USING MODELING AND SIMULATION
IN SCIENCE TEACHING

(H. Weller, EDW 472/SMS 491, Spring 2007)

MODELS AND MODEL BUILDING (Gilbert & Ireton, 2003)

- Model and target: "A model is a system of objects or symbols that represents some aspect of another system, called its **target**" (p. 1).

- Models in our daily lives: "Models are far more common in our daily lives than most of us realize. Certainly we recognize some models because they are so obvious, as in the statement, "The tornado roared through town like a giant vacuum cleaner!" (p. 3).

- Danger of misconceptions from modeling: "Model building is at the heart of learning; for models to be useful, we must clearly distinguish models from their targets. Otherwise we can end up with misconceptions about both what we have learned and the process of learning itself" (pp. 1-2).

- Model building by students: "Model building can help students assemble their seemingly fragmented knowledge about concepts and relationships into larger, more clearly understood constructs" (p. vii).

EXPRESSED MODELS IN SCIENCE (Gilbert & Ireton, 2003, pp. 9-16)

"If we wish to communicate with others, we must develop the means to do so. We do this by creating representations of our mental models. These representations are collectively known as 'expressed models'" (p. 9).

Concrete Models

Concrete models are tangible material models that we can generally interpret with great ease.

- Scale Models: Scale models are intended to look like their targets. They facilitate recognition, but also may be used to identify features of the targets that are of particular interest (e.g., a particular volcanic cone). Scale models tend to be static. The functional similarities they may share with their targets tend to be very limited. *Examples*: A plastic model of a space shuttle, a plaster model of a particular mountain.

- Functional Concrete Models: Functional concrete models are intended to represent certain functional relationships of their targets. They have relatively less emphasis on retaining scalar relationships and on accuracy of appearance. They may well distort the relative sizes and positions of various bodies of the system, in order to illustrate their arrangements. These diagrams can be highly misleading when they are used for instruction, since students may not be aware of these distortions. *Example*: A classroom model of the solar system, a pictorial diagram of the solar system.

- Diagrammatic Models: In diagrammatic models, words ands symbols represent various objects and relationships, rather than representing a scene directly. *Examples*: systems diagrams, flow charts, blueprints, concept maps, topographical maps, and similar kinds of two-dimensional line drawings.

- Mathematical Models: Mathematical models are based on quantitative values and relationships. *Examples*: simple mathematical relationships (e.g., =, <, >), formulas, graphs, and computer models.

- Formulas and Equations: Formulas and equations are abstract models that have propositional formulas (e.g., $F = ma$). Equations are mathematical relationships. Though used in science, they reside in the domain of mathematics. Unlike science, mathematical models cannot be validated by observations—they are governed instead by internal logic.

- Computer Models: Computer models are mathematics-based constructs. They are most often used to create images of phenomena, to find and test relationships in complex systems, and to test multiple hypotheses. *Examples*: Web-based applets which provide visual models of the relationship of (usually) two variables; simulations that show visual models of complex phenomena (with or without data entry by the learner); computer-based tools to manipulate massive databases, which allow modeling of complex “what if?” questions.

Abstract Models

- Verbal-Theoretical Models: All structured wrtings are verbal models. Words organized into sentences represent mental models that, in turn, represent real entities in the external or internal environment. Some, though not all, of such models are theories. *Example*: the scientific theory of the evolution of species is a model constructed from the factual evidence and the inferences of science.

  - *Theoretical models*: Theoretical models are comprised of ideas. Theoretical models are data-based. They are not imaginary creations without a basis in fact; rather they are based on shared observations, recorded as data.

  - *Hypothetical models*: Hypothetical models are proposed causal links or explanations for something we observe or infer. Like theoretical models, hypothetical models develop from preexisting ideas and observations. Like theoretical models they are inferences.

- Similes, Analogies, and Metaphors: All models are analogical by nature. But an analogy is a proposition of the form “A is to B, as C is to D, where the A-B and the C-D systems have a model-target relationship.

CHARACTERISTICS OF ALL MODELS (Gilbert & Ireton, 2003, pp. 16-17)

- Artificial: All models are human constructs, even if they make use of an existing system or object. *Example*: The Earth is round like an orange.

- Utilitarian: Models are constructed to serve particular purposes. Information is often deliberately omitted from a model in order to reveal a desired target. *Example*: A classroom model of the Earth may be useful for geographic relationship, but not useful for geologic processes.

- Simplified: Models are generally far simpler and contain less information than their targets. Because of this simplification, a model lacks the effects of variables – or attributes – that may be present in its target.

- Interpreted: All models must be understood and interpreted on their own terms. Some require more interpretation than others. *Example*: A scale model is generally pretty clear on its face, but a road map requires the user to consult the map's key to make sense of scale, road types, town sizes, etc.

- Imperfect: Models should never be considered perfect or complete representations of their targets. Only the target can be perfect. Models are 'right' or 'wrong' only in relation to criteria that define their "goodness of fit." Models imperfectly and probabilistically represent their targets. There are always errors in relation to their fit.

USEFULNESS OF A MODEL IS DETERMINED BY (its "goodness of fit" to the target for our purposes, which is determined by): (Gilbert & Ireton, 2003, p. 17)

- Relatedness to other models (esp. other models of the same target): Also termed "consistency." How well does it fit with other models?

- Transparency: A measure of how obviously the model fits the target. Some models are very transparent, while others are opaque. When a model is opaque, we don't really get a good sense of what is being represented. *Example*: The metaphor inherent in using the term "string" to describe the smallest entity in the universe. Because the term is mathematical, the use of this physical metaphor is probably opaque to many people.

- Robustness: A measure of how insensitive the model is to changes in its assumptions. In general, the more assumptions needed to link the model to the target, the greater the likelihood that the model will need to be changed or discarded later. The model is robust if it requires few assumptions to be understood.

- Fertility: A measure of how much the model explains. The best models explain more about their targets than lesser models targeting the same system. The most fertile models give rise to new understanding and broad insight.

- Ease of Enrichment: A measure of how easy it is to add to and extend the model. All other things being equal, better models are easier to extend and enrich.

SOLVING ONLY THE MODEL WITHOUT SOLVING THE REAL-WORLD PROBLEM (Weller, 1992, pp. 330-331)

- Employing Kliebard's (1982, p. 14) words of warning on the tendency of metaphors to become literal, the user's 'willing sense of make-believe is converted into a literal prison.'

- A caveat borrowed from the field of computer simulation cautions that no one solves the problem; everyone solves the model (p. 331). Therefore, "if the model does not possess a sufficiently accurate representation, we can easily have 'junk input' and 'junk output'" (Balci, 1990, p. 25).

INSTRUCTIONAL COMPUTER SIMULATIONS (Weller, 1996, pp. 467-468)

- Definition of a simulation: "A program that allows the user to interact with a computer representation of either a) a scientific model of the natural or physical world or b) a theoretical system.

- Omits distracting features: "Typically, distracting features are omitted from the representation to enhance particular instructional goals."

- User alters the state of the program: "An interactive program 'enables the student to change the model from a given state to a specified goal state by directing it through a number of intermediate states. Thus the program accepts commands from the user, alters the state of the model, and, when appropriate, displays the new state' (Thomas & Hooper, 1991, p. 509).

- Strength of a simulation: "The strength of a simulation, according to Thomas and Hooper (1991, p. 509), is that it 'forces the students to search their memory for knowledge that relates to the problem being solved, assimilate that knowledge into a solution, and evaluate the result."

- Weakness of a simulation: "The weakness of a simulation is that it 'only indirectly indicates whether a student's understanding is correct and provides no new knowledge beyond what the student possesses or can create' (Thomas & Hooper, p. 509)."

- Science Microworlds: "In recent years, science microworlds, logical extensions of the simulation, have emerged. These are highly complex simulations that enable users to explore a particular problem by inventing their own activities and experimenting, testing, and revising hypotheses (Simonson & Thompson, 1994)."

- Typical instructional uses: "Based upon how a simulation is used for study, Thomas and Hooper (1991) classified simulation into the following 4 categories:
  1. Experiencing Simulations: Are used to set the stage, cognitively or affectively, for future learning and are used before formal presentation of the material to be learned.
  2. Informing Simulations: Are used to transmit information to the student and to supplement or replace the lecture or textbook as a means of initial formal exposure to a topic.
  3. Reinforcing Simulations: Apply knowledge in the same context in which it was learned and are used to strengthen specific learning objectives.
  4. Integrating Simulations: Aid the student in integrating separate facts, concepts, and principles into functional units and assimilating them with other units. They are used in any situation where several knowledge elements have been learned independently and need to be applied collectively.

REFERENCES

- Balci, O. (1990). Guidelines for successful simulation studies. In O. Balci, R. P. Sadowski, & R. E. Nance (Eds.), Proceedings of the 1990 Winter Simulation Conference (pp. 25-32). Piscataway, NJ: IEEE.

- Gilbert, S. W., & Ireton, S. W. (2003). Understanding Models in Earth and Space Science. Arlington, VA: NSTA Press.

- Kliebard, H. M. (1982). Curriculum theory as metaphor. Theory Into Practice, 21(1), 11-17.

- Simonson, M. R., & Thompson, A. (1994). Educational Computing Foundations (2nd ed.). New York: Merrill.

- Thomas, R., & Hooper, E. (1991). Simulations: An opportunity we are missing. Journal of Research on Computing in Education, 23(4), 497-513.

- Weller, H. G. (1996). Assessing the impact of computer-based learning in science. Journal of Research on Computing in Education, 28(4), 461-485.

- Weller, H. G., & Hartson, H. R. (1992). Metaphors for the natures of human-computer interaction in an empowering environment: Interaction style influences the manner of human accomplishment. Computers in Human Behavior, 8, 313-333.