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Supporting Secondary Students

in Building External Models to Explain Phenomena

By Dan Damelin and Joe Krajcik

Modeling, a central practice used in all science disciplines, is essential to the pursuit of scientific knowledge. Scientists develop, revise, and use models of relationships between variables to provide a predictive or causal account of scientific phenomena; engineers build models to test and revise design solutions. *The Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS) identify modeling as one of eight science and engineering practices. Indeed, students should engage in modeling to learn and use the same practices scientists and engineers regularly employ. However, there are few tools designed for students to easily construct models, so there is little research on how the use of a modeling building tool could affect the way students develop conceptual frameworks related to scientific phenomena.

Supporting Secondary Students in Building External Models is a collaborative project with Michigan State University and the Concord Consortium, funded by the National Science Foundation (NSF) to examine how to support secondary school students in constructing and revising models to explain scientific phenomena and design solutions to problems. External models are both concrete and visible to others, and may appear as a set of equations, a qualitative description of mechanisms, or a simulation. A mental model, on the other hand, refers to an internal, private framework of concepts used to represent an individual's understanding of some phenomenon or design solution. The purpose of both types of models is to explain what we see and predict what we will see next. The central tenet of the project is that increased student engagement with external models leads to measurable improvements in the quality and sophistication of students' conceptual understanding as represented by their internal models.

Introducing SageModeler

To build robust mental models, students need easy-to-use tools with which they can design, test, share, and discuss representations of these models. The centerpiece of this environment is a systems modeling tool. There are many types of models, but a significant number of phenomena are best represented using systems models. By constructing a systems model to represent a mental model, students can then test the outcome of their assumptions—what factors to include and how relationships between those factors produce a certain behavior or outcome.

We are developing a new web-based systems modeling tool—SageModeler—based on the MySystem concept mapping tool developed at the Concord Consortium, and on Model-It, a systems modeling tool developed by Elliot Soloway, Joe Krajcik, and their colleagues.* Our goal is to scaffold student learning so that young students, beginning in middle school, can engage in systems thinking at earlier stages in their conceptualization process.

Students can use SageModeler as a simple diagramming tool, then—with pedagogical support from teachers and a curriculum that supports modeling—specify relationships between factors. Defining these relationships as words (for instance, "as factor *a* increases, factor *b* increases by the same amount") relieves students of complex math, and allows them to focus on understanding simple relationships between variables (Figure 1). We will also make it possible for more mathematically sophisticated students to construct models that later can be refined using algebraic definitions, and extend the modeling features to include a traditional systems dynamics modeling approach.

Developing a robust mental model that has explanatory and predictive power occurs through a process of designing, testing, and refining external models. As with almost all dynamic model development, scientists compare the results of the model with some external data set in order to

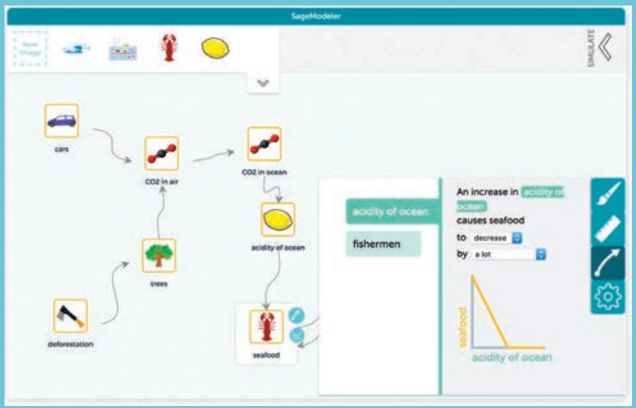

Figure 1. SageModeler can use words and pictures of graphs to set relationships between variables, making it possible for students to create a runnable model without the need for writing equations.

Figure 2. SageModeler embedded in CODAP allows for data analysis even when using semi-quantitative values and functions. Notice where the graph axes are "low" to "high" and how the table uses bars to represent relative values.

better understand a system and improve their models. To facilitate iterative development based on data analysis, SageModeler is embedded in CODAP, the Common Online Data Analysis Platform (Figure 2). CODAP is an intuitive graphing and data analysis platform that takes the outputs from the systems models, as well as any other data source—published data sets, such as ocean temperatures or CO_2 emissions, results of computational models like Next-Generation Molecular Workbench or NetLogo, or data from sensors—and combines them into a single analytic environment.

Instructional units

We will design, develop, and test several short project-based learning units that support students in developing and using models. Each unit will last approximately two to three weeks and will engage students in constructing models to explain phenomena and in revising their models to better fit comparison data.

Designed for the middle grades, our first three-week unit (Why do fishermen need forests?) introduces students to several aspects of the carbon cycle, focusing on transfer of carbon dioxide between the atmosphere, hydrosphere, and biosphere. Students create, test, evaluate, and revise their own models while exploring the concepts of carbon sequestration by trees, deforestation, transfer of carbon dioxide between the atmosphere and hydrosphere, ocean acidification and its effect on calcifying species, photosynthesizing species, biodiversity, food webs, and human nutrition and economy.

The instructional materials align with the NGSS to engage students in three-dimensional learning by using crosscutting concepts (systems and systems modeling, cause and effect, and energy and matter) with various scientific practices (particularly modeling, but also analyzing and interpreting data and engaging in argument with evidence) and disciplinary core ideas. The materials support students in building an understanding of the performance expectations from NGSS.

Research

Our research plan explores the effect of student-constructed external models on the development of their internal mental models or conceptual understanding. We propose that when students build external models, they develop connections among ideas, creating a network of ideas in their conceptual understanding. As students engage in the modeling process their understanding evolves and the framework of ideas that forms their conceptual understanding changes. New expressions of this understanding are demonstrated by a refinement of their systems model, forming a feedback loop between engagement with building external models and the development of a conceptual understanding.

We will examine the quality of student-created models, the potential of these models to provide feedback on students' understanding of a range of disciplinary core ideas, and the development of students' modeling capabilities. Our goal is to increase students' science learning by constructing external models and to explore student engagement with modeling as a scientific practice. For curriculum designed with this goal in mind, we believe SageModeler can help students engage in one of the most fundamental practices of science—building models to explain and predict phenomena—while developing more complex and nuanced understandings of scientific phenomena.

* Metcalf-Jackson, S., Krajcik, J., & Soloway, E. (2000). Model-It: A design retrospective. In M. Jacobson & R. Kozma (Eds.), *Advanced designs for the technologies of learning: Innovations in science and mathematics education*. Hillsdale, NJ: Erlbaum.

LINKS

Building Models
http://concord.org/building-models

SageModeler
http://concord.org/building-models/sage-modeler