Cognitive Models of Learning

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Synonyms
Cognitive skill acquisition; Computational models of learning; Conceptual change

Definition
A cognitive model is a descriptive account or computational representation of human thinking about a given concept, skill, or domain. Here, the focus is on cognitive knowledge and skills, as opposed to sensori-motor skills, and can include declarative, procedural, and strategic knowledge. A cognitive model of learning, then, is an account of how humans gain accurate and complete knowledge. This is closely related to metacognitive reasoning and can come about as a result of (1) revising (i.e., correcting) existing knowledge, (2) acquiring and encoding new knowledge from instruction or experience, and (3) combining existing components to infer and deduce new knowledge. A cognitive model of learning should explain or simulate these mental processes and show how they produce relatively permanent changes in the long-term memory of learners. It is also common to consider impoverished cognitive models of learning which can be useful for diagnosis of learner errors and misconceptions, and in many cases, prescribing appropriate instructional interventions.

Theoretical Background
Cognitive modeling is a basic tool for the field of cognitive science used to account for human thinking for just about any imaginable context. A cognitive model for a given domain or problem solving task typically represents an expert’s knowledge, which can sometimes take years (or even a decade) to form in the mind of that expert. For a learner seeking to become an expert in that domain, the developmental path to that desirable end state can be just as complex, if not more, than the domain knowledge itself. The tools of cognitive science can also be used to describe the processes learners engage to acquire knowledge and expertise in a given domain. To construct such cognitive models of learning, a variety of approaches are used to collect relevant data while students are engaged in learning. These include thinkaloud protocols, problem solving traces, diagnostic tests, and even neurological analyses of brain activity. Because learning can occur in different ways, in different contexts, and for different knowledge types, a variety of models that account for learning have emerged. Further, cognitive models of learning can take a descriptive form reporting empirical observations and strategies revealed from learner thinkalouds to a more formal, computational form suitable for simulation on a computer (Ohlsson, 2008).

Acquisition of cognitive skills is a common focus of cognitive models of learning. Here, learning is focused on solving problems in a given domain. Substantial empirical evidence exists showing that cognitive skill acquisition progresses in three stages: (1) cognitive stage: learners develop a declarative encoding of the domain knowledge, (2) associative stage: through practice, errors in knowledge are identified and repaired, and (3) autonomous stage: continued practice increases speed and accuracy during execution of the cognitive skill. Models of cognitive skill acquisition generally strive to follow the same pattern, and deal with the complexities that learners also face. They track learning of individual rules, or knowledge components, to
multiple interacting pieces of knowledge at once, and finally, on to the final stages when practice produces autonomy (VanLehn, 1996).

Cognitive models of learning are tied closely to metacognition, which can informally be understood as “thinking about thinking.” Metacognitive thinking represents an essential aspect to cognitive models of learning because they define control mechanisms the learner must apply in order to actually acquire new knowledge. That is, to reach the end state of possessing usable and accessible new knowledge in long-term memory, learners must actively regulate their own cognitive processes, decide where to direct their attention, self-assess to decide if they understand, self-explain in order to establish connections between domain principles and the object of study, decide if they will seek help, and so on. For example, learners who study worked out examples learn more effectively if they choose to frequently stop to check their own understanding and identify underlying principles that provide justification for problem solving steps (Chi, Bassock, Lewis, Riemann, & Glaser, 1989). A good example of a computational model of these activities, along with other learning mechanisms, is captured in the computational cognitive model of learning, Cascade (VanLehn, 1999). The model simulates learning from worked out examples as well as from problem solving and produces cognitive changes on the impasse–repair–reflect cycle, a model derived from empirical studies of human learners (Chi, et al., 1989). During learning, if Cascade finds that its current domain knowledge is insufficient to move forward in reading or problem solving (i.e., it is at an impasse), this triggers a learning event. The system seeks to modify its existing knowledge or add a new rule that will allow it to overcome the impasse (i.e., a repair). Finally, reflection is achieved via explanation-based reasoning on the proposed solution to determine correctness. In Cascade, the approach is to leverage commonsense knowledge in conjunction with existing knowledge to construct new rules for future use (VanLehn, 1999, pp. 86-87).

Broadening the perspective beyond cognitive skill acquisition, researchers have also investigated cognitive models of conceptual change during learning and development. Here, models deal directly with the fact that learners enter into learning situations with preconceived and naïve conceptions and misconceptions about the world. Recent research on conceptual change has shifted focus to the learner by introducing intentional conceptual change, defined as “goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge” (Sinatra & Pintrich, 2003, p. 6). These approaches therefore overlap significantly with metacognitive models of learning, but with substantially more of a focus on developmental and repair activities necessary for long-term conceptual understanding.

Important Scientific Research and Open Questions

Cognitive models represent an important class of tools in the study of human cognition and learning. To date, researchers have made incredible strides in studying and modeling complex human learning (Ohlsson, 2008; VanLehn, 1999). However, any model of human learning is almost by definition, incomplete. It is always necessary to restrict a cognitive model of learning in some way, whether it be the domain it operates on or the kinds of reasoning of which it is capable. Nowhere is this more evident than in recent efforts to integrate affective and emotional processes into models of learning (Kort, 2009). Here, researchers are focused on understanding the interplay between emotion and learning to answer basic questions such as when instruction is most effective, at what point do learners respond positively to challenge, and when does frustration hinder or impede learning. These questions represent key open questions in both the psychological literature on human learning, as well as in the cognitive modeling literature. Ohlsson (2008) points out that an assumption made by many computational models of learning is that learning mechanisms are tested independently (p.384). This suggests that as more models are tested for validity and completeness, they should be done so in complex learning contexts that involve multiple learning mechanisms. It is the interaction between learning mechanisms that may pose a hidden threat to the success of existing
computational models of learning. In addition, research on emotions in learning processes can be viewed as a positive step because they are inherently contextual (i.e., learning is never focused on sitting down to simply experience an emotion – it always involves a cognitive target). Finally, very few cognitive models of learning have integrated findings from cognitive neuroscience, and so this represents a key open area of future research. To date, researchers have determined areas of the brain that are involved in learning, emotion, and automaticity. This empirical data may shed light on cognitive models of learning by providing evidence for setting of parameters (e.g., rate of learning or memory decay) and testing of underlying assumptions.

Cross-References

→ ACT
→ Cognitive dissonance in the learning process
→ Cognitive load theory
→ Cognitive skill acquisition
→ Computational models of human learning
→ Conceptual change
→ Developmental cognitive neuroscience and learning
→ Human cognition and learning
→ Metacognition and learning

References


