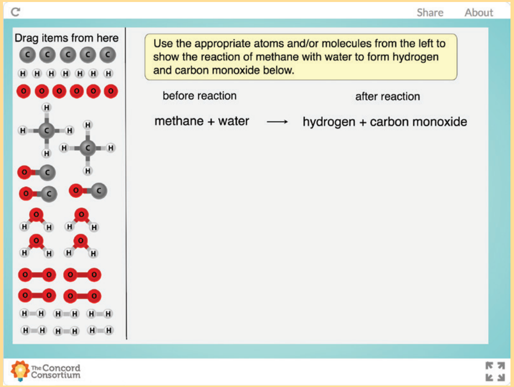
Developing the LPs and task design templates is part of the *domain modeling* process, after which individual assessment tasks are created. In the process of task design, we consider where technology can best be applied to achieve the task design features. We then review each task for scientific accuracy, equity, and fairness, and test the assessments with students in a classroom setting and in a more individualized environment where students can think aloud while being observed during engagement with the assessment tasks.

Because the tasks are online, log data of student interactions with the tasks and the interactive components provides valuable information about task difficulty as well as student strategies for exploring computational models and the drawing tool. Using electronic data from students in our research cohort, researchers are able to analyze anonymized data across classrooms, teachers, and schools, aiding in our efforts to establish the validity of our tasks, and making it easier to locate and implement improvements in task design.

## Conclusion

The Next Generation Science Assessment project has developed and tested assessments for several PEs in middle school physical science. Additional assessment tasks relevant to several middle school life science PEs are currently under development and will be available soon. We are also developing teacher guides for the tasks and suggested rubrics linked to each task.

We are encouraged by the strong interest in these assessments tasks. As more states and districts strive to enact an NGSS-aligned approach to teaching and learning, we hope to develop additional tasks oriented toward more PEs in new disciplinary areas and for a wider range of grades.



Use the appropriate atoms and/or molecules from the left to show the reaction of methane with water to form hydrogen and carbon monoxide below.

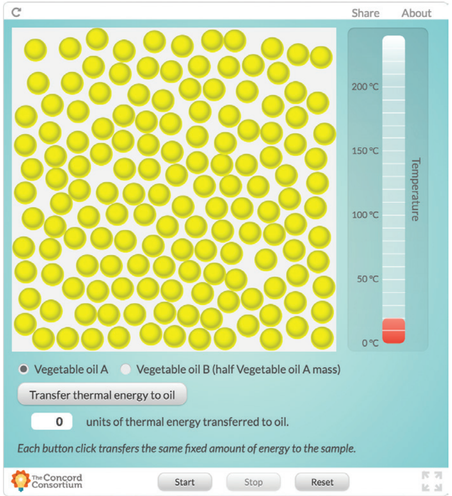
before reaction

after reaction

methane + water ⟶ hydrogen + carbon monoxide

**Figure 2.** Draw tool with atomic and molecular components students can drag into the canvas to model a chemical reaction. See the task: https://authoring.concord.org/activities/5244

**Figure 3.** A simulation used to design and carry out an experiment. See the task: https://authoring.concord.org/activities/5435



● Vegetable oil A ○ Vegetable oil B (half Vegetable oil A mass)

0 units of thermal energy transferred to oil.

*Each button click transfers the same fixed amount of energy to the sample.*

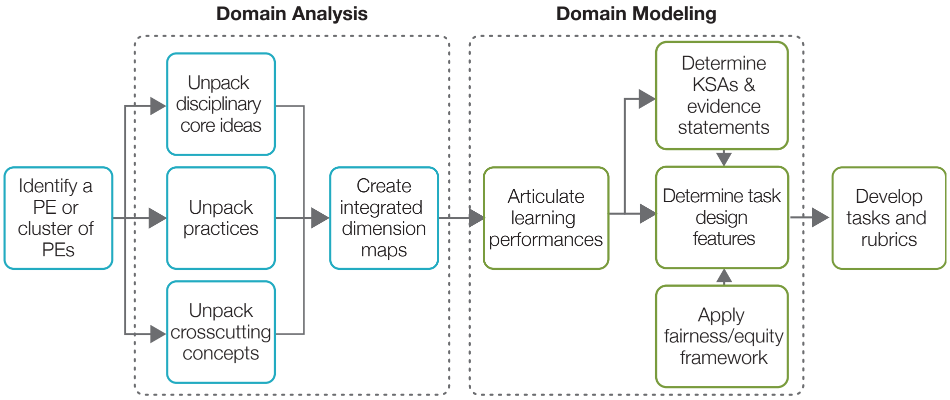


**Figure 4.** Design process for developing assessment tasks for classroom formative use. (Harris, Krajcik, Pellegrino, & McElhaney, 2016*). Used with permission.

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* Harris, C. J., Krajcik, J. S., Pellegrino, J. W., & McElhaney, K. W. (2016). *Constructing assessment tasks that blend disciplinary core ideas, crosscutting concepts, and science practices for classroom formative applications.* Menlo Park, CA: SRI International.

### LINKS

Next Generation Science Assessment
http://nextgenscienceassessment.org/

**Amy Pallant**
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directs the GEODE project.

# Modeling Plate Tectonics

## for Learning

*By Amy Pallant*

**From the seafloor to the tallest mountain range, every landform on Earth has a story to tell that stretches back over geologic time. Earth's geologic wonders have been shaped over hundreds of millions of years by the movement and interaction of a set of tectonic plates that make up the outer layer of Earth. While scientists can speculate about plate motion, the geodynamics responsible for a wide variety of landforms and events is complex to teach and learn.**

Earth science teachers can explain specific phenomena along plate boundaries, but they also have the difficult task of helping students develop a systems-level conceptual understanding of plate tectonics. This big-picture reasoning includes multiple events and processes taking place simultaneously around the globe, and it requires students to recognize what happens at plate boundaries as well as how each tectonic plate is surrounded by—and interacts with—adjacent plates at the same time.

The theory of plate tectonics explains the formation and global distribution of geological phenomena. It is a unifying theory in Earth science. Through the movement and interaction of tectonic plates, material circulates back and forth between Earth's crust and the mantle—the layer between the crust and the outer core.

The Geological Models for Explorations of Dynamic Earth (GEODE) project, funded by the National Science Foundation, is developing new geodynamic plate tectonic modeling software for middle school Earth science classrooms that allows students to observe and describe the formation of surface geologic features in terms of plate interactions. The goal of the interactive modeling environment and curriculum is to help students reason spatially and temporally about how plate movements result in the global distribution of various geological phenomena, such as undersea mountain ranges, deep ocean trenches, dramatic volcanic mountains, and vast plains. The software features a system of plates bounded on all sides by other adjacent plates, which interact like those found on Earth.

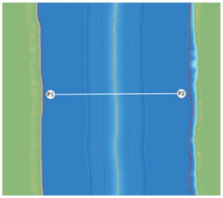

**Figure 1.** A bird's-eye view of a divergent plate boundary.

**Figure 2.** Cross-section view of the divergent boundary of Figure 1.

## Earth's surface features

We began software development by modeling divergent boundaries, locations where plates are moving away from each other. Imagine a giant conveyor belt moving two plates apart. Eventually, an underwater volcanic mountain range forms along that divergent boundary from magma that rises from deep within the Earth.

One of our first prototype models is this type of ocean-spreading ridge. A top view (Figure 1) looks down from above at the spreading ridge. Figure 2 shows a cross-section of the divergent boundary of Figure 1. When the model is running, the student sees the movement of the plates, the addition of new crust at the ridge, and the subsequent variation in topography as the underwater mountain range forms. Topographical differences are represented in the top-view model as variations of blue. In the cross-section view they appear as a jagged surface.

The model also shows the crust sinking and getting thicker as it moves away from the spreading ridge, representing the increased density of the cooling crust as it shifts. But even in this simple model we need to consider many design issues. How tall should the mid-ocean ridge be in the cross-section? How do we model the jagged pattern typically found along the mid-ocean ridge caused by faulting. Can we show the magma reaching the surface? How do we make it clear that the layer below the surface is not liquid but solid rock at a temperature just below its melting temperature? (It flows more like road tar than magma.)

Similar issues emerge when modeling convergent boundaries where plates are moving toward each other. Along convergent boundaries, the plate with the denser crust is dragged below the plate with the less dense crust, a process called subduction. At an ocean-continent boundary, the denser oceanic crust subducts beneath the less dense continental crust. At a continent-continent boundary, however, the situation is more complicated.

The model must be able to show how two continents once separated by an ocean collide at a convergent boundary. First, the oceanic crust subducts, bringing the continents closer to each other, with volcanoes forming on the overriding plate. When the continent on one plate reaches the boundary and cannot subduct, it collides with the continent on the other plate, forming mountains (like the Himalayas) along the boundary (Figure 3). But those are just the surface features. The heights of mountains are matched by equivalent "roots" below the mountains. A cross-section view must also show this. Additionally, the model must take into account the collision of two continents, since the plate motion slows down and then stops, which in turn affects the motion of all other plates on the planet.

## Multiple boundaries and interactions

Our goal is to develop a geodynamic model showing multiple interacting plates so students can observe interactions that are occurring at different places at the same time. After all, if one side of one plate is diverging from a second plate, then the opposite side of the first plate must be converging on another plate.

Students will be able to create different starting conditions on an imaginary planet with multiple plates interacting in similar ways to tectonic plates on Earth. This will allow them to explore the dynamic interactions along plate boundaries and associated geologic phenomena by changing the planet's conditions. Students will learn how plate motion has shaped the configuration of Earth's continents, and be able to explore the evolution of the surface of a planet and how its features change over time. The GEODE curriculum will help them understand where volcanic arcs are located, why there are different patterns of earthquakes around the world, and how supercontinents are formed and separate. Understanding these phenomena will enable students to make reasonable predictions about the future of Earth's surface features.

By helping students recognize the interconnectedness of Earth's dynamic plate system, GEODE aims to foster reasoning about changes that occur over geologic time. Earth science is traditionally taught largely in a descriptive manner with videos, text, and non-interactive simulations. Modeling holds huge potential for transforming Earth science education by supporting students' understanding of complex dynamic systems.

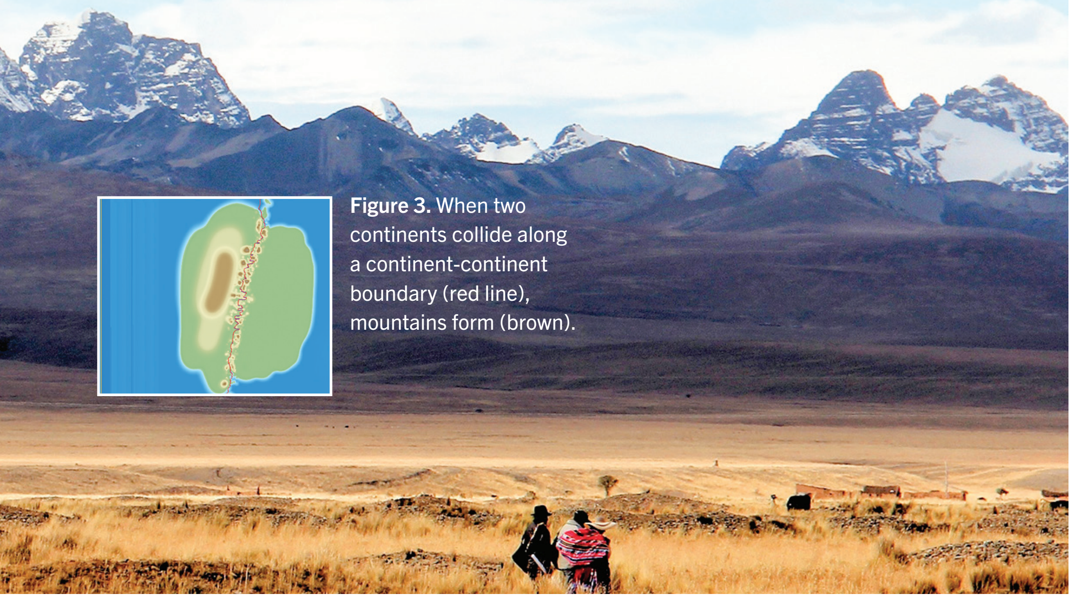

**Figure 3.** When two continents collide along a continent-continent boundary (red line), mountains form (brown).

Andes backyard, the spectacular Cordillera Real (Royal Ranges) | Photo by krheesy, Flickr (CC BY 2.0)

**LINKS**

GEODE
https://concord.org/geode

# Sensing Science

## through Modeling Matter

*By Carolyn Staudt and Jamie Broadhead*

**Carolyn Staudt**
(cstaudt@concord.org) directs the Sensing Science project.

**Jamie Broadhead**
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Early learners have significant—and highly untapped—potential for understanding abstract concepts and reasoning in sophisticated ways. Research has shown that technology offers powerful support for conceptual science learning in the early grades. The new Sensing Science through Modeling Matter project is developing and researching a technology-enriched curriculum to support learning about matter and its changes at the kindergarten level. We hope that creating a curiosity for science in the early grades is a strong foundation for later STEM learning.

Funded by the National Science Foundation (NSF), the project brings together researchers from Purdue University and the Concord Consortium to pilot model-based inquiry lessons and dynamic technology-based visualizations with over 300 students at four sites in Indiana and four sites in Massachusetts. Building on results from prior projects, we expect to further knowledge about how early learners can create robust conceptual models of the nature of matter. We hypothesize that the use of model-based instruction, if supported by dynamic, technology-based visualizations, holds potential for helping kindergarten students construct a foundational understanding of the particulate nature of matter.

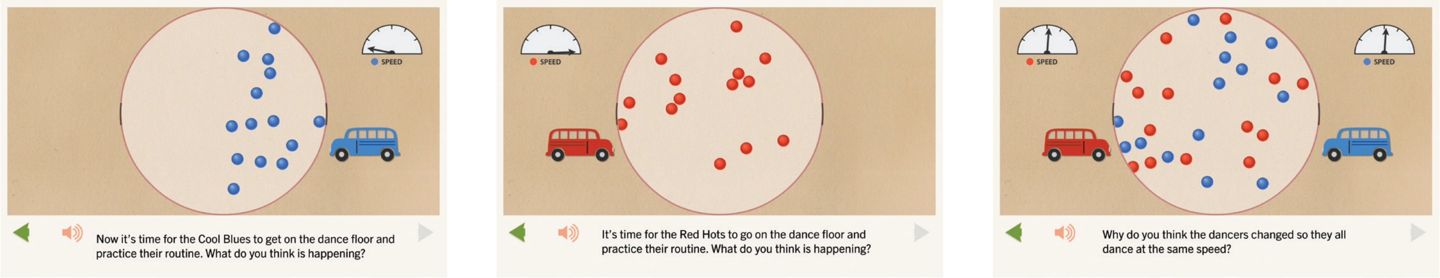
The goals of Sensing Science through Modeling Matter are: 1) revise a curricular unit about matter for kindergarten classrooms, 2) design a parallel curricular unit incorporating technology, and 3) test a series of model-based activities with students for feasibility and maturation effects.

### Revise an existing curricular unit about matter for kindergarten students

Our plan is to modify an existing second grade inquiry-based modeling unit developed at Purdue by Co-Principal Investigators Lynn Bryan and Ala Samarapungavan. The NSF-funded Modeling in Primary Grades project demonstrated that the use of a model-based curriculum helps second graders make significant gains in physical science learning, including the ability to articulate increasingly detailed and elaborate explanatory models, as a result of participation in a discourse-rich, inquiry-based physical science curriculum.

### Design a curricular unit incorporating technology

Using Principal Investigator Carolyn Staudt and Co-PI George Forman's prior work and an inquiry-based modeling approach developed at Purdue, we are developing a new unit that will integrate, dynamic technology-based representations. The Sensing Science: Temperature and Heat for Early Elementary Students project at the Concord Consortium established important



Now it's time for the Cool Blues to get on the dance floor and practice their routine. What do you think is happening?

It's time for the Red Hots to go on the dance floor and practice their routine. What do you think is happening?

Why do you think the dancers changed so they all dance at the same speed?

**Figure 1.** The Land of Bump (https://lob.concord.org) interactive online story, starring the "Red Hots" and "Cool Blues." When these characters, represented as red and blue dots, randomly bump into each other, their speed changes.

understandings about the capability of dynamic visualizations to help foster kindergarten students' thinking about dynamic relationships between heat and energy transfer and the nature and makeup of matter.

During this work, we co-developed an online animated story called The Land of Bump with FableVision (Figure 1). The Land of Bump introduces the motion of particles as related to temperature and energy transfer in an accessible, interactive way. As the "Red Hots" practice on the dance floor, their fast motion is reflected on a speedometer, just as the slower motion of the "Cool Blues" is displayed on a speedometer. Kindergarten through second grade students observed how the Red Hots and Cool Blues mixed while they competed on the same dance floor. The young children were able to describe how bumping resulted in a similar speed for all particles. While not all students could articulate the more complex concepts of heat transfer, conduction, and insulation, the curriculum provided them with the building blocks for later understanding of the kinetic heat model.

We are currently creating a new online story called The Flying Zippies, again in collaboration with FableVision (Figure 2). This whimsical online story introduces the world-famous Zippies who perform in the circus. They start out sleeping in the solid state within their dressing room and are excited by faster moving air particles within the Big Top to change into the liquid state. Eventually, warmer air changes them to the gas state and they fly around the circus tent, hence their name—the Flying Zippies!

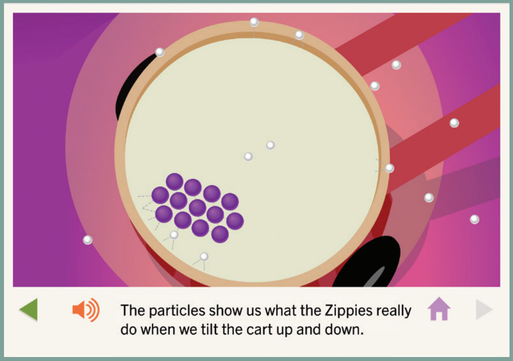
With this new story, we are researching if kindergarten students will generate representations of the states of matter, including the key idea that all matter is made of particles, and that particles are in motion in all three states—solid, liquid, and gas—though the spacing and extent of motion among particles differ depending on the state of matter.

## Test a series of activities for feasibility and maturation effects

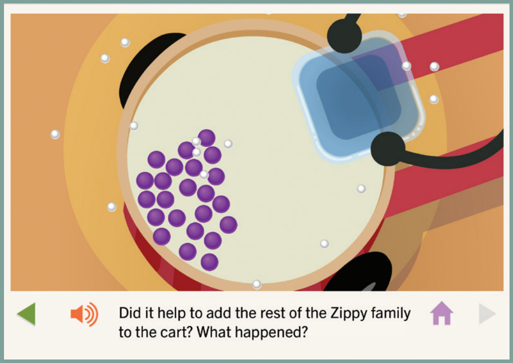
Running the activities in classrooms in Indiana and Massachusetts, we will determine how this curriculum can best integrate model-based learning with technology visualizations and will account for any maturation effects exhibited by kindergarten students. Do children start the school year with the relevant cognitive resources to develop an understanding of particulate models or must these resources be developed through instruction?

We are especially interested in understanding how kindergarteners understand and use particulate models to explain physical phenomena such as states of matter and phase changes. Does the use of modeling and technology-based dynamic representations influence kindergarteners' ability to learn to model physical phenomena? Our goal is to support conceptual, model-based learning of science concepts through technology and build foundational underpinnings in the early grades to support later understanding.

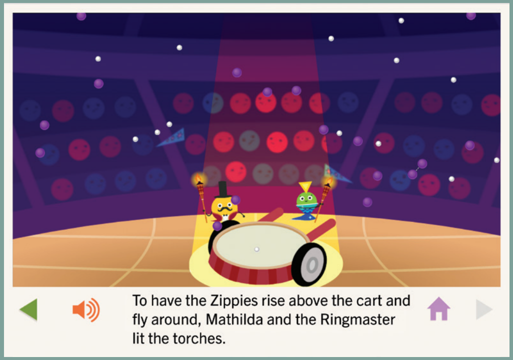
2. The Flying Zippies!


The particles show us what the Zippies really do when we tilt the cart up and down.

2a. Solid


Did it help to add the rest of the Zippy family to the cart? What happened?

2b. Liquid


To have the Zippies rise above the cart and fly around, Mathilda and the Ringmaster lit the torches.

2c. Gas

**Figure 2.** Change of state—solid (a) to liquid (b) to gas (c)—in The Flying Zippies. The award-winning FableVision is collaborating on the development of this interactive online story.

**LINKS**

Sensing Science II
https://concord.org/sensing-science-2

# Under the Hood:

## Weaving Collaboration into Code

*By Doug Martin and Scott Cytacki*

**Doug Martin**
(doug@zoopdoop.com) is a software developer who has worked on many Concord Consortium projects as a consultant.

**Scott Cytacki**
(scytacki@concord.org) is a Senior Software Engineer.

**While Concord Consortium activities have long encouraged collaboration between students, we're finding new ways to build student collaboration into our software codebase. One goal of our Common Online Data Analysis Platform (CODAP) is to enable students to work in a dynamic shared CODAP document in which any student's changes are instantly synchronized to everyone else's automatically.**

We've been using Google's Firebase technology in online activities that require teams of students to solve simulated real-world electronics problems on a shared breadboard circuit on separate computers linked by the Internet (see "Under the Hood: Creating Multi-User Activities with Firebase" in the Spring 2016 *@Concord*). So we knew Firebase could handle synchronizing CODAP's data.

By using new features in CODAP's data interactive plugin API, we could add synchronization with minimal changes to CODAP's internal code. The collaboration code is a plugin that listens for changes to CODAP's data structures, and then uses Firebase to share those changes (Figure 1). With this approach, existing CODAP documents can be made collaborative by adding the plugin and resaving the documents.

CODAP's Collaboration Service plugin starts with a setup "wizard" built inside the plugin that the document author uses to set which parts of the document to make collaborative and how students will collaborate (all together or in subgroups). The rest of the collaboration code focuses on ensuring that each CODAP user is operating on the same data by using Firebase as the single source of truth on the state of the data.

When a CODAP document that uses the collaboration plugin is first loaded, all shared data local to the document is cleared and then reloaded based on the current content of the Firebase database for that collaborative document. Any subsequent local change such as an addition, update, or deletion to CODAP's data causes CODAP to notify the collaboration plugin, which then propagates the changed data to Firebase. Next, Firebase informs all other plugin instances that are open. These plugin instances then update their CODAP documents using endpoints in the data interactive API (Figure 2).

Using Firebase as the single source of truth makes the code easy to reason about, but comes with some tradeoffs. It works well for documents containing other CODAP data interactive plugins that generate small or infrequent data changes. However, it is not ideal for documents that generate large changes frequently, which cause the application to become less responsive while data is being reconciled in the local CODAP instance. We're currently exploring ways to offload some of this work either by using newer browser technology such as web workers or extending the CODAP data interactive API to handle bulk requests so that the application remains responsive. The goal is to make the technology robust, so collaboration can take place as seamlessly as possible.

```
function handleCODAPRequest(request, callback) {
  var success = false;
  var values = null;
  var resourceType = request.resource && request.resource.match(/^[^[]*/)[0];

  switch (resourceType) {

    case 'dataContextChangeNotice':
      var contextMatches = request.resource.match(/^[^[]*\[([^\]]*)]/);
      var contextName = contextMatches ? contextMatches[1] : '#default';
      success = true;
      request.values.forEach(function(action) {
        dataManager.dataContextDidChange(contextName, action);
      });
      break;

    case 'documentChangeNotice':
      if (request.values.operation === 'dataContextCountChanged') {
        dataManager.dataContextCountDidChange();
        success = true;
      }
      break;
  }
```

**Figure 1.** Code snippet showing how the Collaboration Service listens to CODAP change notifications.

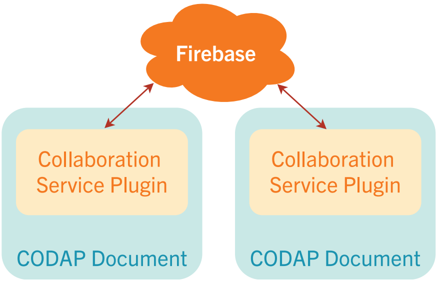


**Figure 2.** Firebase can communicate to other instances of CODAP running in the same collaboration group. The collaboration code is a plugin within CODAP.

**LINKS**

CODAP
https://codap.concord.org

CODAP's Plugin-API
https://github.com/concord-consortium/codap/wiki/CODAP-Data-Interactive-Plugin-API

CODAP's code
https://github.com/concord-consortium/codap

# Innovator Interview:

## Saeid Nourian

snourian@concord.org

### Q. Where were you born?

**A.** I was born in northern Iran. I moved to Tehran when I was 7 and to Canada when I was 16. I miss the food and the people of Tehran. I visited Iran three years ago and met a group of distant relatives. Although we had just met, we laughed nonstop. Iranian people have an amazing sense of humor.

### Q. When did you become interested in computer science?

**A.** When I was 12, I saw a movie about a computer that could reply to your questions and it made an impression on me. I bought programming books before I got my first computer. I drew a keyboard and pretended to type code, and my sister wrote down each letter I touched. That's how obsessed I was with having my first computer!

### Q. What was your first program?

**A.** I wrote a chess game, which got me interested in math and eventually led me to create Graphing Calculator 3D, which has been downloaded by half a million people. I turned that into my startup, which I started when I was an undergrad at the University of Ottawa.

### Q. Describe Graphing Calculator 3D*.

**A.** It has powerful data visualizations, which were originally a small feature. Most of my math courses were 2D, so I didn't think 3D would be popular, but multivariable calculus students loved it. Graphing Calculator 3D is easy to use and produces high-precision 3D graphs in real time. Once you plot, you get smooth 3D transitions. There's a free version and a paid version.

### Q. Where did your love of programming intersect with formal education?

**A.** We didn't have computers or computer classes in my school. I took computer classes outside of school. After my dad bought me my first computer, I learned on my own. I took some computer courses in high school, but they were too easy. University instructors focused on software from an algorithm or design perspective. They assumed programming was something you learn on your own.

### Q. Tell us about your interest in virtual reality.

**A.** I got into virtual reality when I worked for a professor for a summer after my sophomore year. He asked me to stay in his lab, and I did my master's and Ph.D. with him. I designed my own physics engine in a 3D virtual environment.

### Q. What's the potential of VR for learning?

**A.** Training is the most popular application of virtual reality, which immerses you in an environment. One of my Ph.D. projects was a surgery simulation, training surgeons to do cataract eye surgery with haptic feedback—when your knife makes an incision through tissue, you feel resistance.

### Q. You've brought your 3D perspective to Energy3D.

**A.** Students can design a house within a few minutes and learn the basics of energy efficiency. Students modify their house to make it more efficient, for example, by putting windows on the South-facing wall or changing the insulation material. Then they add solar panels and run a simulation to see how good their design is.

### Q. What's exciting about students using this software?

**A.** Students get very creative and push the software to its limits. They also demonstrate more interest in engineering. There's a competition among students to make the coolest design and the most energy-efficient house.

### Q. What's the future of Eneryg3D?

**A.** Our plan is to make it more collaborative, where students design houses in a shared virtual environment. We want to foster excitement for science, engineering, and collaboration, plus a sustainable energy-efficient future.

### Q. What's interesting about working here?

**A.** The Concord Consortium encourages freedom of thinking and proposing your own ideas. It's a universe of experiments.

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* http://www.runiter.com/graphing-calculator/

The Concord Consortium

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## Growing the Data Science Education Field

The data revolution has arrived. From weather forecasts to web browsing, we live in a world defined by data. Data scientists are now among the most in-demand positions across STEM organizations nationwide. Tomorrow's citizens and STEM workers need to be well prepared to work fluidly with data.

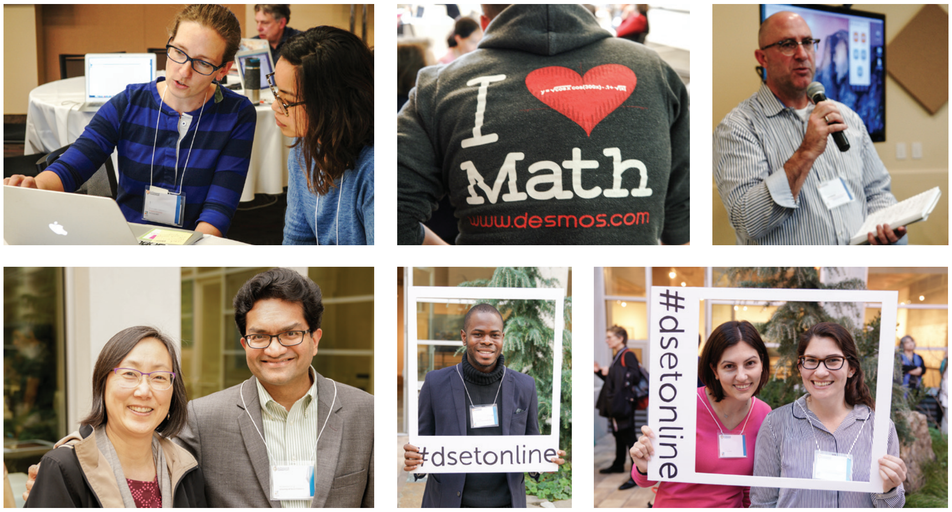
However, the growing presence of data science masks a huge gap: we have only begun to understand how to prepare learners to fill this role. Solving this problem requires the urgent, organized creation of an entirely new field of data science education.

The Concord Consortium is proud to be spearheading the effort to jumpstart this new field and furthering the goal of determining how best to bring about effective learning with and about data. A seminal event was the first Data Science Education Technology (DSET) conference. In February 2017 we convened over 100 thought leaders from organizations around the U.S. and six continents in Berkeley, California—right next to our West Coast office—to define the boundaries and essential elements of data science education and to begin laying out the first steps on a pedagogical and technological roadmap. The energy and enthusiasm at the conference buoyed all attendees and confirmed our suspicion: it is high time to move full speed ahead.

Carrying on the momentum from that launch, we are working to be a catalyst for change, actively building worldwide networks through a variety of activities.

**Data science education meetups** at major science and mathematics conferences invite public participation in the conversation about what data science education is and how best to support its growth. University professors, software developers, curriculum developers, secondary teachers, museum educators, and others are growing the network from the ground up at meetups nationwide. Together, we're seeding robust future partnerships, defining the data science education landscape, identifying gaps between the present state and the desired future, and generating action plans.

**Figure 1.** Over 100 educators and researchers launched the field of data science education at the DSET 2017 conference.



**Data science education webinars** offer inspiring perspectives from some of the "shining lights" of the data science education community. These online seminars gather perspectives from a broad set of constituents, disseminate some of the best knowledge about important principles of data science education, and provide a standing record of the work in this new field as it grows and evolves.

**Broad coalition-building activities** encourage individual teachers as well as major industry partners to play a vital role defining and cultivating data science education. By demonstrating the elements of data science education and providing exemplars and models for others to emulate, they help provide concrete answers to some of the important questions we face: What qualifies as a data science experience? Should data science courses stand alone or be integrated into science, economics, social studies, and mathematics courses across the grade 6–14 curriculum? How can we best prepare tomorrow's data science educators?

Across all of these coordinated efforts, we're working to ensure high-quality, data-rich experiences for learners throughout the education system. We look forward to working together to build networks, collaborations, and new modes of teaching and learning around data science education—and we invite you to join us at an upcoming meetup or webinar: https://concord.org/meetup

**Figure 2.** Map of DSET 2017 participants created with CODAP (https://codap.concord.org).

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**The Concord Consortium | Concord, MA | Emeryville, CA | 978-405-3200 | fax: 978-405-2076**
*@Concord* is published two times a year by The Concord Consortium, a nonprofit research and development organization dedicated to transforming STEM education through technology. This material is based upon worked supported by the Moore Foundation and the National Science Foundation under several grants (DRL-1503196, DRL-1621301, DRL-1316874, DRL-1621176, DRL-1621299, DRL-1620874, DUE-1304485, and DRL-1435470).