Mental Models

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INTRODUCTION

It is widely assumed that mental models are internal representations. Humans are capable of constructing these models when required by demands of an external task or by a self-generated stimulus. "Mind's eye" can see, run, and interact with these mental models. Rather than stored in strictly fixed form in the mind, mental models are constructed on the spot when needed. Repeated application leads to refinement of a mental model and possible automation of its construction and use processes in one's cognitive practice.

Literature often claims a mental model to be the same as a schema. However, in this chapter the two are different, and this understanding is critical for proper conceptualization of a mental model. Human knowledge is largely conceptual. Concepts are connected to other concepts and in this way, form clusters or larger structures usually referred to as schemata. These links define relationships and are channels through which certain variables and information from an environment (and what we already know) flow through concepts and across schemata. Schemata are deployed in the mind processes of constructing and using mental models. Experts hold more refined and more automated processes for construction and use of mental models, and base these on well-developed concepts and schemata.

Mental models are important for processes such as learning, critical thinking, and problem solving. Capacity to construct and use mental models might also be linked to creative thinking. Learners might benefit from experiences that require them to construct and use mental models, in particular within problem-based tasks. Technology can play an important role through its affordance that allows for creation and delivery of interactive and visual conceptual models (Churchill, 2007). These conceptual models can be designed to reassemble experts' mental models, and can be externally supplied to learners to support their cognitive processes and task completion. In this way, conceptual models can act as external intellectual supplements, and their use can lead to creation of new or refinement of existing schemata and related concepts and procedures for their use. In addition, their use would lead to more effective mental modeling capacity for learners.

BACKGROUND

The very first attention to mental models was given in 1943 in the work "Nature of Explanation" by Kenneth Craik. Arno Matthias writes, in a Wikipedia article at http://en.wikipedia.org/wiki/Mental_model, that another early claim for existence of internal models was by Georges-Henri Luquet in a book "Children's Drawings" published in 1927 in Paris. Craik (1943) proposed that humans interpret reality into internal models through interaction with external world. For Craik, humans can use and manipulate mental models and translate them back into action or just register the correspondence between these internal symbolic representations and external world. Another earlier note to mental models is made by Alexander (1964) in the book "Synthesis of Forms," who suggests that engineers and architects hold mental pictures that they employ during design activities. Since then, in particular during the 1980s, there was huge growth of studies in relation to mental models.

Researchers in areas such as human-machine interaction, human-computer interaction, and skilled performance believe that individuals form mental models of systems that they interact with (e.g., De Kleer & Brown, 1981; Norman, 1983; Staggers & Norcio, 1993; Veldhuyzen & Stassen, 1977). Veldhuyzen and Stassen suggest that such mental models enable a machine operator to assemble and use strategy for managing a task, predict desired results as a consequence of some actions taken, and understand unanticipated phenomena that occur as the task progresses. Operators with well-developed mental models would be able to engage more effectively with a system and predict its behavior. This prediction is carried from inferences, what Norman labels "declarative form of predictability" or by "procedural derivation" made as an individual

runs a mental model. Individuals, for Staggers and Norcio, have ability to run and modify mental models in their minds to test their hypotheses about a system and as they grow in expertise, their ability to manipulate multiple models expands. Jih and Reeves (1992) write that humans also learn to use a computer-based environment by constructing a mental model of its interface. In addition to predictions of results of interaction with a computer-based environment, for Jih and Reeves, mental models also impact the effort that an individual devotes to a task and a level of satisfaction after task completion. A mental model is best understood within a context of a relevant task. Rouse and Morris (1986) suggest that a mental model is a kind of heuristics that brings knowledge and task together. The task might dictate the "level of behavioral discretion" that ranges from unconscious neural information processing to fully conscious decision making. At the same time, an individual might engage with a mental model to a different "level of model manipulation" that can be implicit or explicit, depending if the individual is aware of his or her manipulation of that model. For example, solving a physics problem requires high level of conscious decision making and explicit mental model manipulation. Low level of behavioral discretion is usually present when manipulation of a mental model is driven by outside factors.

Mental model is also discussed in relation to organizational management (Senge, 1990; Senge, McCube, Lucas, Smith, Dutton, & Kleiner, 2000). According to Senge, one can hold mental models that can vary in scope from simple generalizations to complex theories. When confronted with new experiences, most individuals observe and bring forward only those mental models that reinforce what is important to them. If mental models remain unexamined, they will remain unchanged, that is, the mental models limit individuals' ability to change (Senge, et al., 2000). For Senge, if an organization wants to introduce progressive changes, it must enable its member to change mental models that might be impeding these changes.

In cognitive psychology, a mental model is considered as a kind of internal symbolic representation that is constructed in the mind by an individual from interaction with and adaptation to the external world. For Johnson-Laird (1989), the purpose of mental models is to make inferences, while reasoning is a process of manipulating mental models. Vosniadou (2002) suggests that it is assumed that mental models are constructed on the spot when needed. However, another form of representation is also central to cognitive psychology: a schema (Paivio, 1974). A schema is "an organized structure that exists in memory and, in aggregate with all other schemata, contains the sum of our knowledge" (Winn & Snyder, 1996, p. 117). A schema is also a dynamic structure composed of concepts that are linked together. Although some literature appears to suggest schema to be the same as a mental model, for Winn and Snyder, the two are different and "a mental model is broader in conception than a schema because it specifies causal actions among objects that take place within it" (p. 118). Similar to others (e.g., De Kleer & Brown, 1981; Mayer, 1989; Seel & Stritmatter, 1989), Winn and Snyder suggest that a key property of a mental model is that it "can be run like a film or computer program and watched in the mind's eye while it is running" (p. 118). Similarly, Vosniadou suggest that mental models "can be explored extensively, run in the mind's eye, so to speak, in order to generate predictions and explanations" (p. 4), while for Johnson-Laird (1989), a mental model contains elements of a simulation and by running it, individuals can modify existing models or construct new ones.

What is content of mental models? For Merrill (2002), mental models combine schemata and processes for using this knowledge while Brien and Eastmond (1994) suggest that the mental models combine declarative knowledge (concepts, propositions, principles, laws, and processes) and procedural knowledge (production rules, procedures, and heuristics). Glaser and Bassok (1989) suggest that in addition to declarative and procedural knowledge, mental models also incorporate control knowledge (that determines how declarative and procedural knowledge is used). For Veldhuyzen and Stassen (1977), knowledge is summarized in mental models while for Norman (1983), mental models also include beliefs. Others (e.g., Carley & Palmquist, 1992; Staggers & Norcio, 1993) suggest that mental models are organized structures that consist of concepts and their relationships. Staggers and Norcio suggest that mental models are visual, while for Jonassen and Henning (1999), mental models are dynamic, multimodal, and conceptual and operational (rather than just conceptual).

Literature suggests that effective learning experiences should engage learners to construct and use mental models (e.g., Brien & Eastmond, 1994; Jih & Reeves, 1992; Jonassen & Henning, 1999; Merrill,