# Perceptual and Cognitive Load in Learning to Diagnose Static and Dynamic Medical Images

*Tamara van Gog*
*Institute of Psychology, Erasmus University Rotterdam*
*P.O. Box 1738, 3000DR Rotterdam, The Netherlands*
*vangog@fsw.eur.nl*

**Abstract.** As a result of technological advancements, medical images are becoming increasingly visually complex, and dynamic rather than static. This poses serious challenges for medical students who need to learn to diagnose such images, because the increase in perceptual and cognitive load that is often associated with dynamic and complex visual stimuli may have adverse effects on medical students' learning processes and outcomes. In this contribution we will discuss instructional design principles that may reduce possible adverse effects on learning from complex dynamic visualizations caused by high perceptual and cognitive load.

**Keywords:** cognitive load; instructional design; visualizations

## Cognitive Load Theory and Instructional Design

According to Cognitive Load Theory (CLT), the effectiveness of instruction is determined by the extent to which the characteristics of working memory (WM) and long-term memory (LTM) are taken into account in the design of instruction (Sweller, Van Merriënboer, & Paas, 1998). Cognitive schemata are the product of learning; these are structures in which knowledge is stored and organized in LTM. Learning takes place by associating new information elements with each other (schema construction) or with prior knowledge (schema elaboration) in WM. WM capacity, however, is limited to seven plus or minus two elements or chunks of information when holding information (Miller, 1956) and even fewer (ca. 4) when processing it (Cowan, 2001). This poses a bottleneck for learning when tasks contain a high number of interacting information elements. Because those elements have to be processed in WM simultaneously for learning to take place, such tasks impose a high load on WM. In CLT, this is referred to as intrinsic cognitive load (Sweller et al., 1998). Knowledge and expertise develop through the building of increasing numbers of ever more complex schemata in long term memory by combining elements consisting of lower level schemata into higher level schemata. A schema retrieved from long-term memory can be handled in WM as a single information element. Therefore, the number of interacting elements and the intrinsic load imposed by a learning task decreases for learners who have prior knowledge of that task. Moreover, though high amounts of practice, some (sub)schemata can become automated and no longer require controlled, effortful processing, which further reduces the load on WM (Schneider & Shiffrin, 1977). Next to this intrinsic load imposed by the task, there is also load imposed by cognitive processes that are evoked by the way in which a learning task or a series of tasks is designed or delivered to learners. This load can result from processes that are either ineffective for learning (i.e., extraneous cognitive load) or directly contribute to learning (i.e., germane load; Sweller et al., 1998). CLT argues that for instruction to be effective, intrinsic load should be optimized, extraneous load should be minimized, and germane-load should be optimized, so that available WM capacity is not exceeded and is used most effectively (Sweller et al., 1998).

Research inspired by CLT has resulted in many instructional design principles that achieve this aim. Mostly, however, these design principles have been investigated and applied to problem-solving  and other cognitive tasks. Very little research has been conducted from a CLT perspective on instructional design principles to foster the acquisition of perceptual skills. Perceptual skills are important many domains of learning, however, and play an especially prominent role in some areas of medicine, for example in diagnosing x-rays, skin lesions, or ECGs. These are some relatively simple examples, though, as medical images are becoming increasingly complex and dynamic.

## Instructional Design for Acquisition of Perceptual Skills

Because there is an intricate connection between perceptual and cognitive processes, CLT principles might nonetheless be of use for designing instruction for medical students who need to learn to diagnose increasingly complex and dynamic visual images. On the one hand, only information that is perceived will be available for processing in WM. On the other hand, what is attended to depends for a large part on the knowledge a person already possesses. In sum, it is important to ensure that students attend to the right information at the right time.

### *Ensuring the Right Information is Attended to at the Right Time*

As mentioned above, information needs to be perceived in order to be processed in working memory (which is necessary for learning to occur). Eye tracking research has shown, however, that novices tend to look at the most salient parts of an image (which are not necessarily the most relevant ones), whereas individuals with more prior knowledge focus faster and/or in greater proportion on relevant information and tend to ignore irrelevant information even when it is more salient (e.g., Canham & Hegarty, 2010; Haider & Frensch, 1999; Jarodzka, Scheiter, Gerjets, & Van Gog, 2010; Van Gog, Paas, & Van Merriënboer, 2005). So especially novices may need instructional guidance to focus their attention on relevant parts of an image. Although such guidance may be required in general, it is presumably especially necessary when there is a high perceptual load (i.e., a lot of information to attend to) and when dynamic visualizations contain transient information, because there is only a small time window during which the information is available, and if it is not attended to at the right moment, it will simply no longer be available for processing. Transience also brings about other problems, because information needs to be maintained in working memory in order to be able to link it with information that follows later, but all the while the new information provided in the visualization also needs to be processed. This increases working memory load and may hamper learning.

Instructional attention guidance can be provided in different ways. Parts of an image can be visually highlighted, which tends to increase attention to those areas. But the question remains then, whether students can make sense of what they perceive. Verbal explanations by an expert or teacher might also be necessary to give meaning to the highlighted area. With relatively unambiguous stimuli, such verbal information might even suffice to guide attention to relevant aspects of a display. Cognitive load research has shown that learning from worked examples or modeling examples in which an expert demonstrates performance of a task, is more effective and often more efficient than learning by doing. Most Thus far, examples have mainly been used for teaching problem-solving or psycho-motor procedures. An interesting question for medical education is whether they can also be used to help students acquire the perceptual skills necessary to interpret or diagnose medical images. Van den Berge, Van Gog, Mamede, Rikers, Schmidt, and Van Saase (2010) showed that the use of worked examples during instruction on ECG interpretation was more effective than learning by doing. Using dynamic modeling examples consisting of patient video cases of epileptic seizures, Jarodzka et al. (this symposium) showed that modeling examples can help students acquire perceptual skills, but that additional attention guidance in the examples may be necessary (see also Van Gog, Jarodzka, Scheiter, Gerjets, & Paas, 2009). To deal with the other problem caused by transience, that there is insufficient time to maintain and process information, dynamic visualizations may for example be segmented, with short pauses in between the segments, so that incoming information is very shortly suspended and time is available for processing information without having to attend to new incoming information (Spanjers, Van Gog, & Van Merriënboer, 2010).

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