MODELS (11B)

A model of something is a simplified imitation of it that we hope can help us understand it better. Scientists spend a good deal of time building, testing, comparing and revising models—whether mathematical, physical, or conceptual—and using them to communicate and get ideas about how the real world works. Tables used in determining insurance payments, projections about endangered species, non-destructive testing of bridges, and weather forecasting are all based on models. When a model does not mimic a phenomenon well, the nature of the discrepancy is a clue to how the model can be improved. Models may also mislead, suggesting characteristics that are not really shared with what is being modeled.

The map is organized around two strands—*uses of models* and *limitations of models*. In the elementary grades, the focus is on uses of a variety of models as communication devices and, when the things being modeled are readily observable, on how the models are like and unlike those things. In middle school, the focus is on models of phenomena not accessible through direct observation and on the role of various models, including simulations, in helping us think about phenomena. In high school, the focus is on what can and cannot be learned from models, including computer-based models.

Maps in Chapter 2: THE NATURE OF MATHEMATICS are closely related to the ideas on this map. In particular, the **MATHEMATICAL MODELS** map in *Atlas 1* addresses more extensively the processes of mathematical modeling that are touched on here.

NOTES

The K-2 benchmark "Many toys are like real things in some ways…" builds on a common understanding of models as three-dimensional miniatures of objects but notes similarities between toys and the real things in terms of what they do in addition to what they look like. New benchmarks at the grades 3-5 and 6-8 levels point out ways in which models may differ from what they represent and the need to consider whether a model's behavior matches key aspects of what is being modeled.

The high-school benchmark 11B/H3 includes two fairly sophisticated ideas: (a) a model can be tested by comparing its predictions to observations, and (b) a close match between predictions based on the model and observations does not mean that another model might not work equally well or better.

Numerous off-map connections highlight the importance of models to various aspects of science and engineering.

RESEARCH IN *BENCHMARKS*

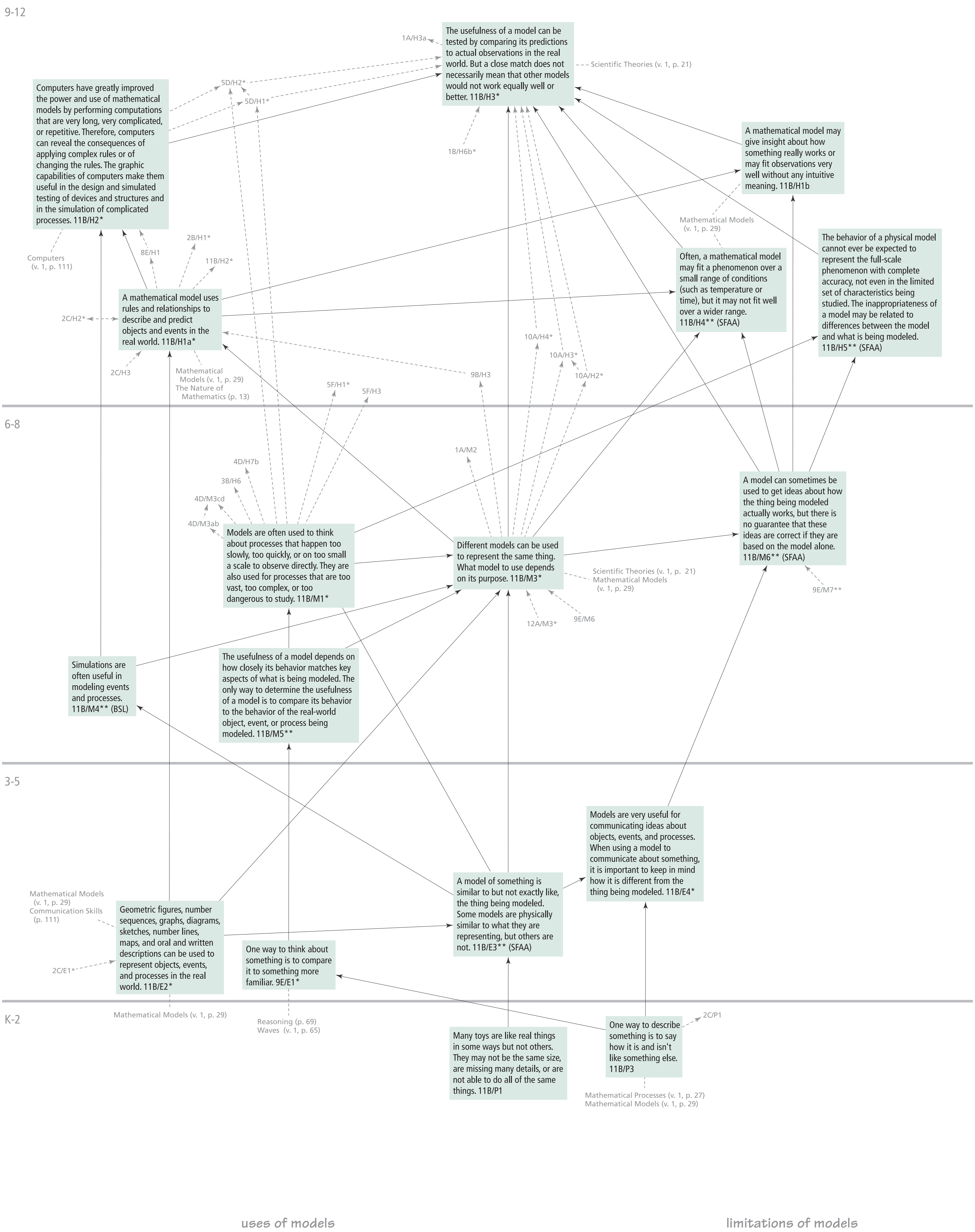
Students in lower elementary grades have some understanding that models can be used to show how something works, but they believe that perceptual similarity between the model and what it is used to represent is very important when developing or evaluating models (Penner, Giles, Lehrer, & Schauble, 1997). With repeated cycles of modeling and reflection, lower elementary students can focus more on similarities in function and less on perceptual similarities, and upper elementary students can understand the need for symbolic conventions (rather than only physical resemblance) when developing maps, diagrams, and other related display notations (Lehrer & Schauble, 2000).

Prior to instruction, or after traditional instruction, many middle- and high-school students continue to focus on perceptual rather than functional similarities between models and their referents, and think of models predominantly as small copies of real objects (Grosslight, Unger, Jay, & Smith, 1991; Treagust, Chittleborough, & Mamiala, 2002; Schwartz & White, 2005). Consequently, students often interpret models they encounter in school science too literally and unshared attributes between models and their referents are a cause of misunderstanding (Coll, France, & Taylor, 2005; Harrison & Treagust, 1996). Some middle- and high-school students view visual representations such as maps or diagrams as models, but only a few students view representations of ideas or abstract entities as models (Grosslight et al., 1991).

Many middle- and high-school students think that models are useful for visualizing ideas and for communication purposes (Schwarz & White, 2005; Grosslight et al., 1991). Only a few students think that models are useful in developing and testing ideas and that the usefulness of a model can be tested by comparing its implications to actual observations (Grosslight et al., 1991).

Middle-school and high-school students accept the idea that scientists can have more than one model for the same thing (Grosslight et al., 1991). However, having multiple models may mean for them that one could have literally a different view of the same entity, or that one could emphasize different aspects of the entity—omitting or highlighting certain things to provide greater clarity. Students are rarely aware that there could be different models to explain something or to evaluate alternative hypotheses. They find multiple model use in school science confusing and rarely use multiple models to think about phenomena; even if they do, the idea that one model is "right" and "real" persists (Harrison & Treagust, 1996, 2000). Students may know that models can be changed, but changing a model for them means (typical of high-school students) adding new information or (typical of middle-school students) replacing a part that was made wrong (Grosslight et al., 1991).

Developing and evaluating models *combined* with explicit instruction and reflection about the nature of models and modeling for an extended period of time can be effective in helping middle-school students make progress toward the following ideas: Models are not necessarily physical objects but could be conceptual representations that help scientists to predict and explain; there can be multiple models for the same phenomenon; and models are useful in visualization, predicting phenomena, and conducting investigations that are not otherwise possible (Schwarz & White, 2005). The ideas that scientists revise their models in light of new insights or new data and that not all models are of equal value may be harder to develop (Schwarz & White, 2005).


9-12
The usefulness of a model can be tested by comparing its predictions to actual observations in the real world. But a close match does not necessarily mean that other models would not work equally well or better. 11B/H3*
1A/H3a
Scientific Theories (v. 1, p. 21)
Computers have greatly improved the power and use of mathematical models by performing computations that are very long, very complicated, or repetitive. Therefore, computers can reveal the consequences of applying complex rules or of changing the rules. The graphic capabilities of computers make them useful in the design and simulated testing of devices and structures and in the simulation of complicated processes. 11B/H2*
5D/H2*
5D/H1*
1B/H6b*
A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning. 11B/H1b
Mathematical Models (v. 1, p. 29)
Computers (v. 1, p. 111)
8E/H1
2B/H1*
11B/H2*
Often, a mathematical model may fit a phenomenon over a small range of conditions (such as temperature or time), but it may not fit well over a wider range. 11B/H4** (SFAA)
The behavior of a physical model cannot ever be expected to represent the full-scale phenomenon with complete accuracy, not even in the limited set of characteristics being studied. The inappropriateness of a model may be related to differences between the model and what is being modeled. 11B/H5** (SFAA)
2C/H2*
A mathematical model uses rules and relationships to describe and predict objects and events in the real world. 11B/H1a*
2C/H3
Mathematical Models (v. 1, p. 29)
The Nature of Mathematics (p. 13)
10A/H4*
10A/H3*
10A/H2*
9B/H3
5F/H1*
5F/H3
6-8
1A/M2
4D/H7b
3B/H6
4D/M3cd
4D/M3ab
Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly. They are also used for processes that are too vast, too complex, or too dangerous to study. 11B/M1*
Different models can be used to represent the same thing. What model to use depends on its purpose. 11B/M3*
A model can sometimes be used to get ideas about how the thing being modeled actually works, but there is no guarantee that these ideas are correct if they are based on the model alone. 11B/M6** (SFAA)
Scientific Theories (v. 1, p. 21)
Mathematical Models (v. 1, p. 29)
9E/M7**
12A/M3*
9E/M6
Simulations are often useful in modeling events and processes. 11B/M4** (BSL)
The usefulness of a model depends on how closely its behavior matches key aspects of what is being modeled. The only way to determine the usefulness of a model is to compare its behavior to the behavior of the real-world object, event, or process being modeled. 11B/M5**
3-5
Models are very useful for communicating ideas about objects, events, and processes. When using a model to communicate about something, it is important to keep in mind how it is different from the thing being modeled. 11B/E4*
Mathematical Models (v. 1, p. 29)
Communication Skills (p. 111)
Geometric figures, number sequences, graphs, diagrams, sketches, number lines, maps, and oral and written descriptions can be used to represent objects, events, and processes in the real world. 11B/E2*
2C/E1*
A model of something is similar to but not exactly like, the thing being modeled. Some models are physically similar to what they are representing, but others are not. 11B/E3** (SFAA)
One way to think about something is to compare it to something more familiar. 9E/E1*
K-2
Mathematical Models (v. 1, p. 29)
Reasoning (p. 69)
Waves (v. 1, p. 65)
Many toys are like real things in some ways but not others. They may not be the same size, are missing many details, or are not able to do all of the same things. 11B/P1
One way to describe something is to say how it is and isn't like something else. 11B/P3
2C/P1
Mathematical Processes (v. 1, p. 27)
Mathematical Models (v. 1, p. 29)
uses of models
limitations of models