Perspectives from the CHDS Media Hub
Cognitive Load, Learning, and Instructional Design

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Cognitive Load Theory: Learning & Instructional Design

How does cognitive load theory inform the design of educational multimedia?

Cognitive load theory (CLT) is a theory of learning that is based on what we know about how learners process new information in working memory (WM) and construct knowledge in long-term memory (LTM) (Sweller 1998, 2020). An understanding of what we mean by "cognitive load" and a conceptual appreciation for CLT, can be helpful in the design of effective educational multimedia and instructional strategies more generally.

How do we process new information and construct knowledge in our brains?

We are confronted with new information constantly – that information is filtered through attention before entering our sensory memory (i.e., we filter what is most relevant), and then is passed on to our WM (Neisser 1967). Unfortunately, our WM is limited to about 4-7 chunks of new information that can be processed at any one time (Miller 1994). We organize, categorize, cluster, and integrate that information into LTM, which has virtually unlimited storage capacity (De Groot 1965, Atkinson 1968, Baddeley 2004). The process of clustering and grouping bits of information into a single element or "schemas," (Sweller 1994) reduces the burden placed on our limited WM.

What does "working memory" have to do with learning?

Consider what happens in our WM and LTM when we learn. During learning, we undergo a process where we repeatedly compare the information in working memory to the existing schema stored in LTM. WM continuously re-articulates this information until we can find a way to "fit" that new information into our greater schema structure within LTM (this is the part of learning where learners must "wrestle" with the content). WM and LTM will continue to haggle over the schematic "shape" of the new information until it can find a way to integrate that new knowledge in a congruent way with the rest of our knowledge, or it will cause an alteration of the already existing schema in LTM to compensate for the new information (e.g., you learn something that changes your preconceived ideas).

In essence, learning is the change in LTM associated with this process, and results in the acquisition of new knowledge and skills (Mayer 2008). The more we use established schema from our LTM, the easier it is for us to draw upon them as needed, a process referred to as "automation." In other words, a learner with well-established pre-existing schema can more easily off-load cognitive load from WM to LTM. This has implications for the instructional design of lessons for novices versus experts.

What are the underlying assumptions of Cognitive Load Theory (CLT)?

CLT centers around three characteristics of learning (Sweller 2020), the limited capacity assumption, the active processing assumption, and the dual channel assumption.

1. Limited capacity assumption

This assumption refers to the limitations of our WM, which was described long before cognitive load theory. Miller (1956) put forward the idea that working memory was limited to processing about 7 (plus or minus 2) chunks of information. An entire body of research has reinforced this idea, and uncovered further nuances, from the neurological mechanisms (Kimberlee D'ardenne 2012; Mongillo 2008; Sreenivasan 2014; Manohar 2019) to the behavioral characteristics (Baddeley 1992; Miller 1994; Ricker 2010) of WM.

2. Active processing assumption

This assumption refers to all the ways a learner needs to be actively engaged during the process of knowledge construction (Clark 2006). For example, a learner needs to filter out irrelevant information that enters sensory memory, pass on what is considered relevant to WM, organize and cluster new information into schema, and integrate new information with prior knowledge in LTM through reconstruction of existing schema (Mayer 2003).

3. Dual channel assumption

This assumption refers to the processing of information in two separate channels which, like the limited processing assumption, was described before cognitive load theory was formalized. Paivio's (1986) dual-coding theory proposed there are two cognitive subsystems, a "verbal" component that deals with language, and a "nonverbal" component that deals with the processing of images. Baddeley proposed that WM could be subdivided into partially independent processors, one for processing verbal materials based on auditory WM and one for processing diagrammatic/pictorial information based on visual WM (e.g. Baddeley 1992).

What exactly is "cognitive load" and is there more than one type?

Cognitive load is a central concept critical to cognitive load theory and highly relevant to learning and instructional design (Sweller, 1994, 1999). Cognitive load refers to the "cognitive processing demands" placed on a learner in the context of the limitations of working memory. There are three general types of cognitive load that have been described: (1) intrinsic cognitive load, (2) germane cognitive load, and (3) extraneous cognitive load.

1. Intrinsic cognitive load

Intrinsic cognitive load refers to the cognitive processing that is needed to comprehend new information. Intrinsic cognitive load will depend on the nature of the material, the learner's prior knowledge, the learner's affect, and contextual features of the learning environment (Clark 2006).

For example, consider a hypothetical lesson covering a complex topic with 15 bits of new information. More advanced learners will have pre-existing schemas related to this topic stored in long term memory – they will be able to recruit these from LTM to "off load" the new information in working memory, leaving them additional room to process and integrate new information. That same material, presented to a novice learner without pre-existing schemas in LTM, will be experienced in WM as 15 separate individual elements, completely overwhelming their processing capacity.

2. Germane cognitive load

Germane cognitive load refers to intrinsic cognitive load that is associated with more difficult learning tasks, more complex learning material, and occurs when learners engage in "deep cognitive processing" (Mayer 2008). Germane cognitive load can be created purposefully by an instructor, to enhance the process in which learners organize and integrate new information, both to create new schema and to reconstruct existing schema from LTM (Mayer 2008; Paas 2003). Like intrinsic cognitive load, germane cognitive load will depend on the learner's prior knowledge. This is why understanding the prior knowledge (e.g., facts, beliefs, misconceptions, etc.) of learners is so fundamental to effective instructional design.

3. Extraneous cognitive load

Unlike intrinsic and germane cognitive load, which are both essential for learning, extraneous cognitive load refers to information processing that is not needed or is irrelevant to the learning goals of the lesson. This might include (a) completely unrelated information, visual elements with no purpose, etc., (b) extensive details that are not necessary for the particular learning task, (c) an instructional format that introduces distraction, such as animation for "animation" sake. With the limited capacity of WM, we want to avoid giving the learner any extraneous cognitive load to allow for as much room as possible for intrinsic and germane loads – both of which are integral to the knowledge acquisition and assimilation process.

What does CLT and "working memory" have to do with instructional design?

Instruction design, with attention to CLT, is the deliberative process of considering the three types of cognitive load when designing a lesson, selecting a pedagogical approach, and constructing materials. The three types of cognitive load need to be considered in the context of (a) the learner's prior knowledge and beliefs, (b) the complexity of the content, and (c) the features of the learning environment.

In a nutshell, the goal is to make the cognitive processes associated with learning as effective and efficient as possible, using a three-pronged strategy:

- **Reducing extraneous cognitive load** by removing components of a lesson plan that use up limited working memory resources (e.g., irrelevant cognitive activities, distracting information, etc.) but do not contribute to learning.
- **Managing essential processing** by creating materials, designing lessons, and using pedagogical strategies that promote the efficient use of WM.
- **Fostering generative processing** by designing learning experiences that encourage students to engage in strategies that help them organize, assimilate, integrate, and retain new information (e.g., self-explanation, peer teaching, active problem-solving, etc.) (Sweller 1998).

Learn more

To learn more about advances in CLT and their relevance to instructional design, see Sweller et al. (2020). To learn more about the application of CLT to multimedia learning, see Mayer et al. (2014). For an overview of multimedia design principles and insights for educators, see our monograph "Cognitive Theory of Multimedia Learning" (Goldie and Waxman 2021).

Cognitive Load Theory: Learning and Instructional Design (cont.)

References and Resources

Baddeley, A. (1992). Working Memory. *Science (Washington)*, *255*(5044), 556–556.

Clark, J. M. & Paivio, A. (1991). Dual coding theory and education. Educational Psychology Review, 3(3), 149-170.

Kimberlee D'ardenne, Neir Eshel, Joseph Luka, Agatha Lenartowicz, Leigh E. Nystrom, & Jonathan D. Cohen. (2012). Role of prefrontal cortex and the midbrain dopamine system in working memory updating. *Proceedings of the National Academy of Sciences*, *109*(49), 19900–19909. https://doi.org/10.1073/pnas.1116727109

Manohar, S. G., Zokaei, N., Fallon, S. J., Vogels, T. P., & Husain, M. (2019). Neural mechanisms of attending to items in working memory. *Neuroscience and Biobehavioral Reviews*, *101*, 1–12. https://doi.org/10.1016/j.neubiorev.2019.03.017

Mayer RE (2001). Multimedia learning. New York: Cambridge University Press.

Mayer RE (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. Cognition and Instruction 19, 177-213.

Mayer RE and Moreno R (2003). Nine ways to reduce cognitive load in multimedia learning. Educational Psychologist 38, 43-52.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. The psychological review, 63, 81-97.

Miller, G. A. (1994). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *101*(2), 343–352. https://doi.org/10.1037/0033-295X.101.2.343

Mongillo, G., Barak, O., & Tsodyks, M. (2008). Synaptic Theory of Working Memory. *Science*, *319*(5869), 1543–1546. https://doi.org/10.1126/science.1150769

Paivio, A. (1986). Mental Representations. New York: Oxford University Press.

Ricker, T. J., AuBuchon, A. M., & Cowan, N. (2010). Working memory. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*(4), 573–585. https://doi.org/10.1002/wcs.50

Silvanto, J. (2017). Working Memory Maintenance: Sustained Firing or Synaptic Mechanisms? *Trends in Cognitive Sciences*, *21*(3), 152–154. https://doi.org/10.1016/j.tics.2017.01.009

Sreenivasan, K. K., Curtis, C. E., & D'Esposito, M. (2014). Revisiting the role of persistent neural activity during working memory. *Trends in Cognitive Sciences*, *18*(2), 82–89. https://doi.org/10.1016/j.tics.2013.12.001

Sweller J (1988). Cognitive load during problem solving: Effects on learning. Cognitive Science 12, 257-285.

Sweller J (1989). Cognitive technology: Some procedures for facilitating learning and problem-solving in mathematics and science. Journal of Educational Psychology 81, 457-466.

Sweller J (1994). Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction 4, 295-312.

Sweller J, van Merrienboer JJG, Paas F. (1998). Cognitive architecture and instructional design. Ed Psychol Rev. 10(3):251–296.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review*, *31*(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5

Thomas M, Ansari D, Knowland V. (2019). Annual Research Review: Educational neuroscience: progress and prospects. Journal of Child Psychology and Psychiatry 60:4, pp 477–492

Yaghoub Mousavi, S., Low, R., & Sweller, J. (1995). Reducing Cognitive Load by Mixing Auditory and Visual Presentation Modes. *Journal of Educational Psychology*, *87*(2), 319–334. https://doi.org/10.1037/0022-0663.87.2.319

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