Encyclopedia of the Sciences of Learning
Springer Science+Business Media, LLC 2012
10.1007/978-1-4419-1428-6_589
Norbert M. Seel

Model-Based Learning

Barbara C. Buckley[1]

(1) WestEd, 400 Seaport Court, Suite 222, Redwood City, CA 94063, USA

Barbara C. Buckley
Email: bbuckle@wested.org

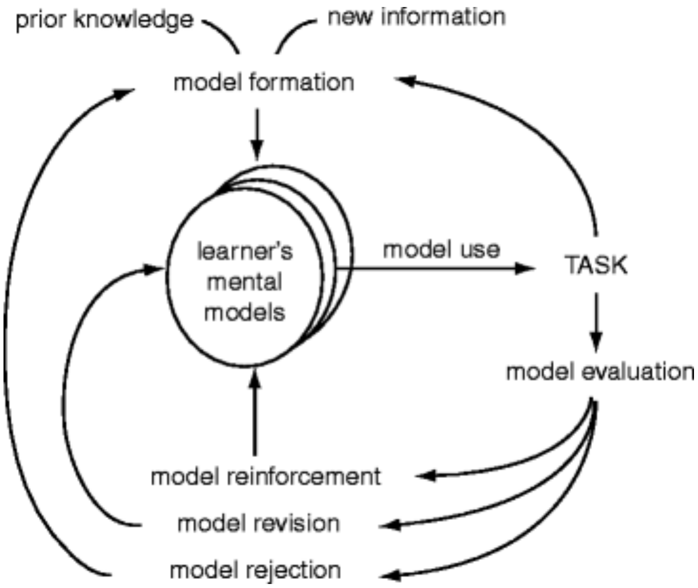
Without Abstract

Synonyms

Knowledge integration; Model-building

Definition

Model-based learning is the formation and subsequent development of mental models by a learner. Most often used in the context of dynamic phenomena, mental models organize information about how the components of systems interact to produce the dynamic phenomena. Mental models arise from the demands of some task that requires integration of multiple aspects and/or multiple levels of a system or situation (See Fig. 1). Model formation integrates prior knowledge and new information about the instance into a mental model of the situation. When the mental model is used to accomplish the task, it is evaluated for its utility in performing the task. If the mental model is deemed useful, it is reinforced and may become routinized with repeated use. If the mental model is deemed inadequate, it may be rejected and another model formed, or it may be revised and then used to try again. Revisions may involve making changes to an element of the model or it may take the form of elaboration – adding elements to the model in order to better accomplish the task. Elements may also be dynamic systems. Ideally, model-based learning results in rich, multilevel, interconnected mental models that are extensible and useful for understanding the world.



Model-Based Learning. Fig. 1 Model-based learning

Theoretical Background

Following in the footsteps of Craik (*1943*), Johnson-Laird (*1983*) characterized mental models as internal representations of "objects, states of affairs, sequences of events, the way the world is and the social and psychological actions of daily life." They enable reasoning that supports making predictions and generating questions, hypotheses, and explanations. They structure one's understanding of the world by organizing the components of a phenomenon and the interactions of the components that produce some emergent behavior, property, or result. This makes mental models very useful for integrating and extending one's understanding of complex phenomena in a wide variety of settings and domains.

Model-based learning begins with a task, whether explicit or tacit. That task is likely to be trying to understand or produce some phenomenon or representation thereof. The external representations (representations include text as well as diagrams, animations, gestures, physical or computer models; in short, any external representation that stands for something else) are generated from an individual or group's mental models. They may be categorized as either expressed or consensus models. Expressed models are representations of various types generated for a particular purpose. Consensus models, on the other hand, are models developed, agreed upon, and used by a group with some degree of permanence, such as the students in a class or the scientists and scholars of a domain (Gilbert and Boulter *2000*).

The contributors to Gentner and Stevens' *Mental Models* (*1983*) provide an informative array of work on mental models and their use in understanding dynamic phenomena. The chapters range across domains, from electricity to Micronesian navigation to artificial devices. Most of the contributors think about knowledge representation and processing in terms of computational semantics. They employ a very wide collection of methodologies that include protocol analysis, cognitive psychology experiments, developmental studies, novice-expert studies, and multiple settings for observations and comparisons and more. In an attempt to contribute to a theory of how people understand the world, the researchers write primarily about knowledge representations in a domain and phenomenological theories of human processing. Norman (p. 7) makes useful distinctions among models that make it clear that the authors are all writing about their own mental and computational models of learners' mental models and their use in qualitative reasoning. Williams, Hollan, and Stevens (p. 131) define mental models as a collection of connected autonomous objects. "An autonomous object is a mental object with an explicit representation of state, an explicit representation of its topological connections to other objects, and a set of internal parameters. Associated with each… is a set of rules which modify its parameters and thus specify its behaviors (p. 133)." They used protocol analysis to examine one subject's formation and revision of a model of a heat exchanger, facilitated by a "dialectic between the developing mental model and experiential knowledge, (p. 152)." This is an example of model evaluation and revision. deKleer and Brown (p. 155) delve into the assumptions and ambiguities in mechanistic mental models. They distinguish among *device topology* (structure), *envisioning*, a *causal model*, and *running*. *Envisioning* is the process of reasoning from the device's structure to its functioning using known principles (model formation). A *causal model* describes how the structural components interact to produce the behavior or functioning of the device. *Running* the causal model allows one to predict or produce a behavior (model use). deKleer and Brown also discuss embedded models, that is, models whose components are themselves models to describe the depth of knowledge about a device. Using historical protocol analysis, Wiser and Carey (p. 267) describe the formation and revision of consensus models of heat and temperature and their differentiation. Clement (p. 325) highlights the similarities between students' naïve mental models and Galileo's expressed models.

Building on this work, Buckley (*2000*) used a combination of naturalistic observation and cognitive psychology techniques to examine the understanding of a student using an interactive multimedia resource to learn about the circulatory system. Her analysis identified components of deKleer and Brown's theory at work in a classroom context. In contrast to even the most able students in the class, this student's intentional model-building was evident in researching and planning a presentation for the class and in explaining how a new surgical technique would work when given a newspaper illustration. When conducting research, this student posed three questions that intuitively instantiated deKleer and Brown's theory: What are the parts? What are their purposes? How do they work together? She explored video of live circulatory phenomena, such as a heart beating in an open chest and blood cells circulating through capillaries, all structured around a schematic of the circulatory system. The student's card sort of parts of the circulatory system was anatomically structured. Her presentation was clear and correct. When asked about the novel surgical technique, she was able to reason about how it would work; more able students in the same classroom study had to be reminded that the heart beat before they could even begin to reason about the technique. From the multiple sources of data collected, Buckley constructed a multilevel expressed model that represented the student's mental model of the circulatory system in terms of parts and behavior, and how the interaction of parts at one level produce the behavior of the higher anatomical level.

The contributors to Gilbert and Boulter (*2000*) provide multiple perspectives and examples for how model-based learning contributes to the development of mental, expressed and consensus models in science education. Boulter and Buckley (p. 41) developed a typology to support research on how expressed models might contribute to a learner's mental model. They categorize expressed models found in classrooms in terms of the mode of representation employed (concrete, verbal, visual, mathematical, gestural, and mixtures thereof) and the attributes of the representation. Attributes include distinctions between quantitative and qualitative, static and dynamic, and deterministic and stochastic. They illustrated the use of the typology with examples from the solar system and the circulatory system. In order to characterize and define mental models and examine methods for investigating them, Franco and Colinvaux (p. 93) present examples of model revision by describing how Einstein's combination of the concepts of inertial and gravitational mass shaped his work on general relativity. They describe similar examples from children's development of models of the earth. Buckley and Boulter (p. 119) focus on the role of representations (expressed models) in building mental models of the circulatory system and the solar system, because "Phenomena may be hidden within or may be too small, too large, too fast, or too slow for humans to see. Even when phenomena are within the range of the human perceptual system, it can be difficult for learners to detect the parts of a system or model. This is especially the case when directly observing phenomena or images thereof. Nature doesn't come with labels, and boundaries between parts are often indistinct (p. 133)." They examine what aspects of the phenomenon (structure, behavior, or mechanism) are represented and how the particulars of a representation may present semiotic challenges for learners' sense-making. They discuss the difficulties of making clear the components and their interactions in various representational modes and suggest some representational techniques that might help learners overcome the semiotic challenges of a given representation. Reiner (p. 157) discusses the role of mental models in thought experiments, in particular, the use of an imagery strategy. She suggests that thought experiments are a tool for generating, testing, and refining mental models. She explores the nature of thought experiments and of embodied, tacit, non-propositional knowledge. In a case-study, she shows how embodied knowledge is reflected in thought experiments while modeling a situation in a physics problem.

Important Scientific Research and Open Questions

Mental model-building for the purpose of operating in the world is ubiquitous and spontaneous; much of it is unconscious (Johnson-Laird *1983*). When it is not, motivation plays an important role in model-based learning (Seel *2003*). What motivates a learner to engage in model-based learning? Psychologists who conduct research in motivation have contrasted intrinsic vs. extrinsic motivation, the desire to understand vs. the desire to perform, or spontaneous vs. intentional vs. directed learning. Model-based learning is no doubt influenced by all of these, as well as the epistemology of the learner. If students believe that the illustrations or physical models they encounter in instruction are to be memorized and regurgitated, they are unlikely to invest the effort required to construct mental models of the phenomena being represented (Gilbert and Boulter *2000*). If, however, they are motivated by the desire to understand, they will try to construct mental models and pose questions accordingly (Buckley *2000*).

The construction of knowledge whether by an individual or a group involves a fluid interaction of mental models, expressed models, and consensus models. Whether this is formalized within a domain such as science or guided in a classroom or engaged in by an individual who seeks to understand, model-building requires cycles of model generation, use, evaluation, and revision. This results in a progression of models, whether historic, naturalistic, or guided by instruction, which produces a network of connected knowledge that can be traversed and examined in diverse ways. This creates a conceptual ecology that influences future learning.

The authors cited in this entry and countless others have contributed to the development of a consensus model of model-based learning and to embedding it in a consensus model of model-based teaching and learning. All call for additional research to validate these models through an eclectic and functional collection of methodologies that enable us to draw inferences about the state of a learner's mental models and their evolution. Model-based learning theory is a powerful organizer for learning, teaching, and assessment. The model of model-based learning is an intermediate model. That is, it must be supported by research in cognition and in the underlying mental representations and neurochemistry. Its utility for designing learning environments, both computer-based and classroom-based, must be examined. Finally, the ramifications for policy-level decisions about standards, assessment, and teacher education must be considered.

Cross-References

Mental Models

Mental Models in Improving Learning

Model-Based Reasoning

Model-Based Teaching

Model-Facilitated Learning

Simulation and Learning: The Role of Mental Models

References

Buckley, B. C. (2000). Interactive multimedia and model-based learning in biology. *International Journal of Science Education, 22*(9), 895–935.

Craik, K. J. W. (1943). *Nature of explanation*. Cambridge: Cambridge University Press.

Gentner, D., & Stevens, A. L. (Eds.). (1983). *Mental models*. Hillsdale: Lawrence Erlbaum.

Gilbert, J. K., & Boulter, C. J. (Eds.). (2000). *Developing models in science education*. Dordrecht: Kluwer.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Seel, N. M. (2003). Model-centered learning and instruction. *Technology, Instruction, Cognition and Learning, 1*, 59–85.