

## **SCHEMA MENTAL MODELS AND LEARNING: AN OVERVIEW**

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**Abstract:** The present paper elaborates on the role of schema and mental models in teaching and learning. In this paper, the author presents an overview of the major researches conducted in cognitive psychology and education related to the schema and mental models. Schema is considered one of the essential aspects of knowledge formation among learners. A mental model is the combination of schema and cognitive processes for enriching the knowledge that is already possessed by the learner. It is the internal representation of external reality. The reviews reveal that schema and mental model activation enhances learning and it also modifies teachers' concept regarding students' mental models. The knowledge of schema will help them to sequence the classroom interaction procedure according to the changing demands of the learner society.

**Keywords:** Schema, mental models, cognitive structure, problem-solving.

### **Introduction**

In every learning situation, the learners utilize their schema and mental processes so as to attain the desired learning outcomes. Schema or prior knowledge is described as the existing knowledge of the learners to receive new knowledge. The prior knowledge can be activated by linking content to the existing knowledge or by building appropriate background knowledge by creating suitable learning experiences for the learners. The major skills or mental processes as the outcome of effective teaching resulted from the activation of prior knowledge are 1) abstracting 2) identifying cause-effect relationship 3) compare and contrast 4) classifying and organizing 5) justifying 6) inductive and deductive reasoning 7) problem solving 8) imagining and creating 9) judging 10) applying knowledge to real-life situations. The schema should be activated from the very beginning of the lessons, and it can be extended up to the review sessions. An individual develops his schema through his experiences in the world- that is by utilizing his mental models, which is, in turn, the external representation of internal thoughts. Schema is the cognitive map, an individual possesses about a particular topic, content, or event. It is in connection with what an individual knows or thinks about what he knows. Schema activation helps learners to make connections and helps to transfer knowledge to practical situations. The researches show that our brain has a tendency to connect old learning traces to new learning. As learning is a never-ending process, building enough background knowledge is made possible even during learning session than at the beginning only.

### **Schema Theory**

Schema, a term widely used in Psychology, Education, and Linguistics, refers to a conceptual system utilised for understanding how knowledge is considered and used. Production of a schema is the basis for cognitive development which is developed by the influence of external stimuli. Schemas are the 'mental tools' that form the basis of the thinking process and provide the learners with a 'mental toolkit'. Knowledge of schema will help the teachers to understand the major factors involved in the learning process. Schema theory explains how readers use prior knowledge in comprehension and learning from text (Rumelhart, 1980). The term schema was first introduced by Bartlett and Burt (1933) as "an active organization of past reactions or experiences". Rumelhart (1980) considers schema as a data structure that represents generic concepts stored in the memory of an individual. Merrill (2012) states that a knowledge structure is a form of schema such as those that learners use to represent knowledge in memory.

Widdowson (1980) considers schema as cognitive constructs utilized for organizing information in long- term memory. The major assumption of schema theory is that every act of comprehension is dependent on one's knowledge of the world (Anderson, Reynolds, and Goetz, 1977). This knowledge of the world is based on the mental model of the individual. Cook (1989), states that "the mind, stimulated by keywords or phrases in the text, or by the context, activates a knowledge schema". Schema theory considers knowledge as a network of mental frames called schema. "Schemata is the building blocks of cognition" (Rumelhart, 1982) which "enable the individual to recall, concentrate attention on

major information and predict likely event” (Anderson, Spiro, and Anderson, 1978). Schemata identify the relationship of objects with other objects, actions, events, etc. Rumelhart (1980) states that “schemata can represent knowledge at all levels from ideologies and cultural truths to knowledge about the meaning of a particular word to knowledge about what patterns of excitations are associated with what letters of the alphabet. We have schemata to represent all levels of our experience, at all levels of abstraction. Finally, our schemata are our knowledge. All our generic knowledge is embedded in schemata”. Schema theory considers that all individuals have a tendency to fit the knowledge acquired by them into their memory structure so as to make sense of that knowledge. Schema theory postulates that this obtained knowledge is stored in the brain in the form of chunks of information that the learners can retrieve it later. The individuals coded the new knowledge either to a ‘pre-existing schema’ or arranged as a new script. Schemata can be considered as organized mental structures that help the learners in understanding and associating what has been introduced to them.

Schema can be described as repeated behaviour patterns through which the individual learners can develop their ideas meaningfully. These repeated behaviours help the learners to predict, imagine, to think logically and solve problems and to develop their own choices and decisions. The major tenet of schema theory postulates that written texts do not convey an independent meaning rather it gives directions to how the readers can retrieve information based on their previous knowledge. Shuying An (2013) points out that the schemata of a reader are organized in a hierarchical manner, with the most general at the top and the most specific at the bottom. Schema theory specifies comprehension as an interaction between the individual’s prior knowledge and self. Effective reading combines stored non- visual information in the brain and the given visual information in the text.

### **Types of Schema**

Based on the nature of the contents, schemata can be classified as a) *Formal Schema* – Carrel and Eisterhold (1983) consider formal schema as the background knowledge of the formal and rhetorical organizational structures of various types of texts. It is otherwise called textual schema. It includes knowledge of different types of texts, genres, understanding, the use of different text types etc., b) *Content Schema* - Carrel and Eisterhold (1983) state that content schema is the background knowledge of the content area related to a text. It deals with the conceptual knowledge about what happens within a particular topic, and how these all related to each other to form a coherent whole, c) *Culture Schema* - Rivers and Temperley (1978) point out that cultural schema is shaped by shared experiences, values and attitudes in cultural contexts. The research reveals that the implicit cultural aspect of a text interacts with the reader’s cultural background knowledge of the content and makes it easy to understand effectively and, d) *Linguistic Schema* - It is the knowledge of vocabulary and grammar. It is essential in understanding any text. Eskey (1988) asserts that “language is more problem in second language reading, and that even educated; guess meaning is no substitute for accurate reading”. According to him, good readers are good decoders and interpreters of text.

### **Schema and Mental Models**

Busselle (2017) explains that “schemas and mental models are cognitive structures that link concepts and represent relationships among those concepts. We create schemas and mental models as we interact with our social and physical environments, including mediated environments and we retrieve them from memory and use them to interpret the people, objects, and events we experience directly and thorough media”. According to Mezirow (2006), schemas enable the mind to organize, retain, and act upon a particular task, but at the same time, it shows an innate capability to distinguish between what is relevant and what is not. When emotions interfere, schemas act in accordance with awareness and provide a plan of action in response to the situation. In effect, schemas are mental models derived out of a person’s experience.

The term ‘Mental Model’ is supposed to be postulated by Kenneth Craik (1952) in his book ‘The Nature of Explanation’. Mental modeling is a term used to explain a process through which the individuals create or retrieve mental models to develop more refined mental models to solve problems. A mental model is useful when the individual stored it in long-term memory and connects it with other mental models like schema, schemes, propositions, etc. A mental model is the internal representation of external reality. It takes into account prior knowledge of the individuals, schema segments, perceptions, and problem-solving strategies (Markham, 1999). Norman (1983) points out that people form internal, mental models of things when they interact with their environment, with others and with the artifacts of technology. These models are sufficient enough to provide predictive and explanatory power for understanding the interaction.

Johnson-Laird (1983) considers mental models as the basic structure of cognition. Its basic characteristics are summarized in four subheads.

1. They are incomplete and constantly evolving.
2. They may contain errors, misconceptions, and contradictions.
3. They may provide simplified explanations of complex phenomena.
4. Even if there is uncertainty about their validity, it is used.

Seel (2003) notes that mental models are situation dependent constructions or reconstructions of previously generated models, essential for problem-solving, and can be idealized via concept maps. "As the concept maps are interactive, dynamic, and adaptable, they are appropriate for the purpose of problem-solving and can be created or used by a single person or by small groups" (Weinberger and Mandl, 2003). Concept maps are external representations, and their output is concept mapping. Concept mapping is used for visualizing the relationship among various concepts. Mental models are the internal representations of reality that individuals utilized for understanding specific phenomena. Mental models provide predictive and explanatory power for understanding interactions with the world around us (Gentner and Stevens, 1983). The basic thing in model-based instruction is that providing learners with models in the form of tasks or representations of casual relations enhances knowledge and skill acquisition in the context if it is provided early during the course of learning (Shute and Rivera, 2008). Carley and Palmquist (1992) point out the major characteristics of mental models.

1. Mental models are internal representations.
2. Language is the key to understanding mental models i.e. it can be represented linguistically.
3. It can be represented as a network of concepts.
4. The meaning of a concept for an individual is embedded in its relation to other concepts in the individual's mental model.
5. The social meaning of a concept can be explained in terms of the intersection of individuals' mental models rather than in a universal sense.

Norman (1983) asserts mental model formation includes our views, attitudes, and beliefs regarding the factors like,

1. The world around us
2. What we think ourselves; as teachers or learners
3. Our prior knowledge and capabilities
4. The tasks we undertake
5. The problems we deal with
6. The strategies we adopt

Jacobs and Shaw, 1998; Moore and Golledge, 1976 consider mental models as internal cognitive structures that individuals form as per their life experiences, perceptions of the world around them, and formal knowledge which help them to interpret, understand and interact with their environment. According to Seel (2003), the mental model building can be done through three main instructional paradigms: discovery learning, guided discovery learning, and the common receptive learning followed by a teacher's explanation or demonstration.

Piaget's researches focused on the intellectual development of the learners, especially how learners' mental models or their schema works and develops. According to the Cognitive Acceleration theory of Michael Shayer and Philip Adey (2002), human beings possess a single cognitive processor, which plays a key role in cognitive development. It helps individuals receive information. It is influenced by certain factors or conditions. There are mainly eight factors such as schema, concrete preparation, cognitive conflict, social learning, teacher mediation, bridging, meta-cognition, and mastery learning.

### **Schema and Mental Models in Learning**

Knowledge is constructed by learners on account of their cognitive structures. Content knowledge and content acquisition is the prime focus of any learning activity. To attain this, knowledge should be actively constructed and the learning process should be learner-friendly. Teachers should be able to guide the learners to assimilate new knowledge to existing knowledge and to modify the existing knowledge to accommodate new knowledge. For this, teachers must be

aware of the prior knowledge of the learners, their schema, and mental models which helps them to design, sequence and present new learning materials.

According to Piaget (1997), “knowledge is constructed through experience, not from the information they are given”. Fried, Zannini, Wheeler, Lee, and Cortez, (2005) state that “learning is contextualized to provide students with realistic roles that serve to enhance the learning process”. Piaget’s (1997) theory of cognitive development explains how learners construct mental models of the world. According to him, the cognitive development of the individual is the result of biological maturation and interaction with the environment. It is a progressive reorganization of mental processes. The basic components of Piaget’s cognitive theory are schema, adaptation processes, and stages of cognitive development. Piaget called schema ‘the basic building block of intelligent behaviour’. These are a set of linked mental representations of the world which we store and retrieve when needed. Piaget’s (1995) learning theory stresses the importance of an active learner in the learning process unless problem-solving will not occur. Rogoff (1990) points out that “children’s cognitive development is an apprenticeship; it occurs through guided participation in social activity with companions who support and stretch children’s understanding of and skill in using the tools of the culture”.

Young (1983) remarks that mental models should be able to explain users’ performance with the system they interact with. Morrow (1985) conducted a study on kindergarten children reading narrative texts and found that when the students are actively engaged in reading, they maintain a mental model of the text during reading, by focusing on relevant characters in a narrative. The study also highlights that mental model processing seems to be visible especially in narrative texts and spatial descriptions.

Analysing the nature of mental models and to identify how individuals develop good mental models is essential for the educational and economic benefit (Seel, 1999; Spector, Dennen, and Koszalka, 2006). The constructed representations through mental models are able to communicate subjective experiences, thoughts, feelings and ideas (Mayer, Moreno, Boire, and Vagge, 1999; Seel, 2003). The studies reveal that learners who possess good mental models demonstrate comparatively good learning outcomes and efficiency than that of learners with less adequate models (Dekleer and Brown, 1981; White and Frederiksen, 1987; Mayer, 1989). The problem-solving capacity of the problem solvers can be at least partially explained the quality of the mental models they possess (Gott, Bennett, and Gillet, 1986).

Pani (2003) in his study observed that mental modeling is a technique where the teacher’s demonstration of the mental processes helps the learners imitate the ‘superior’ reader and it makes the process of reading ‘visible’. The findings of the study revealed that mental modeling is an effective pedagogic strategy for Indian classrooms for motivating the learners in improved reading strategies.

Woolley (2011) in the study highlights that children actively utilize cognitive resources by constructing appropriate mental models during reading comprehension. The difficulties in comprehension are because of the inability to use the working memory appropriately and hence the construction of mental models of story content may be impaired. The comprehension skills of the learners can be improved through inferential reading comprehension strategies which may facilitate the elaboration of the mental modeling of narrative texts. Britton (1994) suggests that “the mental structures that readers derive from a text often will be incomplete or incorrect, when compared to the structure intended by the author”.

A study conducted by Guo-Li (2013) identifies to what extent students utilize their mental models to predict certain uncertain physical phenomena. He conducted a semi-structured interview among 30 physics students to examine their mental modeling and their predictions about the concept of heat convection. Data were analysed by using constant comparative method. The results show that the participants had a variety of mental models of heat convection, including flawed and scientifically compatible mental models. The study also shows that the relationship between the mental models and its predictive nature turns complex along with the problem-solving. This relationship can be understood by its completeness, the scale of analyzing mental models, and the retrieval of different kinds of mental representations.

DiMaggio (1997) asserts that mental models are a combination of socially constructed and recognized cultural elements that any group develops and the organization of cultural knowledge by the individual for their own use. The study of Seel and Ifenthaler (2013) on mental models regarding its application to inductive reasoning in instruction had an assumption that the construction of mental models and related reasoning is a slowly developing capability of cognitive systems as a result of appropriate context and social situations.

Spillane, Reiser, and Reimer (2002); Abrahamson and Fombrun (1994) observed that, in education, mental models mean what constitutes good pedagogy to each teacher, and it is shaped according to the limited bank of options generated by common expectations, collective experience, and shared professional practice and their biases, about how students do and learn something. These images can be based on both the “micro-culture” of a school or a local community and the broadly shared professional and “macro culture”. In connection with this, Ford, (1996) observed that, when individuals use their mental models for sensing new information or ideas from their environment, they can either lead to creativity and innovation or can inhibit it.

Wilke and Losh (2012) conducted a study on eight social science pre-service teachers with the help of lesson plans, interviews, and written rationale and examined their changes through the application of mental models theory. Their mental models developed from general to discipline-specific practices and their conceptions students’ learning focus on learner types than on learning processes.

The studies of Porac and Thomas, (1990); Thomas, Clark, and Gioia, (1993) assert the importance of mental models in decision making, in persons like CEOs and working mothers to simplify the disturbed working environments and the variety of logical options they face at work. Ford and Johnson-Laird (1985) point out that "human beings understand the world by constructing models of it in their minds." It is an essential aspect in accommodating to the world and hence utilizing a Piagetian construct, which is the base for the learning taxonomy developed by Kyllonen and Shute (1989), which postulates that rote, didactic, deductive, and inductive learning methods result in the development of propositions and skills which form the basis for mental models. The construction of mental models "requires the concerted exercise of multiple skills applied to elaborate schemata". Like all taxonomies of learning, propositions are prerequisites to the acquisitions of related schemas and skills, which are the essential prerequisite to mental models.

McNamara, Miller and Bransford (1991) point out that a “mental model built by the reader in the process of reading consists of mental tokens arranged in a structure that depicts the situations described by a text”. Garnham (1981) points out that when the readers were not told about a memory test following the reading, they seemed to process the texts as mental models. They found it difficult to recall the exact sentences and distinguish between sentences present and not present in the text. Their recalling is the result of the mental representation of the text, rather than the propositional one. Newmann (1996) points out that the pedagogic mental model emphasizes connections between the classroom and the real world.

## **Conclusion**

Schema and mental models are the building blocks of knowledge formation. Unlike schemas, mental models are not permanent. Thagard, (2010) views mental models as psychological representations that possess the same relational structure as what they represent. They explain many aspects of human reasoning such as deduction, induction, problem solving, language understanding, and human-machine interaction. In certain learning situations where schemata are absent or insufficient for problem-solving, mental models involve are structuring the cognitive structure which is useful for understanding a novel situation or an unknown problem (Al-Diban, 2012). The knowledge of schema and mental models in the learners helps teachers to identify, design, and implement new teaching-learning strategies and make it available for concept formation and development of higher-order thinking skills.

## **Reference**

- Abrahamson, E., & Fombrun, C. J. (1994). Macrocultures: Determinants and consequences. *Academy of Management Review*, 19(4), 728-755. doi:10.5465/amr.1994.9412190217
- Al-Diban, S. (2012). Mental models. *Encyclopedia of the Sciences of Learning*, 2200-2204. doi:10.1007/978-1-4419-1428-6\_586
- Anderson, R. C., Reynolds, R. E., Schallert, D. L., & Goetz, E. T. (1977). Frameworks for comprehending discourse. *American Educational Research Journal*, 14(4), 367-381. doi:10.3102/00028312014004367
- Anderson, R. C., Spiro, R. J., & Anderson, M. C. (1978). Schemata as scaffolding for the representation of information in connected discourse. *American Educational Research Journal*, 15(3), 433-440. doi:10.3102/00028312015003433
- An, S. (2013). Schema theory in reading. *Theory and Practice in Language Studies*, 3(1). doi:10.4304/tpls.3.1.130-134
- Bartlett, F. C., & Burt, C. (1933). Remembering: A study in experimental and social psychology. *British Journal of Educational Psychology*, 3(2), 187-192. doi:10.1111/j.2044-8279.1933.tb02913.x

- Britton, B. (1994). Understanding expository text. In *M. A. Gernsbacher (Ed.), Handbook of Psycholinguistics* (p. 641–674). San Diego: Academic Press.
- Busselle, R. (2017). Schema theory and mental models. *The International Encyclopedia of Media Effects*, 1-8. doi:10.1002/9781118783764.wbieme0079
- Carley, K., & Palmquist, M. (1992). Extracting, representing, and analyzing mental models. *Social Forces*, 70(3), 601-636. doi:10.1093/sf/70.3.601
- Carrell, P. L., Devine, J., & Eskey, D. E. (1988). *Interactive Approaches to Second Language Reading*. Cambridge, England: Cambridge University Press.
- Carrell, P. L., & Eisterhold, J. C. (1983). Schema theory and ESL reading pedagogy. *TESOL Quarterly*, 17(4), 553. doi:10.2307/3586613
- Chiou, G. (2013). Reappraising the relationships between Physics students' mental models and predictions: An example of heat convection. *Physical Review Special Topics - Physics Education Research*, 9(1). doi:10.1103/physrevstper.9.010119
- Cook, G. (1989). *Discourse*. New York: Oxford University Press.
- Craik, K. J. (1952). *The Nature of Explanation*. Cambridge, England: CUP Archive.
- DeKleer, J., & Brown, J. S. (1981). Mental models of physical mechanisms and their acquisition. In *J. R. Anderson (Ed.), Cognitive Skills and their Acquisition*. Hillsdale, NJ: Erlbaum.
- DiMaggio, P. (1997). Culture and cognition. *Annual Review of Sociology*, 23(1), 263-287. doi:10.1146/annurev.soc.23.1.263
- Ford, C. M. (1996). A theory of individual creative action in multiple social domains. *Academy of Management Review*, 21(4), 1112-1142. doi:10.5465/amr.1996.9704071865
- Ford, M., & Johnson-Laird, P. N. (1985). Mental models: Towards a cognitive science of language, inference, and consciousness. *Language*, 61(4), 897. doi:10.2307/414498
- Fried, A., Zannini, K., Wheeler, D., Lee, Y., & Cortez, A. J. (2005). Anchored instruction. Retrieved from <http://web.cortland.edu/frieda/id/idtheoies/41.html>
- Garnham, A. (1981). Mental models as representations of text. *Memory & Cognition*, 9(6), 560-565. doi:10.3758/bf03202350
- Gentner, D., & Stevens, A. (1983). *Mental models*. Hillsdale, NJ: Erlbaum.
- Gott, S. P., Bennett, W., & Gillet, A. (1986). Models of technical competence for intelligent tutoring systems. *Journal of Computer Based Instruction*, 13(2), 3-46
- Ifenthaler, D., & Seel, N. M. (2013). Model-based reasoning. *Computers & Education*, 64, 131-142. doi:10.1016/j.compedu.2012.11.014
- Jacobs, E. K., & Shaw, D. (1998). Sociocognitive perspectives on representation. In *Williams (Ed.), Annual Review of Information Science & Technology*, 33 (pp. 131-185). Medford, NJ: Information Today, Inc.
- Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inferences and consciousness*. Cambridge MA: Harvard University Press.
- Kyllonen, P. C., & Shute, V. J. (1989). A taxonomy of learning skills. In *Ackerman, P.L., Sternberg, R. J., & Glaser, R. (Eds.), Learning and individual differences* (pp. 117- 163). New York: W. H. Freeman.
- Markham, A. B. (1999). *Knowledge representation*. Mahwah NJ: Lawrence Erlbaum Associates.
- Mayer, R. E. (1989). Models for understanding. *Review of Educational Research*, 59(1), 43-64. doi:10.3102/00346543059001043
- Mayer, R. E., Moreno, R., Boire, M., & Vagge, S. (1999). Maximizing constructivist learning from multimedia communications by minimizing cognitive load. *Journal of Educational Psychology*, 91(4), 638-643. doi:10.1037/0022-0663.91.4.638

- McNamara, T. P., Miller, D. L., & Bransford, J. D. (1991). Mental models and reading comprehension. In R. Barr, M. Kamil, P. Mosenthal, & P. Pearson (Eds.), *Handbook of Reading Research* (2nd ed., p. 490–511). London: Longman.
- Merrill, M. D. (2012). *First principles of instruction*. Hoboken: John Wiley & Sons.
- Mezirow, J. (2006). An overview on transformative learning. In Knud Illeris (Ed.), *Contemporary theories of learning: Learning theorists... in their own words*. London / New York: Routledge.
- Morrow, L. M. (1985). Reading and telling stories: Strategies for emergent readers. *The Reading Teacher*, 38, 870–875
- Moore, G. T., & Golledge, R. G. (1976). *Environmental knowing: Theories, research and methods*. Stroudsburg, Pa: Dowden, Hutchinson & Ross.
- Norman, D. (1983). Some observations on mental models. In D. Gentner & A. Stevens (Eds.), *Mental models* (pp. 7-14). Hillsdale, NJ: Lawrence Erlbaum.
- Newmann, F. M., & Associates. (1996). *Authentic achievement: Restructuring schools for intellectual quality*. San Francisco: Jossey Bass.
- Pani, S. (2004). Reading strategy instruction through mental modelling. *ELT Journal*, 58(4), 355-362. doi:10.1093/elt/58.4.355
- Piaget, J. (1955). *The child's construction of reality*. Oxfordshire, England: Taylor & Francis.
- Piaget, J. (1997). *The origin of intelligence in the child*. London, England: Psychology Press.
- Porac, J. F., & Thomas, H. (1990). Taxonomic mental models in competitor definition. *The Academy of Management Review*, 15(2), 224. doi:10.2307/258155
- Rivers, W. M., & Temperly, M. S. (1978). *A practical guide to the teaching of English as a second or foreign language*. Oxford: Oxford University Press.
- Rogoff, B. (1990). *Apprenticeship in thinking: cognitive development in social context*. New York: Oxford University Press.
- Rumelhart, D. E. (1980). Schemata: The building blocks of cognition. In Spiro et al (Eds.), *Theoretical issues in reading comprehension*. Hillsdale, NJ: Lawrence Erlbaum.
- Rumelhart, D. E. (1982). Schemata: The building blocks of cognition. In J. Guthrie (Ed.), *Comprehension and teaching: Research reviews* (pp. 3-26). Newark, D.E: International Reading Association.
- Seel, N. M. (1999). Educational diagnosis of mental models: Assessment problems and technology-based solutions. *Journal of Structural Learning and Intelligent Systems*, 14(2), 153-185.
- Seel, N. M. (2003). Model-centered learning and instruction. *Technology, Instruction, Cognition and Learning*, 1(1), 59-85.
- Shayer, M., & Adey, P. (2002). *Learning intelligence: Cognitive acceleration across the curriculum from 5- 15 years*. McGraw- Hill Education (UK): Open University Press.
- Shute, V. J., & Zapata-Rivera, D. (2008). Using an evidence-based approach to assess mental models. *Understanding Models for Learning and Instruction*, 23-41. doi:10.1007/978-0-387-76898-4\_2
- Spector, J. M., Dennen, V. P., & Koszalka, T. (2006). Causal maps, mental models and assessing acquisition of expertise. *Technology, Instruction, Cognition and Learning*, 3, 167-183.
- Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research*, 72(3), 387-431. doi:10.3102/00346543072003387
- Thagard, P. (2010). How brains make mental models. In L. Magnani et al (Eds.), *Model based reasoning in Science & Technology, SCI 314* (pp. 447- 461). Berlin: Springer.

- Thomas, J. B., Clark, S. M., & Gioia, D. A. (1993). Strategic sense making and organizational performance: Linkages among scanning, interpretation, action, and outcomes. *Academy of Management Journal*, 36(2), 239-270. doi:10.5465/256522
- Weinberger, A., & Mandl, H. (2003). Computer-mediated knowledge communication. *Studies in Communication Sciences*, 81-105.
- White, B., & Frederiksen, J. (1985). Qualitative models and intelligent learning environments. In R. Lawler & M. Yazdani (Eds.), *Artificial Intelligence and Education*. Norwood, NJ: Ablex.
- Widdowson, H. G. (1980). *Aspects of Language Teaching*. Oxford University Press.
- Wilke, R. A., & Losh, S. C. (2012). Exploring mental models of learning and instruction in teacher education. *Action in Teacher Education*, 34(3), 221-238. doi:10.1080/01626620.2012.693241
- Woolley, G. (2011). Reading comprehension. *Reading Comprehension*, 15-34. doi:10.1007/978-94-007-1174-7\_2
- Young, R. M. (1983). Surrogates and mappings: Two kinds of conceptual models for interactive device. In D. R. Gentner & A. L. Stevens (Eds.), *Mental models* (p. 32-52). Hillsdale, NJ: Erlbaum.