Practice 2

Developing and Using Models

Scientists construct mental and conceptual models of phenomena. Mental models are internal, personal, idiosyncratic, incomplete, unstable, and essentially functional. They serve the purpose of being a tool for thinking with, making predictions, and making sense of experience. Conceptual models, the focus of this section, are, in contrast, explicit representations that are in some ways analogous to the phenomena they represent. Conceptual models allow scientists and engineers to better visualize and understand a phenomenon under investigation or develop a possible solution to a design problem. Used in science and engineering as either structural, functional, or behavioral analogs, albeit simplified, conceptual models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of their application and the precision of their predictive power, it is important to recognize their limitations.

Conceptual models are in some senses the external articulation of the mental models that scientists hold and are strongly interrelated with mental models. Building an understanding of models and their role in science helps students to construct and revise mental models of phenomena. Better mental models, in turn, lead to a deeper understanding of science and enhanced scientific reasoning.

Scientists use models (from here on, for the sake of simplicity, we use the term "models" to refer to conceptual models rather than mental models) to represent their current understanding of a system (or parts of a system) under study, to aid in the development of questions and explanations, and to communicate ideas to others [13]. Some of the models used by scientists are mathematical; for example, the ideal gas law is an equation derived from the model of a gas as a set of point masses engaged in perfectly elastic collisions with each other and the walls of the container—which is a simplified model based on the atomic theory of matter. For more complex systems, mathematical representations of physical systems are used to create computer simulations, which enable scientists to predict the behavior of otherwise intractable systems—for example, the effects of increasing atmospheric levels of carbon dioxide on agriculture in different regions of the world. Models can be evaluated and refined through an iterative cycle of comparing their predictions with the real world and then adjusting them, thereby potentially yielding insights into the phenomenon being modeled.

Engineering makes use of models to analyze existing systems; this allows engineers to see where or under what conditions flaws might develop or to test possible solutions to a new problem. Engineers also use models to visualize a design and take it to a higher level of refinement, to communicate a design's features to others, and as prototypes for testing design performance. Models, particularly modern computer simulations that encode relevant physical laws and properties of materials, can be especially helpful both in realizing and testing designs for structures, such as buildings, bridges, or aircraft, that are expensive to construct and that must survive extreme conditions that occur only on rare occasions. Other types of engineering problems also benefit from use of specialized computer-based simulations in their design and testing phases. But as in science, engineers who use models must be aware of their intrinsic limitations and test them against known situations to ensure that they are reliable.

GOALS

By grade 12, students should be able to

- Construct drawings or diagrams as representations of events or systems—for example, draw a picture of an insect with labeled features, represent what happens to the water in a puddle as it is warmed by the sun, or represent a simple physical model of a real-world object and use it as the basis of an explanation or to make predictions about how the system will behave in specified circumstances.
- Represent and explain phenomena with multiple types of models—for example, represent molecules with 3-D models or with bond diagrams—and move flexibly between model types when different ones are most useful for different purposes.
- Discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications. Refine a model in light of empirical evidence or criticism to improve its quality and explanatory power.
- Use (provided) computer simulations or simulations developed with simple simulation tools as a tool for understanding and investigating aspects of a system, particularly those not readily visible to the naked eye.
- Make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions.

PROGRESSION

Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. Students should be asked to use diagrams, maps, and other abstract models as tools that enable them to elaborate on their own ideas or findings and present them to others [15]. Young students should be encouraged to devise pictorial and simple graphical representations of the findings of their investigations and to use these models in developing their explanations of what occurred.

More sophisticated types of models should increasingly be used across the grades, both in instruction and curriculum materials, as students progress through their science education. The quality of a student-developed model will be highly dependent on prior knowledge and skill and also on the student's understanding of the system being modeled, so students should be expected to refine their models as their understanding develops. Curricula will need to stress the role of models explicitly and provide students with modeling tools (e.g., Model-It, agent-based modeling such as NetLogo, spreadsheet models), so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models.