An Ambitious Proposal for a Common Scientific Cultural Heritage Based on Hands-On and Digital Modeling and Simulation

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This chapter proposes an ambitious program to develop a common scientific cultural heritage based on both hands-on and digital modeling and simulation. If this program is successful, freshmen entering college will have a common scientific culture actively acquired in a few very rich and highly developed modeling environments. They will add to this cultural heritage throughout their undergraduate and professional careers. In addition, citizens of all ages will be equipped to discuss public policy questions involving science.

Although the motivation for this program comes in part from its potential to capture students' attention using all the flash of electronic and hands-on games, its real motivation is the centrality of modeling. In this "information age," much has been made of the progression from information to knowledge and then to intelligence. The distinction between information and knowledge might be captured by the idea of a mental model, which organizes information and, especially, relationships into a form that enables us to understand, express, and analyze the world both as it is and as possible alternatives. Intelligence is the ability to build and apply mental models.

Two points are central to this chapter:

- The importance of, and synergy between, hands-on and digital modeling. For example, consider the refraction in Figures 1 and 2.
- Modeling is an active process. We propose a rich modeling environment in which students modify and build, as well as use, models.

This is a speculative chapter. Although we have bits and pieces, we are a long way from realizing the true dream. Figures 1 and 2 illustrate one very small aspect—refraction—of rich modeling of water environments. Figure 3 is a working mock-up showing how various interrelated ideas can be modeled in a rich setting. A student is studying color-dependent absorption of light at Fermat's Reef by lowering a white card and measuring the intensities of red, green, and

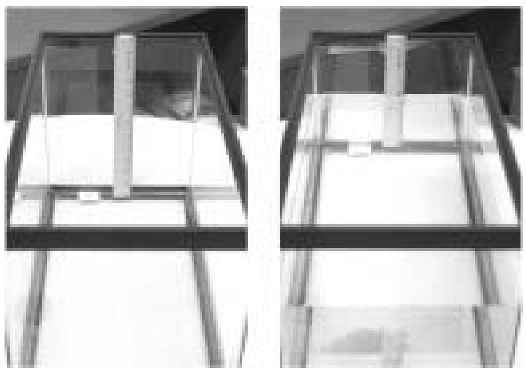

Figure 1. Hands-on modeling: refraction in a $12.95 aquarium.

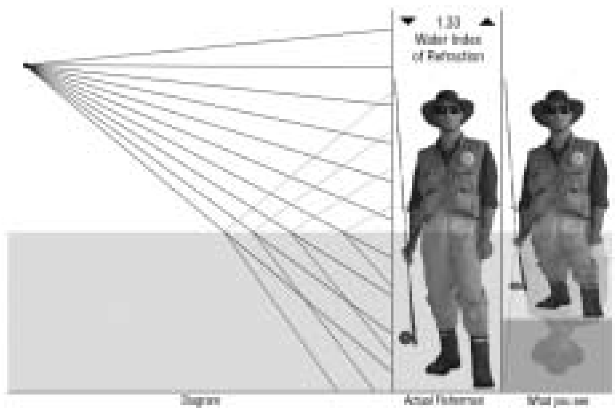

Figure 2. Digital modeling: refraction in Fermat's Pond.

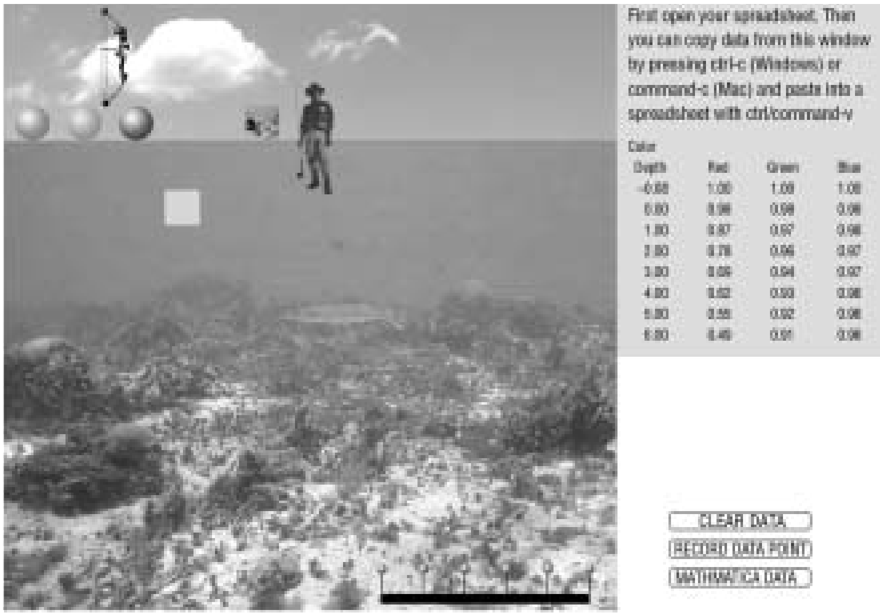

Figure 3. Color-dependent absorption of light at Fermat's Reef.

H. Adey and Karen Loveland. This example enables us to discuss both an incremental approach to modeling and modeling at various spatial and temporal scales. Finally, we choose this example because of its obvious importance.

The architecture of the digital models and the modeling environment we propose matches the architecture of an aquarium. For computer scientists, there are two key ideas: the modeling environment is database centric and object oriented.

The basic step in building a model is akin to buying an aquarium and filling it with water. This is called establishing the model framework. The framework is realized by a database that contains key spatially linked information (for example, the temperature and chemical composition of the water and the intensity and spectral composition of light). The model framework also determines how the database evolves (for example, the way in which chemicals diffuse and particulates settle).

blue light at various depths. Figure 4 illustrates the kind of currently available simulations (for example, the West Point Bridge Design Program) that can be built into rich environments. These are pale shadows of our eventual goal—immersive models that are sensory rich as well as content rich.

We discuss the big idea proposed here in the context of a still big but more specific example—modeling water environments. Our starting point is not digital but hands-on models. We choose this example because small hands-on and very rich models are commonly available—aquariums. We also recommend the excellent book *Dynamic Aquaria: Building Living Ecosystems* (2nd ed., 1998, Academic Press) by Walter

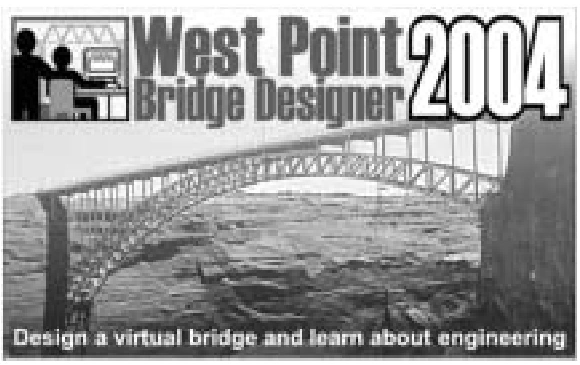

Figure 4. Designing and simulating a bridge.

Various objects interact with each other and with the water through the database. For example, fish consume oxygen and release carbon dioxide, and their activity depends on temperature. The external world is another set of objects, for example, sunlight or aquarium illumination, temperature control, and adding fish food are all modeled by objects interacting with the database.

The same ideas and architecture are used in many different water worlds—aquariums, ponds, lakes, portions of an ocean, rivers, and so forth. They are also used in many other situations, for example, the International Space Station or a cell.

In a first encounter with Fermat's Water Worlds, an elementary school student might work with a simple hands-on fish bowl, adding a few fish and plants and observing it over a period of days or perhaps weeks. At the same time, the same students might work with simple digital models. They could add plants or fish to a hands-on aquarium or a digital aquarium from a library of plants and fish. They could look at the characteristics of each possible fish (for example, reproduction or growth rates and rate of oxygen consumption) and plants (for example, rate of oxygen production). In a first encounter, the factors considered would be few and the complexity of the model low, but as students mature and return again and again to these worlds, the complexity would grow. As much as possible, digital models would track hands-on models. Nonetheless, we would exploit the low cost and potential of digital models to work with more complex models and to work at different spatial and temporal scales. Wherever possible, a library of digital models would be matched with hands-on models or even monitored habitats.

Initially, students would build models relying on libraries of objects and interactions, but more sophisticated students would be able to design every part of the model. For example, students might add commercial fishing to a model of a section of the ocean, and they would have to determine how the fishing would interact with the base model. They could experiment with the effects of different regulations.

Some of the technology of massive multiplayer games would be used to support complex distributed modeling with different players contributing different components of large collaborative models. All of this would be displayed in a sensory-rich way.

As students build a common scientific cultural heritage, they would experience the fun of experimentation. These rich worlds would serve as focal points unifying students' learning across boundaries of subject, time, and institution. They would provide almost game-like experiences with problem-solving and even contests. They would provide rich venues for both hands-on and digital collaboration. Our goals are rich modeling environments that can be used from elementary school through research and that can support both public policy decision-making and more sophisticated public discourse on key public policy questions.