A Learner-Centered Tool for Students Building Models

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At the heart of a working science literacy is the ability to create models that explain real-world phenomena. Just as professional scientists rely on technology for their modeling activities, students, too, can benefit from using computers to build models, to perform "thought experiments," and to gain insight into the behavior of complex systems. The problem is that modeling, as it is currently practiced and supported in software, is too difficult for pre-college students—it requires a great deal of prior knowledge and mathematical ability.

Through redefining the modeling task and applying learner-centered design techniques, we have created a new tool, Model-It, which demonstrates that modeling can be made accessible to high school students. Our approach to learner-centered design focuses on the implementation of scaffolding in software, to address the unique needs of learners. Scaffolding is an educational term that refers to providing support to learners while they engage in activities that are normally beyond their abilities.

In the next section, we identify three key scaffolding strategies, informed by educational and psychological theories of learning, and discuss how they were implemented in Model-It.

Implementing Scaffolding Strategies in Model-It

Grounding in experience and prior knowledge. A learning environment should allow learners to work with representations that are grounded in their prior experiences and knowledge. For example, Model-It begins by providing a set of familiar, pre-defined high-level objects with which to build a model. In the domain of stream ecosystems, these objects might include the stream, macroinvertebrate populations, and a nearby golf course. Objects are represented visually with digitized photographs and graphics (Figure 1). Students can also paste in pictures and create their own objects. For our classroom studies, the background graphic is a photograph of the actual stream the students studied; this personalized representation may help to ground learning in an authentic, meaningful context.

To build a model, students define the factors (measurable quantities) of each object, and define the relationships between factors. Model-It supports a qualitative, verbal representation of relationships, rather than requiring formal mathematical expressions. Students can define a relationship simply by selecting descriptors in a sentence. For example, "As stream phosphate increases, stream quality decreases by less and less" (Figure 2). This is another example of grounding, on a conceptual basis—learners can create relationships simply by representing them on

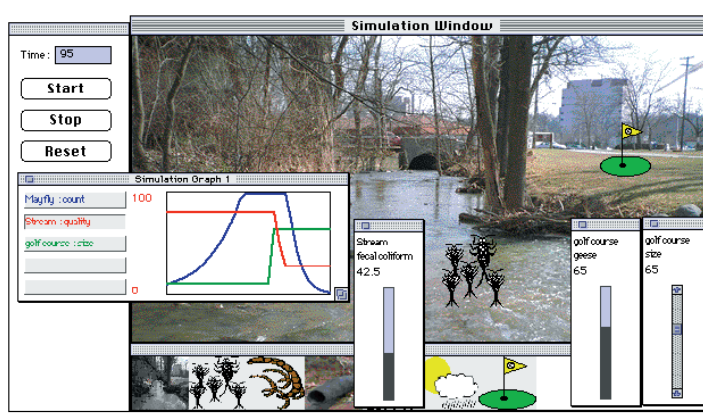

Figure 1.
Model-It's simulation window

the screen as English sentences (presumably the language of their prior knowledge and experience).

Bridging representations. New representations should be connected to the learner's current understandings through examples, analogies, and multiple visual representations. Multiple synchronized representations act as a bridge between current understandings and more expert-like techniques. Model-It, therefore, provides simultaneous, linked textual-to-graphical representations of relationships. Given a qualitative, verbal definition, the software translates the text into a quantitative, visual representation. For example, "decreases by less and less" is interpreted as shown by the graph in Figure 2. These simultaneous representations can support students in learning how to read and interpret a graph. Model-It provides a similar bridging link between the graph and a numerical table, from which the graph can be edited to more accurately represent students' understanding of a relationship.

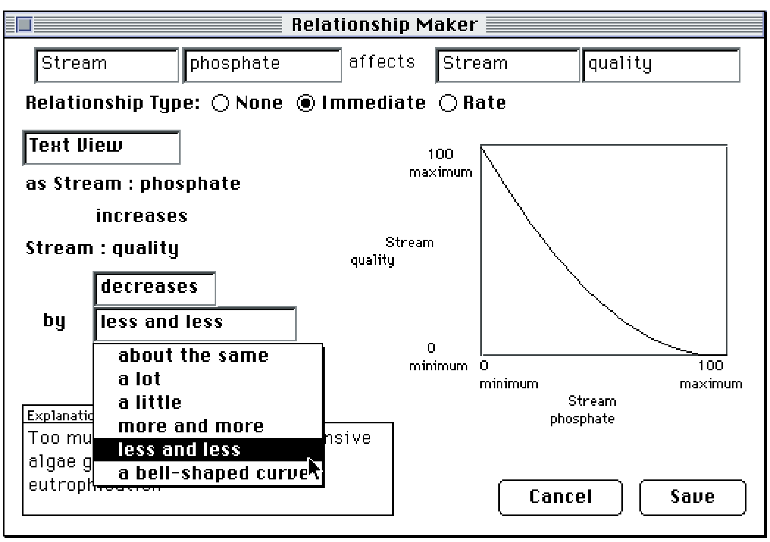

Figure 2.
Defining relationships

Coupling actions, effects, and understanding. An interactive learning environment should provide a tight coupling between the learner's actions, the visual feedback produced by the software as a result of those actions, and the learner's own mental representations of the phenomenon. Model-It provides this tight coupling as students run simulations to test their models (Figure 1). Students select factors to view using meters (vertical indicators) and graphs. During a simulation, meters and graphs provide immediate, visual feedback of the current state of the simulation. Students can directly manipulate current factor values even while the model is running, and immediately see the impact. "What if?" questions are generated and answered nearly simultaneously; hypotheses can be tested and predictions verified within moments. This interactivity may provide opportunities for students to refine and revise their mental models, by comparing the interactive feedback with their expectations. This interactivity may also help engage students with low motivation who might otherwise be uninvolved.

Results

Model-It has been used in three one- to two-week classroom studies, with 22 to 100 14- and 15-year-old students, for a total of over 1,200 student-hours of Model-It usage data. Each study culminated in the assignment of an open-ended modeling task, where students were asked to create their own models to represent some chosen ecological phenomenon. The final models typically exhibited reasonable scientific validity and significant complexity, with an average of at least 15 student-defined factors and relationships.

The open-ended modeling task gave students the flexibility to branch off and explore different topics, often in surprising directions. For example, to demonstrate pollution impacts on a stream, two students chose to put a golf course object into their model, and created a new factor, geese, whose fecal matter became a pollution source when washed into the stream. In a follow-up study where students were asked to build a model of any system they chose, examples ranged from the economics of a lemonade stand to the effects of drugs on the human body.

With Model-It, students appropriately focused on high-level concepts—what are the relationships in the system, what's still missing, and, just where does the oxygen in the stream come from, anyway? We found students were comfortable expressing themselves qualitatively, and once they had done the thought work of conceiving of a relationship, they were able to quickly add it to their model, and run more simulations to see the impact of their change on the system. In class discussions, students proudly and excitedly described how their models worked, and argued the merits of different representations. The bottom line is that the program works. We see students creating reasonable models within a short amount of time, and learning from the process, both about what it means to model, and about the systems they are modeling.

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