MODELS-BASED Science Teaching

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EDUCATION

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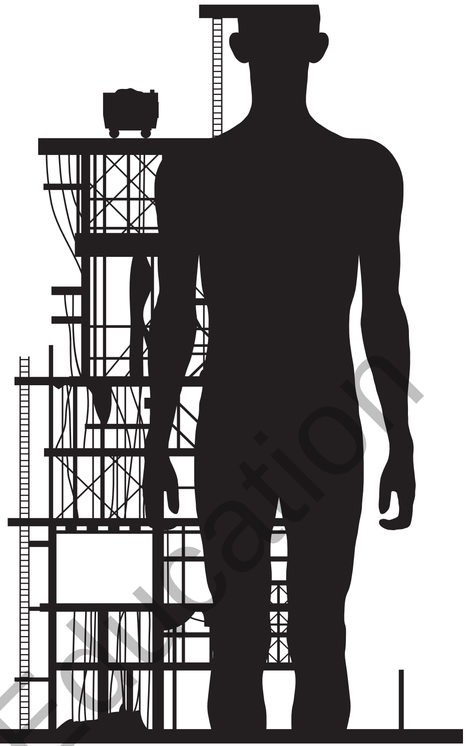
Chapter 1

MBST and the Nature of Models



Equipped with his five senses, man explores the universe around him and calls the adventure Science.

—Edwin Powell Hubble

What Is This Book About?

This book is about modeling: specifically, modeling in science education. Although the Benchmarks for Science Literacy (AAAS 1993) recommended that teachers use models and modeling as a framework for building science literacy, this approach has only recently gained ground in the professional literature. A number of science educators have advocated the use of models as a framework for science education (Matthews 1988; Gilbert and Boulter 2000). Research-based projects such as "Modeling Instruction" (Jackson, Dukerich, and Hestenes 2008) claim considerable success in using models as a framework for conducting inquiry in high school physics. The movement toward explaining science through models and modeling is a logical outgrowth of developments in the cognitive sciences, where mental models are being used to conceptualize the processes and products of thinking.

In this book, we will explore the concept of mental models and how they relate to human learning—specifically, the learning of science. Then we will look at how we can apply this understanding when we teach science. Gobert and Buckley (2000) define models-based teaching as "any implementation that brings together information resources, learning activities, and instructional strategies intended to facilitate mental model-building both in individuals and among groups of learners." Building upon this definition, you can use models-based teaching to help your students develop a better understanding of what science is; how it is practiced and how it fits into the broader domain of their thinking. That is, how they can use model building for context.

By *context*, I mean the explanatory framework of science—it's gestalt. *Gestalt* refers to a unitary whole that is greater than the sum of its parts. The gestalt of science is a unifying conceptualization of science that goes beyond its subject matter content and its techniques of investigation alone to include the relationship of science to (a) the ways in which we think and know, (b) our beliefs about what is true, (c) our beliefs about science, and (d) our assumptions about the role of science in society and culture.

Gestalt combines process, content, and context to give science instruction optimal meaning. Your students will not acquire this gestalt by learning content knowledge and engaging in lab experiences. They also need an overriding framework to pull these activities together in a meaningful way.

Gestalt is important because of the links it establishes with other domains of human activity. Few of your students will practice professional science after they leave school. Some of your students will go their entire lives without meeting a practicing scientist. Your students will become journalists and writers; politicians and business leaders; workers, educators, administrators, environmentalists; lobbyists, bloggers, and, most important of all, voters. In these and other roles, their knowledge of the gestalt—the context of science—will be at least as important as their knowledge of specific science content and their classroom science experiences.

"But," you protest, "there are only so many hours in a school year! I teach them science for an hour a day, and in that time I'm expected to cover a lot of content. I do some inquiry, but inquiry takes time. How do I teach this gestalt of science without losing time for other things?"

That is one of the benefits of a good framework. How you contextualize normal science activities is at least as important as how you actually conduct them. Models-Based Science Teaching (MBST) requires only a small amount of additional instructional time. From that investment, you can reap big benefits.

MBST frames science as a formal process for constructing descriptive and explanatory models. It defines all learning as a process of modeling. This proposition, although simple, has profound implications for teaching the

- Process of scientific investigation
- Nature of the products of science (content)

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- Purposes of science
- Limits of scientific knowledge
- Nature of learning and knowledge across fields
- Relationship between science and nonscience

Within this framework, we reap the added benefit of learning a great deal about ourselves as people. After all, we are all learners, whether or not we are scientists. Science is a process of learning—of modeling. So how is science different from the other ways that we learn? What claims can scientists really make about the knowledge they create? Can science really provide us with the ultimate answers to life, the universe, and everything?

To answer these questions, we first have to understand models. What are they? How do they work? Why do we use them? Once we have this background, we will be ready to proceed to a discussion of mental models, and their importance in human thinking.

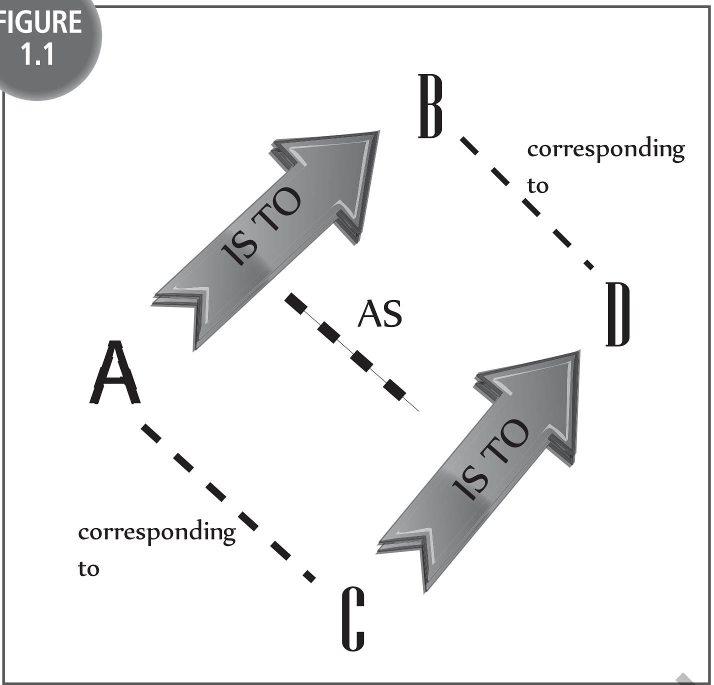
Defining Models

What is a model? You may think you already know the answer to this question; your students probably think they know too, unless they are very young. But their ideas of what a model is, and perhaps your own as well, will be narrower than the definition I present in this book. Chances are, when I talk to you about models, that you first envision concrete objects meant to resemble other objects for which they stand, such as model airplanes, toys, globes, and plastic human torsos.

First off, we need to be on the same page about what a model is. The term *model* has several legitimate meanings. For our purpose, I will define a model as a system of objects, symbols, and relationships representing another system (called a *target*) in a different medium (modified from Gilbert and Ireton 2003). Models may be concrete or abstract, but they all share certain common properties; for example, they all function through analogy (Leatherdale 1974). Analogies are systems that have the general form, "A is to B as C is to D," shown in Figure 1.1. In this diagram, the features A and B (also called *attributes*) have the same relationship to each other as do the corresponding features, C and D, in the target. Attribute A corresponds to attribute C: while attribute B corresponds to attribute D. Otherwise, A/B and C/D are in different systems.

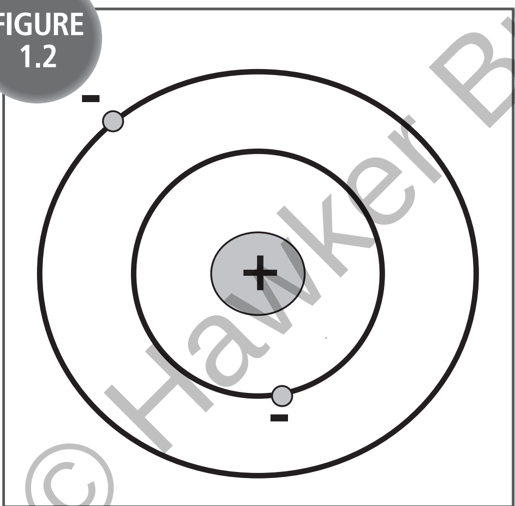
An example of a clearly analogical scientific model is Rutherford's "solar system" model of the atom, shown in Figure 1.2. The Rutherford model of the atom places the nucleus at the center of the atom, corresponding to the Sun at the center of the solar system. The electrons of the atom in orbit around the nucleus correspond to the planets orbiting the Sun (they have the same relationship). This is a simple model with an analogy that is easy to understand and therefore is effective, even if it's partially wrong.

FIGURE 1.1



Analogies are comparisons between systems where the relationships between corresponding characteristics, or attributes, are the same or similar. All models are analogical to their targets.

FIGURE 1.2



The early Rutherford Atom resembled our solar system, where the nucleus corresponded to the Sun, and the electrons correspond to the planets. Electrons and planets orbited the nucleus and Sun respectively.

The process of relating A to C and B to D is called *mapping*. For an analogy to work, we have to be able to map at least some attributes of the target onto the model and vice versa. If the mapping is easy for us, the model is highly *transparent*. The Rutherford atom model is transparent *if* you are familiar with the solar system.

Other models are not so transparent. For example, the cosmological model known as M-Theory (a.k.a., "String Theory") proposes that the universe is comprised of oscillating one-dimensional lines. What does a one-dimensional string look like? What's it made of? I don't really know. Neither, I suspect, does anyone else.

It's hard enough to visualize a one-dimensional line of some undefined composition, but M-theory also says that the universe has eleven dimensions (not the four we are familiar with in space-time). The additional seven dimensions are hard for the average person to understand because they have no familiar counterparts in the perceived world. They are difficult to explain in nonmathematical terms because they *are* mathematical models. The analogy to strings is simply a way to make the theory more concrete.

The string theory example clarifies the need for *rules of interpretation* through which we can define the relationships among the corresponding attributes of target/model systems. For scale models like model airplanes, the rules are usually simple. We recognize the visual similarity right away. But when models don't look anything like their targets, rules are needed. You must know, for example, the rules of interpretation for any mathematical model, even one as simple as "2 + 2 = 4." A "2" doesn't resemble anything in nature, nor does an "=" sign. These symbols represent abstract qualities (ideas) and nothing physical. You must know what they mean and how to use them.

Table 1.1 identifies several classes of common models. Some look nothing like their targets, but all of them are models under our previous definition. Like a landscape painting, each of them allows us to glimpse some isolated aspect of reality to which we might not otherwise have access; but none of them describes their target fully, nor should any of them be mistaken for their targets. This may seem intuitively obvious, but the confusion of models with their targets is a common source of misunderstanding.

The accuracy with which a model represents its target is called its *fit*. We construct a model for a particular purpose and its fit is a measure of how well we achieve that goal. A good model may be a poor fit if we use it for the wrong purpose. Fit and transparency are two different things. A highly transparent model may be a poor fit if it's used for the wrong purpose. The best road map in the world will probably not be a very good model for a pilot cruising at 10,000 feet.

All models are simplifications of their targets. Unnecessary details obscure the meaning of the model. But even more than that, a model is not necessary if you can work with the target. We make models because we cannot use or study the target usefully or practically in our situation. Most models are dramatically simplified, so that we are focused only on the elements that are most important to us.

Because models are simplified, they are always in some ways inaccurate and misleading. A road map, for example, cannot tell us much about the conditions of the road. A graph of an event is only marginally like the event in real time. Models

TABLE 1.1

Examples of Models in Several Categories

Class of Models	Examples
Concrete models	Scale models
	Mockups
	Figurines
Pictorial/graphic models	Blueprints
	Photographs
	Diagrams
Mathematical models	Formulae and equations
	Graphs
	Topographic maps
Verbal models	Descriptions
	Scripts
	Directions
Simulation models	Simulation games
	Cockpit simulators
	Crash test dummies
Symbolic models (semiotic models)	Words, numbers
	Mathematical figures
	Stoplights, stop signs

always lack some information, and they often suffer from unavoidable distortions caused by the change in medium. A typical road map does not tell you about hills, for example.

Despite these shortcomings, models are extremely valuable to us. In fact, as we shall see, they are indispensible. You may not be aware of it, but you construct models every day. These models exhibit all of the characteristics we have just discussed. They are purposeful, simplified, and often inaccurate and misleading. You are constructing one such model even as you read this page: it is a mental model through which you are making sense of these otherwise meaningless strings of symbols we call words.

Mental models are the foundations for understanding MBST. We will introduce and elaborate on them in the next chapter.

Summary

Models-Based Science Teaching is an approach to framing science built upon current metaphors and models in cognitive and computer sciences. In MBST, science is defined as a process of building descriptive and explanatory models of natural phenomena.[1] MBST incorporates into its own explanatory framework the theoretical notion of mental models.

Models are analogical systems that represent other systems, called targets. All models have certain defining characteristics: They are purposeful, simplified, and frequently can be misleading unless you understand the rules for interpreting them. Virtually anything we create to represent something else is a model.

Normally we strive to build models that are transparent and that fit the target best for our particular purpose. Any given target may be represented in different ways for different purposes. Mental models have the same characteristics that all models have.

For Discussion

1. Identify the target, parallel relationships, and corresponding attributes of (a) a world globe, (b) a street map, and (c) a line graph showing the change of water pressure with increasing depth.
2. Explain how each of these models is simplified and erroneous in comparison to their targets.
3. You are 5'6" tall and weigh 120 lbs. You are struck by an alien ray. Suddenly you triple in size in all three spatial dimensions. What happens to your weight? What problems might this cause you?

[1] A phenomenon is any observable event or occurrence.