A. The Brain System & Prior Knowledge

A. Humans are conscious of and can monitor only the contents in our ***working memory*** (Sweller, Van Merrienboer, & Paas, 1998). Working memory is used to process information, such as organizing, contrasting, comparing, or working on information in some manner. These mental tasks may include language comprehension (e.g., keeping in mind ideas from a sentence to be combined with ideas later in that same reading), problem solving (e.g., remembering the price and number of items to calculate per unit cost of an item when comparison shopping), and planning (e.g., figuring out the order and route for picking up your children in timing with dinner and extracurricular activities). Our working memory capacity is limited. It is capable of holding only about 7±2 items of information at one time (Miller, 1956), which reduces to about 2-3 items when we process information because any interactions between items held in working memory requires working memory capacity (Sweller et al., 1998). Limitations in working memory only apply to new information obtained through sensory input, i.e., see, hear, feel etc. (van Merrienboer & Sweller, 2005). There appears to be no known limitations on working memory capacity when dealing with information retrieved from long term memory (Sweller, 2003, 2004).

B. ***Long-term memory*** consists of a large, relatively permanent collection of information. This information is organized and stored in the form of mental models (schema) and can be retrieved and used automatically without much if any mental effort (automation) (van Merrienboer & Sweller, 2005). For example, driving involves attending to and processing many mental and physical tasks simultaneously (e.g., checking mirrors, signaling, knowing rules of the road, etc.) that gets organized and automated over time and with practice. Mental models vary in their degree of complexity and automation. They reduce strain on working memory capacity because even highly complex mental models can be treated as one item in working memory, or not even require working memory at all (e.g., driving has become automated). Expertise comes from knowledge stored in these mental models, not from an ability to engage in reasoning with many elements that have not been organized in long-term memory (van Merrienboer & Sweller, 2005). Expertise develops as learners mindfully organize and connect simple ideas into more complex ones. If nothing has been changed in long-term memory, nothing has been learned in an enduring way (Sweller, 2004).

C. Mental models (schemas), which are constructed from ***prior knowledge and experiences***, direct how new information is processed and organized in working memory (van Merrienboer & Sweller, 2005). For example, when we do not have a mental model for a language foreign to us, we might not hear where one word ends and the other begins. Mental models enable an expert chess player to recognize a particular mid-game position at a single glance, while a novice player only sees an unstructured set of single chess pieces. If there is no prior knowledge (no existing schema), then we organize the new information randomly. That randomly organized information would need to be tested for soundness and effectiveness, as we begin to build a mental model. The processing requires working memory capacity. Prior knowledge may also have been organized poorly or ineffectively, and thus new information may or may not fit. This situation, in turn, also strains working memory to process and organize new information into existing mental models.

D. Prior knowledge exists not only at the level of "concepts," but also at the levels of perception, focus of attention, procedural skills, modes of reasoning, and beliefs about knowledge (Roschelle, 1995). Learners' prior ideas, their "common sense," and "everyday thinking," are intelligent and useful. If those ideas are not engaged, learners often dismiss teaching as irrelevant (Hammer & van Zee, 2006, p. 14).

Conversations & Social Activities

1. The opportunity to *externalize and reflect on one's thinking facilitates learning*, especially complex science concepts. Externalizing is written or verbal articulation of ones' evolving understanding, which allows learners the opportunity to share their unformed ideas with others (Sawyer, 2006). Reflection is the act of thinking about the process of learning and thinking, as a means to detect inconsistencies in ones' thinking and help to identify connections between areas of conceptual understanding (Davis, 2003; National Research Council (NRC), 2007).

2. Students in K-12 to university settings show greater understanding when they engage in collaborative dialogue with peers where they provide explanations as part of arguments and justifications, and when they seek and provide help (Mercer, Dawes, Wegerif, & Sams, 2004; van Blankenstein, Dolmans, van der Vleuten, & Schmidt, 2011; Veenman, Denessen, van den Akker, & van der Rijt, 2005; Venville & Dawson, 2010). Students who were given the opportunity to talk, argue, and defend their ideas in small groups showed positive change in their understanding of difficult and complex concepts, like evaporation (Tytler & Peterson, 2000) and climate change (Mason & Santi, 1998).

3. Learning *occurs in a complex social environment*, and thus should not be limited to being examined or perceived as something that happens solely on an individual level. Learning is a social activity because it involves people, the things they use, the words they speak, the cultural context they're in, and the actions they take (Bransford et al., 2006; Rogoff, 1998). Members in the activity build knowledge together (Scardamalia & Bereiter, 2006).

4. *Learning opportunities* situated in everyday experiences provide learners with a reason to understand (Greeno, 2006; Kolodner, 2006). It generates memories with a frame of reference, which facilitate retrieval and application of prior knowledge and experiences to new situations (Kolodner et al., 2003). Authentic contexts help learners form connections between new and old information, which lead learners to develop better, larger, and more associated conceptual understanding (Blumenfeld, Kempler, & Krajcik, 2006; Kolodner, 1993; Schank, 1982).

5. Families, friends, peer groups, and larger social networks are all units of learning, as well as significant contexts in which learning occurs (Bransford et al., 2006). These units and contexts support social interactions that may occur in different, interdependent ways, such as imitation, collaboration, and instruction.
    a. *Imitation*—learning from watching other people—is ubiquitous among humans across the lifespan (Bransford et al., 2006; Meltzoff & Decety, 2003).
    b. *Collaboration*—learning from working with people—is a coordinated, synchronous activity that results from a continued attempt to build a common understanding of an idea or a problem (Roschelle & Teasley, 1995), where the emergent understanding is a product of the group (Dillenbourg, Baker, Blaye, & O'Malley, 1996).
    c. *Instruction*—learning through guidance from people—is the process of more knowledgeable individuals helping less experienced learners to make meaning of new experiences, where the knowledgeable person may be an adult or peer (Vygotsky, 1978; Wood, Bruner, & Ross, 1976).

Engagement in Learning

1. Learners need to expend considerable mental effort and persistence in order to learn complex ideas deeply; such commitment requires various types and levels of engagement to learn. Engagement is presumed to be malleable (Fredricks, Blumenfeld, & Paris, 2004).

2. Engagement is multi-dimensional, and is an interaction between the individual and their environment. There are three types of engagement:
    a. ***Behavioral engagement*** refers to the ways in which learners participate in learning experiences (Fredricks et al., 2004). The concept includes learners' conduct (e.g., showing up and adhering to rules of the environment) and levels of involvement in tasks (e.g., attention, concentration, effort, and contribution).
    b. ***Emotional engagement*** refers to learners' affective reactions (their feelings and emotions) to the learning context, which may be influenced by their: interactions with the people and context involved; interest in the subject matter; and how they value the subject matter (Fredricks et al., 2004). Value may be: intrinsic (e.g., interest in the topic), functional (e.g., perception of how tasks are related to future goals and life), or attainment oriented (e.g., personal importance placed on the task).
    c. ***Cognitive engagement*** refers to learners' psychological investment in learning (the motivation), and also the cognitive learning strategies they employ (the methods) (Fredricks et al., 2004). It incorporates thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills.
        i. Motivation to participate may be affected by their feelings of competence in being able to succeed (e.g., abilities are learned and can be developed versus abilities are innate and cannot be changed); and be driven by their learning goals (e.g., mastering the task and understanding versus for performance and task completion).
        ii. Learning strategies include: cognitive (e.g., memorize, elaborate, connect and organize ideas); metacognitive (e.g., setting goals, planning, self-monitoring, evaluating progress, and making adjustments); and volitional (e.g., manage attention, affect, and effort in face of distractions)
        iii. Motivation can lead to achievement by increasing the quality of cognitive engagement. Conceptual understanding and skills capabilities are enhanced when students are committed to building knowledge and using deeper learning strategies (Blumenfeld et al., 2006, p. 476).

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