Students making systems models

An accessible approach

BY DANIEL DAMELIN,
JOSEPH S. KRAJCIK,
CYNTHIA McINTYRE,
AND TOM BIELIK

From the large to the small, many phenomena can be conceptualized as sets of interacting parts that form a system with emergent properties. Understanding and thinking about phenomena from a systems perspective is critical in many areas of science, because the world is complex and interconnected in ways that can often be described best using system models. Defining a system and constructing a model of that system allows scientists to focus on variables that are critical to explaining a phenomenon. We expect our students, like real scientists, to explore systems and system modeling as a necessary step in developing scientific literacy. Although scientists often use a systems perspective to frame their studies, and *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013) have identified Systems and System Models as a crosscutting concept, we have found that students do not naturally think in terms of systems.

Teaching and learning about systems can be challenging with-

out the right tools and curricular supports. Using a systems approach takes practice and requires significant guidance from teachers and peers. The process involves describing appropriate boundaries, identifying what part of the system must be investigated to explain the phenomenon, and determining what is outside of the system. It also requires honing in on the key features or variables within a system that have a significant effect on its behavior and being able to specify *how* each variable influences the others.

Although a pedagogical approach focused on constructing and revising models to develop internal conceptual frameworks results in positive student gains

(Lehrer and Schauble 2006), most full-fledged modeling tools are too complex for students, especially students at the middle level. Although developing models is a complicated process, Hipkins, Bull, and Joyce (2008) found that, given appropriate supports, students could engage in systems thinking at earlier ages than one might expect.

We developed a tool to support students in designing and building models of systems that can be tested and revised. Our underlying design principles that guided the development of the tool included making it easy to represent the system under study, generating data without requiring students to write math-

ematical equations or do any programming, and visualizing the output in a productive way that encourages iterative model development.

Promoting student system modeling using SageModeler

SageModeler is a free, open-source tool that scaffolds learning so that young students, beginning in middle school, can engage in systems thinking through designing, building, and revising models (see Resources). Using the web-based SageModeler system modeling tool, students can explore a variety of systems, such as water and air quality in their communities, climate change, and ecosystems (see sidebar).

Scaffolding is available in several forms:

- visual representation of variables and relationships, which can be customized by students;

- simple drag-and-drop interface for constructing a systems diagram;

- ability to define functional relationships between variables without having to write equations; and

- an exploratory data-analysis environment designed for students.

Students start by using Sage-Modeler as a diagramming tool, which allows them to create their representation of a particular system, define the variables, and draw links to represent how factors impact each other within the system. A simple interface allows the user to represent each variable with an image taken from a public domain clipart site. Students can then drag and drop the images onto the main canvas and make linkages by connecting these variables to each other.

Although a great deal of learning and discussion can occur during the diagramming phase of system modeling, the next step is for learners to characterize the relationships between variables to see output from their model.

Using SageModeler in the classroom

SageModeler is a flexible tool that can be used to model a wide variety of phenomena. The following is one way to get students engaged in modeling:

1. Introduce the phenomenon through one or more techniques: reading/research, video, in-class demonstration, or student lab/activity.

2. Have students brainstorm variables that are part of the system to be modeled.

3. Ask students to hone in on key variables and build an initial model.

4. Bring the class together to discuss the models that students built.

5. Explore a particular aspect of the system in more detail, ideally in a way that will provide students with data or observations that can be compared with the output from their own model.

6. Revise models, share, and repeat.

The following phenomena work well with SageModeler:

- Climate change
- Kinetic molecular theory and gas behavior
- Magnetic forces
- Collisions, forces, and energy
- Evaporation
- Water quality
- Environmental effects on disease
- Weather patterns

See Resources for additional details on using SageModeler.

To avoid writing equations when specifying these relationships, SageModeler takes a semiquantitative approach to defining how one variable affects another. Initial variable values are set using a slider that goes from "low" to "high," and students use words with associated graphs to define the links between variables. For example, if "deforestation" is linked to "the amount of carbon dioxide in the air," students can set up a relationship that reads, "An increase in deforestation causes an *increase* in the amount of carbon dioxide in the air by *a little*." The italicized parts of the previous sentence are defined using pull-down menus and are associated with a simple graph showing that relationship (Figure 1). The links between variables also change visually to show those relationships. Blue arrows signify decreasing relationships and red ones signify increasing ones. The width of the line represents the amount of change (e.g., a thick line means the output changes "*a lot*" as the input changes, whereas a link that starts thin and gets wider toward the arrowhead means an increase or decrease by "*more and more*") (Figure 2).

FIGURE 1: Setting relationships between variables using words and graphs rather than equations
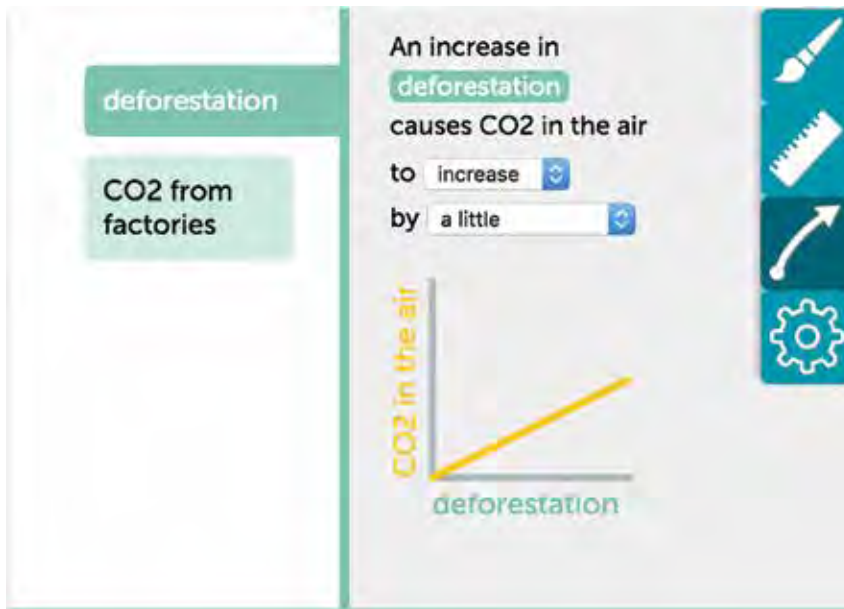

FIGURE 2: An example of an ocean acidification model

Defining relationships with words helps students overcome the mathematical obstacles typically associated with creating computational models and allows them to focus on a conceptual understanding of the relationships between variables. We also added an option that allows students to draw the relationship between two variables on a graph if none of the predefined relationships match how they think the two variables are connected.

Once a system has been diagrammed and the relationships between variables have been defined, the model can be run, generating output in the form of a table or graphs that provide students with feedback regarding the behavior of their model. Allowing students to test the results of their model can generate valuable dialogue in the classroom. We have observed students debating relationships in their models and revising their models as a result of examining and discussing their outputs with their teacher and their peers.

To better understand their system and improve their models, students can also compare the results of their model with an external data set, just as scientists do. SageModeler is embedded in the Common Online Data Analysis Platform (CODAP) (Finzer and Damelin 2015). CODAP is an intuitive graphing and data analysis platform that takes the outputs generated by the system model, as well as any other data source—from published data sets to results of computational models or data from sensors—and combines them into a single analytic environment.

Through an iterative process of building the system model, sharing and discussing it with others, testing it to observe its behavior, and comparing the output of the model to some other validating data set, students develop a deep conceptual understanding of the system at hand and build modeling skills that can be applied across disciplines and in new situations.

Developing curriculum to support systems thinking

We are currently developing project-based learning units that will engage middle and high school students in constructing models to explain phenomena and in revising their models to better fit comparison data (Krajcik 2015; see Resources).

The first unit helps students gain proficiency in the *NGSS* 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" (NGSS Lead States 2013). Students explore the driving question, "Why do fishermen need forests?" Designed for middle school students, this unit introduces several aspects of the carbon cycle, focusing on the transfer of carbon dioxide between the atmosphere, hydrosphere, and biosphere. As the unit progresses, students engage in hands-on activities, teacher demonstrations, readings, and inquiry investigations. They explore environmental data related to carbon sequestration in trees, carbon transfer, ocean acidification and its effects on aquatic species, and impacts on human nutrition and economy. Each of these explorations provides opportunities for students to engage in another cycle of designing, testing, sharing, and revision, making their models of ocean acidification better match the real world and increasing students' ability to apply this knowledge to other related topics.

Conclusion

The *Framework* and the *NGSS* identify Systems and System Models as one of the significant crosscutting concepts, and Developing and Using Models as one of the key science and engineering practices. Because there are few easily accessible tools designed for student construction of models, we created SageModeler to facilitate both student modeling and understanding of complex systems. When students engage in three-dimensional learning through building, testing, sharing, and revising their own models of complex systems, they take the necessary steps toward developing usable knowledge that can be applied more broadly in understanding the natural world. ●

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RESOURCES

SageModeler—*http://concord.org/projects/building-models#cc1*

Using SageModeler—*http://concord.org/sagemodeler-how-to*

Free curriculum units—*http://learn.concord.org/building-models*

Daniel Damelin [*ddamelin@concord.org*] is a technology and curriculum developer at the Concord Consortium in Concord, Massachusetts. **Joseph S. Krajcik** is the Lappan-Phillips Professor of Science Education and director of the CREATE for STEM Institute at Michigan State University in East Lansing, Michigan. **Cynthia McIntyre** is director of communications at the Concord Consortium in Concord, Massachusetts. **Tom Bielik** is a research associate at Michigan State University in East Lansing, Michigan.