Modeling Theory of Cognition—Theoretical Foundation of Modeling Instruction

Author's Note: One of the reasons I greatly appreciate Modeling Instruction is the underlying Modeling Theory of Cognition developed by Dr. David Hestenes. The Modeling Theory of Cognition provides the philosophical foundation for the pedagogy of Modeling Instruction; combining these two ideas results in the powerful learning found in classrooms that fully implement the pedagogy Modeling Instruction. Most of the following information was published in Chapter 2 of my dissertation; for more information, visit nathantbelcher.com/edd-program-writings or the papers in the References section.

The Modeling Theory of Cognition uses ideas from constructivism to posit that humans construct mental models to understand the world. Figure 1 provides a prototypical example of cognition, which is the comprehension of a narrative.

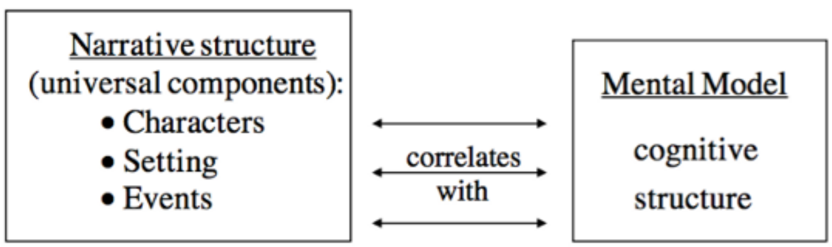

Figure 1. Prototypical example of cognition as the construction of a narrative; the narrative generates construction of a mental model. From "Modeling Theory and Modeling Instruction for STEM Education" by D. Hestenes, 2015, *epiSTEME 6 International Conference to Review Research on Science, Technology and Mathematics Education*. Copyright 2015 by David Hestenes. Reprinted with permission.

The narrative may be read or heard using language (for example, telling a story) or observed using the senses (for example, a hunter using hoof prints to track a deer); both methods generate a mental model. The use of language between two people activates a mental model for both the producer and receiver, facilitating a coordination of mental models between the producer and receiver. In this framing of cognitive linguistics, known as cognitive semantics, "language does not refer directly to the world, but rather to mental models and components thereof! Words serve to activate, elaborate or modify mental models" (Hestenes, 2006, p. 11).

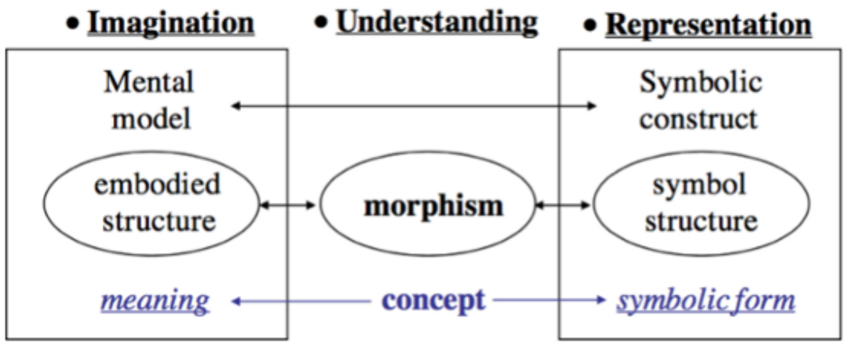

Figure 2. Modeling theory of cognition relating imagination, understanding, and representation. From "Modeling Theory and Modeling Instruction for STEM Education" by D. Hestenes, 2015, *epiSTEME 6 International Conference to Review Research on Science, Technology and Mathematics Education*. Copyright 2015 by David Hestenes. Reprinted with permission.

As a person constructs a mental model, they generate a concept using the process in Figure 2. The person creates a mental model and provides an embodied structure, which establishes meaning for the mental model. A morphism—defined as an analogy that preserves form—allows the person to develop a symbol structure. In conjunction with the symbolic construct and symbolic form, the mental model is elevated to a concept. This is defined as a (form, meaning) pair, allowing the person to communicate their concept with others.

Figure 3. Schema of a concept and conceptual model. "Modeling Theory and Modeling Instruction for STEM Education" by D. Hestenes, 2015, *epiSTEME 6 International Conference to Review Research on Science, Technology and Mathematics Education*. Copyright 2015 by David Hestenes. Reprinted with permission.

Figure 3 provides further information on the definition of a concept. The symbolic form of a concept is defined by three parts: A symbol is the public method of illustrating a concept, the form is the framework of the concept, and the meaning is an individual's interpretation of the concept. For example, consider the concept of "position." The symbols (x, y, z) are one option for public representation, the form is developed from the geometric structure of space and defined by a coordinate system, and the meaning is that an object is located at the place in space defined by the coordinate system and numbers for each of x, y, and z.

Figure 3 also provides a definition for a conceptual model, which follows the same form as a concept. Representations are the public method for describing the concepts in a conceptual model, the structure is the framework of the concepts in a conceptual model, and the referent is an individual's mental model of the concepts in a conceptual model (Hestenes, 2015). Because conceptual models are public, the representations and structure are determined by group consensus; however, these may change if the group determines that another representation or structure better symbolizes the conceptual model.

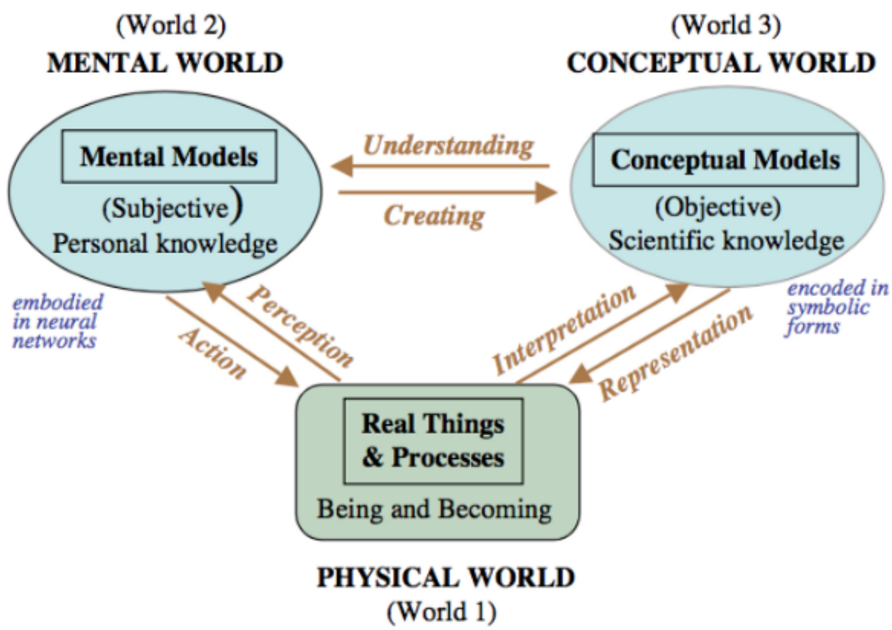

Figure 4. Relationships between the physical, mental, and conceptual worlds (Hestenes, 2006, p. 10). From "Notes for a Modeling Theory of Science, Cognition and Instruction" by D. Hestenes, 2006, *Proceedings of the 2006 GIREP Conference*. Copyright 2006 by David Hestenes. Reprinted with permission.

Figure 4 describes the interaction between personal mental models, conceptual models, and the physical world. The crucial distinction is between the mental world and conceptual world; the mental world contains an individual's models, whereas the conceptual world includes the scientifically accepted conceptual models. The goal of science education is to help students transform their mental models into agreement with the conceptual models, leading to a sophisticated understanding of the physical world. This goal is accomplished by determining student preconceptions, providing an opportunity to change their conceptions through laboratory activities or thought experiments, and reinforcing the new conceptions through further laboratory activities or other methods.

The Modeling Theory of Cognition explains how humans use information to build a model, both personally with mental models and collectively with conceptual models. In addition to the process of building a model, the Modeling Theory of Cognition uses a specific definition for the term model: "A model is a representation of structure in a system of objects" (Hestenes, 2015, slide 15). A system is a set of related objects, which may be real or imaginary, physical or mental, or simple or composite; the system itself is known as the referent of the model (Hestenes, 2016). The structure is the set of relations among its objects, with four types of structure are sufficient for a model in any scientific discipline: a) Systemic structure specifies composition, object properties, and causal links; b) Geometric structure specifies configuration and location in a reference frame; c) Interaction structure specifies interaction laws for causal links; and, d) Temporal structure specifies changes in state variables (Hestenes, 2015).

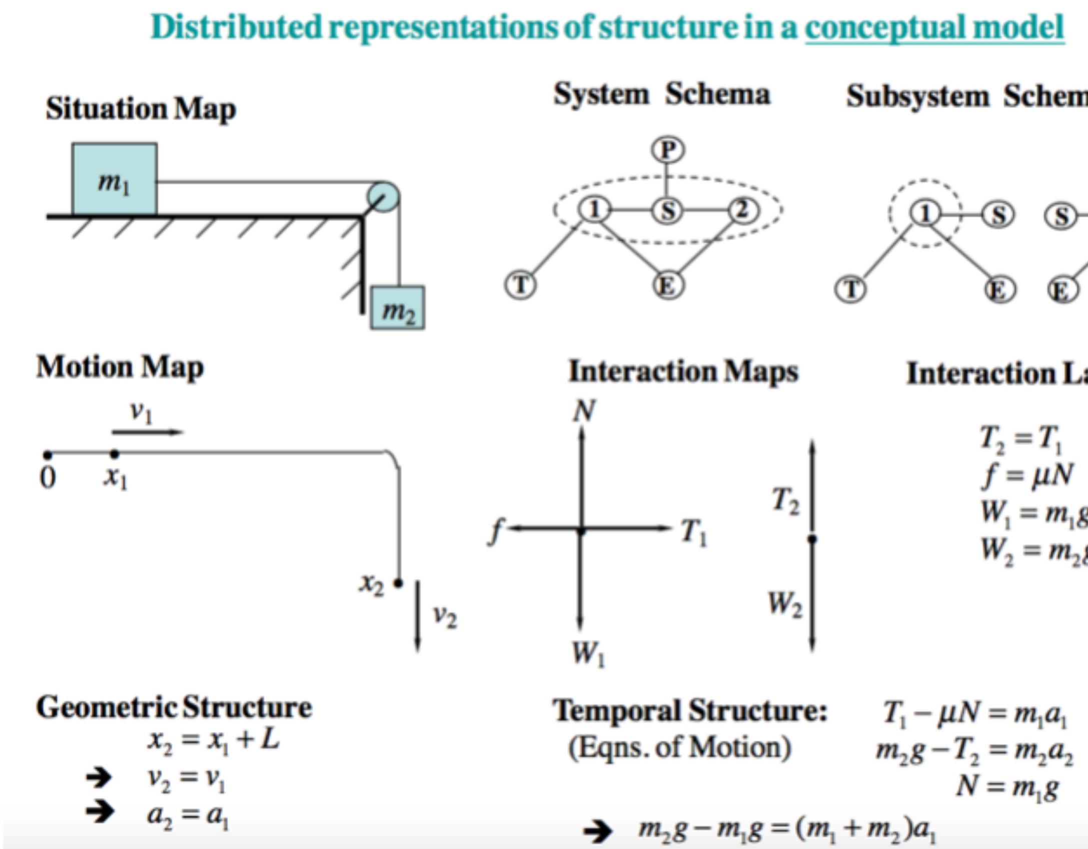

Figure 5. Example of structure in the unbalanced force model. From "Modeling Theory and Modeling Instruction for STEM Education" by D. Hestenes, 2015, *epiSTEME 6 International Conference to Review Research on Science, Technology and Mathematics Education*. Copyright 2015 by David Hestenes. Reprinted with permission.

In general, representations include verbal and written communication, mathematics, diagrams, graphs, and computational programming; however, each type of structure has specific representations. Figure 5 provides a full set of representations of the structure of the unbalanced force model, which is an important model in physics that is best known for Newton's second law (**F**=m**a**). Depending on the cognitive development of the student, different representation are emphasized. For example, students in a middle school science course would have a higher focus on graphs and diagrams, with a lesser focus on complex mathematical relationships. However, in AP Physics C, students are expected to use graphs and diagrams to develop complex mathematical relationships.

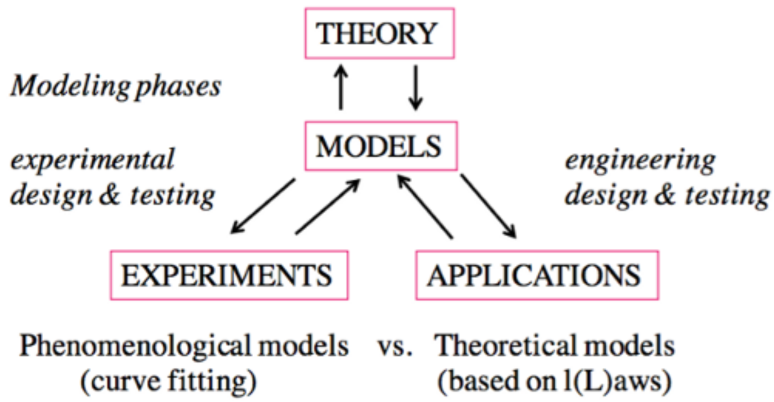

Figure 6. Overview of Modeling Instruction; scientific models are the content core and modeling is the procedural core of each science. From "Modeling Theory and Modeling Instruction for STEM Education" by D. Hestenes, 2015, *epiSTEME 6 International Conference to Review Research on Science, Technology and Mathematics Education*. Copyright 2015 by David Hestenes. Reprinted with permission.

The emphasis on models and the process of modeling forms the philosophical basis for Modeling Instruction; as seen in Figure 6, models are at the core of the curriculum, instruction, and assessment decisions in Modeling Instruction. In Modeling Instruction, students use information from experiments to develop an initial mental model, discuss and perform more experiments to validate and refine their mental model so that it approximates the scientifically-accepted conceptual model, and use the conceptual model to determine the limits of the model and applications of the model. This process is known as the Modeling Cycle, which students use many times throughout a course with different content. If Modeling Instruction is well-implemented throughout K-12 education, students develop a deep understanding of the modeling process and a foundation of scientifically-accepted conceptual models.

References:

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