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Model-Based Teaching

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Without Abstract

Synonyms

Model-centered instruction

Definition

Model-based teaching is instruction designed to support the development and evolution of learners' mental models. We define mental models as internal representations of integrated knowledge that include components of a dynamic system and their interactions, which produce some emergent behavior or property. Learners build, extend, elaborate, and improve the accuracy and completeness of their mental models, much as science extends our understanding of the world about us. Settings may be formal classrooms or informal learning activities. Teaching philosophies may range from didactic to discovery and may employ instructional strategies and tactics that operate over months of instruction to those that operate over seconds (Clement and Rea-Ramirez *2008*; Gilbert and Boulter *2000*).

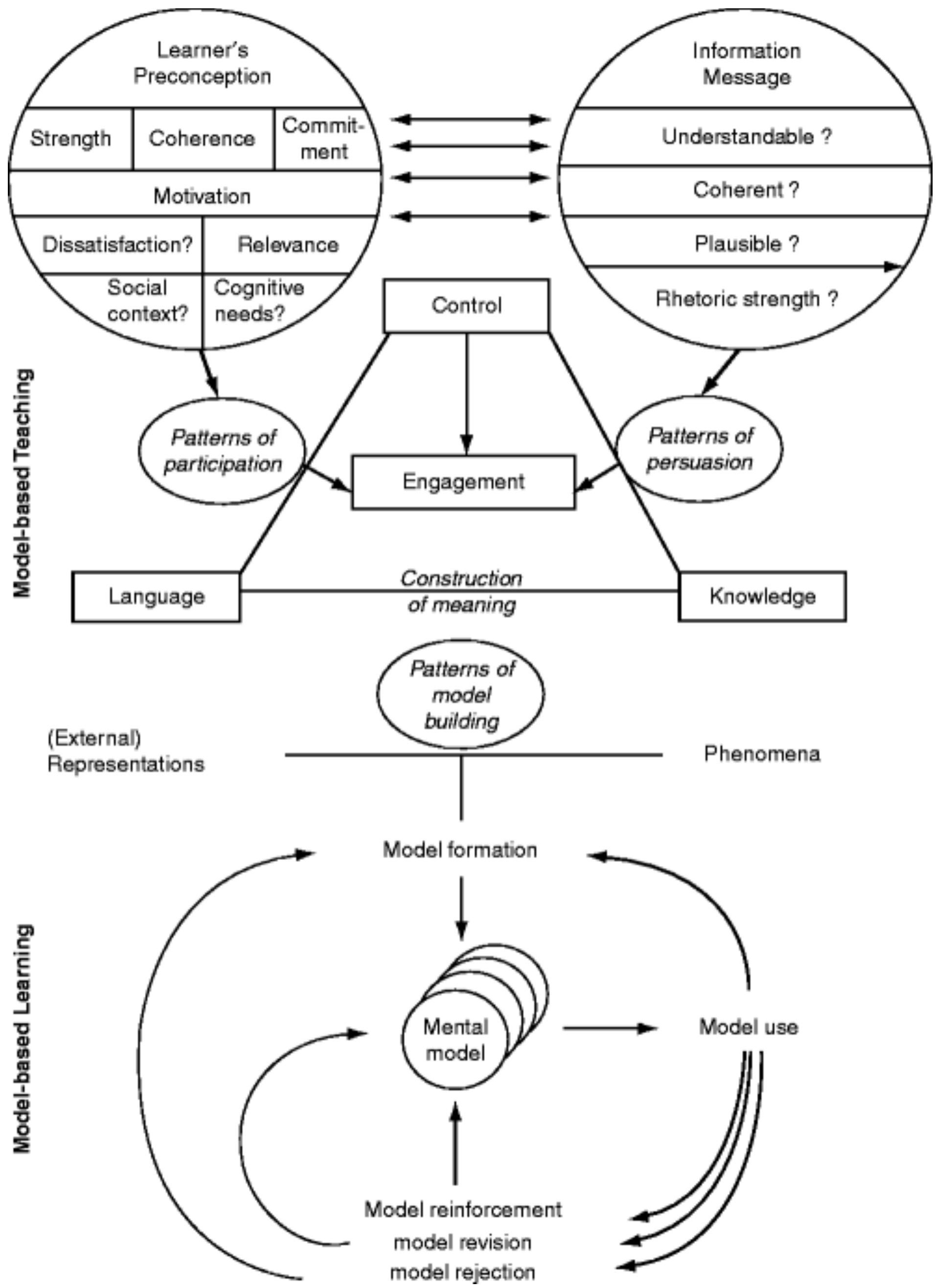
Theoretical Background

The core beliefs of model-based teaching are the assumptions that "*mental* modeling is a universal way of thinking, that *expressed* models are a universal component of communication, and that *consensus* models are produced by all social groupings that have some degree of permanence" (Gilbert and Boulter *2000*, p. 343). Both expressed and consensus models are external representations that interact with mental models. The use of external models in model-based teaching is common. Mayer (*1989*) focused on the use of conceptual models (external) and their role in helping students build mental models of the systems they study. He concluded that conceptual models can improve students' systematic thinking and their ability to solve transfer problems, and urged the use of dependent measures such as conceptual recall, verbatim retention, and problem-solving transfer as more sensitive measures of systematic thinking. He argued that a good conceptual model (external) should be complete, concise, coherent, concrete, conceptual, correct, and considerate of the learner (pp. 59–60).

Stewart and colleagues (*2005*) focus on inquiry and problem-solving as instructional strategies through which students develop, evaluate, and reject, revise, or elaborate their mental models. Students are given problems or tasks that require reasoning not only from cause-to-effect (e.g., making predictions) but also from effect-to-cause (e.g., explaining observations). In the process of forward and backward reasoning, students test and evaluate their models against data, which in turn leads to model revision or elaboration.

In addition to writing on the nature and significance of models and modeling in science education, the researchers of the Centre for Models in Science and Technology (CMISTRE) focused on external consensus models used for teaching and learning and their role in the development of learners' mental models (Gilbert and Boulter *2000*). The researchers describe the role of external models in explanations in chemistry and physics and biotechnology. They also describe how they function as a critical part of discourse in classrooms, in computer modeling of phenomena, and in the development of teachers' pedagogical content knowledge. This work contributed much to the growing research and theory base of model-based learning.

Seel (*2003*) extended the definition of model-based teaching and learning that combined the work of Buckley and Boulter (Gilbert and Boulter *2000*, pp. 122 and 304), as shown in Fig. 1. In particular, he expanded the learner characteristics beyond prior knowledge to include affective and cognitive factors that influence not only the learner's interpretation of the information message (which he also expanded and articulated), but also patterns of participation and persuasion in the construction of meaning that takes place in classrooms and other learning contexts. Informed by Mayer's work (*1989*), Seel and his colleagues (*2003*) investigated the effectiveness of providing a conceptual model at the beginning of the learning process and the long-term impact of a multimedia learning program that was guided by cognitive apprenticeship approach. Their investigations focused on a learning-dependent progression of mental models. Through the use of learner-generated causal diagrams, they examined both the acquired domain-specific knowledge and the stability of the initially constructed mental models, conducting five replication studies. They found that the learners' mental models were not intact adoptions of the external conceptual models presented during instruction. Rather, they concluded that the learners' mental models were constructed *when needed* (author's emphasis) to deal with a particular situation.



Model-Based Teaching. Fig. 1 The interplay between model-based learning and instruction (Seel 2003, p. 73)

Clement and Rea-Ramirez (2008) expand our understanding of teaching strategies and techniques in a collection of research studies that took place in classrooms focusing on a similar evolution of mental models. Their contributors describe student–teacher co-construction of mental models in a variety of domains and focus on a wide range of teaching strategies and techniques. Effective model-based teaching begins with an integrated target model (an age-appropriate version of the expert consensus model) and an effective learning pathway. While traversing this pathway, both students and teachers contribute elements to the expressed models. They describe a pathway that begins with students' models, usually expressed as drawings, followed by cycles of model criticism and revision. The stimuli for revision range from discrepant questions to experiments that demonstrate the shortcomings of a mental model. Throughout the studies, teachers set the agenda and decide which of the revisions to address at what time. Ideally, students are kept in a

Vygotskian-like “reasoning zone,” which Clement and Rea-Ramirez define as “an area of discussion where students can reason about ideas and construct new ideas productively” (p. 19). When the discussion ranges outside the reasoning zone, the teacher must provide enough support to bring it back into the zone. Teachers may scaffold students’ reasoning with a “leading question, hint, new observation, reference to an earlier comment, discrepant question or piece of information” (p. 19). This requires a skillful teacher and decisions made in the midst of discussions.

Clement and Rea-Ramirez tie these studies together into an organizing framework that expands the definition of model-based teaching and learning. They begin with two main goals: finding an appropriate learning pathway toward an age-appropriate target model and finding teaching strategies that help students move along that pathway. They assert that, “Pathways that stretch across large topic areas, such as different systems in the human body, set up the important goal of making a curriculum coherent by integrating the student’s knowledge into an interconnected framework of ideas” (p. 257). Clement (p. 255) articulates six levels of organization for curriculum design and teaching. He charts both goal structures for learning outcomes and teaching strategies relevant to that level organization. At the highest level (6) the focus is on curriculum integration studies intended to help students develop integrated target models across units, which has implications for sequencing and connecting units. The lowest level (1) focuses on dialogical tactics intended to promote active idea sharing and social norms for discussion in science class and implemented by the teacher in less than 20 seconds. In between these extremes, the goals and strategies focus on the progression of intermediate models that comprise the learning pathway for both planning and implementation. Strategies that come into play at the different levels include introducing problems, building model parts, facilitating syntheses, as well as observations and teacher moves that stimulate the cycles of model generation, evaluation, or modification needed to move students’ mental models forward.

Horwitz and colleagues (*2010*) created a complex multilevel model-based learning environment for genetics. At the heart of the genetics environment is a multilevel computer model of transmission genetics that ranges from DNA molecules to pedigrees. All are represented in computer models that are linked, so that changes in the DNA base pairs may result in allele changes that may result in changes in observable characteristics of the organism (dragons), and could result in heritable traits. Based on earlier work with GenScope, they embedded these models into a series of learning activities intended to help students build increasingly complex mental models. They provided scaffolding that supported the learner’s interpretation of the representations, drew attention to the relevant model information, and set forth a series of tasks intended to stimulate construction and modification of mental models. Learners were also asked to reify and reflect on their understanding in textual form. Within a learning activity, the tasks became increasingly complex and the scaffolding decreased. The ultimate task for these learners was to determine the genotypes of two invisible dragons through breeding experiments. A key feature of the environment was that the system monitored student answers and actions, and provided specific feedback as students progressed through each activity. This feature also enabled Horwitz et al. to embed assessments seamlessly into the learning activity and provide immediate feedback, as well as reports for teachers and researchers. They demonstrated the feasibility of this model-based instruction in large-scale studies that involved nearly 2,000 students in over 70 biology classrooms worldwide.

Important Scientific Research and Open Questions

A common theme among the researchers cited here is the need to specify learning pathways that start with naïve or alternative conceptions and progress through a series of intermediate models that lead to a target model, which in turn can be considered on the path to the expert consensus model. Is there an optimal learning pathway or are there many paths to the same target model? Are some paths more productive than others?

Another common theme is the creation of a "comprehensive and empirically valid theory of instructional design of model-centered learning in various instructional settings" as expressed by Seel (2003, pp. 80–81), but echoed by all. How does one use model-based teaching and learning theory to create effective museum displays or intelligent tutoring systems or curricula or to guide classroom discourse? These authors have provided us with a wide range of examples. We cannot do any of this work without the ability to assess learner's mental models, or as Seel (2003) quotes Scandura, "any theory of teaching and learning must include some way of finding out what students know at any phase of learning" (p. 80).

The theory of model-based teaching and learning has significance for a wide range of educational endeavors. At the policy level, it suggests that we should be framing our standards more explicitly as target models that stretch over large topics rather than fragmented propositional knowledge. This has ramifications for large-scale, high stakes assessments. If we value model-based learning, then we should be assessing the extent of students' models and their ability to engage in model-based reasoning and inquiry. We also need to educate teachers so that they can help our students do well on such assessments by supporting mental model-building and by making model-based learning an explicit and taught learning strategy and skill. None of these are easy tasks, but they are important complex work that needs to be done. In order to accomplish this work, we need research that ranges from brain-based and cognitive research on the processes of model-building to classroom-based research and beyond to high-stake assessments.

Cross-References

Mental Models

Mental Models in Improving Learning

Model-Based Learning

Models and Modeling in Science Learning

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