Fall 2022

Chapter 02: Cognitive Load Theory and Instructional Message Design

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Instructional Message Design:
Theory, Research, and Practice
(Volume 2)

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Citation:

Shaffer, E. L. (2022). Cognitive Load Theory and Instructional Message Design. In M. Ramlatchan & C. Kohler (Eds.), *Instructional Message Design: Theory, Research, and Practice* (Vol. 2). Kindle Direct Publishing.

2. Cognitive Load Theory and Instructional Message Design

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Key Points:

- Cognitive processing is required for all learning tasks, and is separated into components of intrinsic, extraneous and germane cognitive load
- Working memory and long-term memory vary greatly in their functions and capacity
- The effects of all types of cognitive load can vary based on learner expertise
- Message design can significantly decrease the level of extraneous cognitive load
- Intrinsic load can be decreased through proper anticipatory actions of the designer or instructor

Abstract

Cognitive Load Theory's (CLT) purpose is to aid in the design of messages, instructional and otherwise, so that learning and message retention are more effective. CLT was introduced in 1998 by John Sweller and his colleagues. They used the constructs of three areas of memory, sensory, working, and long-term memory, to develop a theory to address the limited capacity of working memory. Through these efforts, they created the concepts of intrinsic, extraneous, and germane cognitive load and used these concepts to explain how various loads are placed on working memory. The purpose of this

chapter is to describe the three areas of memory, the three concepts of cognitive load, and address various effects created by intrinsic and extraneous cognitive load while guiding instructional designers on best practices to minimize load and maximize performance.

Introduction

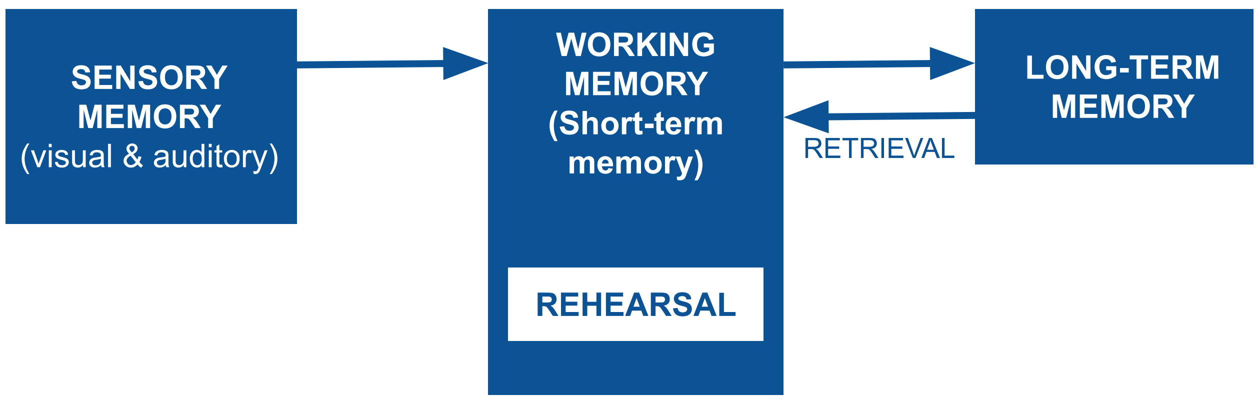
Sweller et al. (1998) published the article *Cognitive Architecture and Instructional Design* and formally introduced Cognitive Load Theory (CLT) and its general principles. Though concepts related to this theory had been introduced in other articles before that time, including the theory itself in a 1998 article, this article went deeper into the effects and issues associated with measuring cognitive load and has become a seminal work within the instructional design field (Sweller et al., 2019). As a result, CLT has distinguished itself as a fixture in design in traditional classrooms and multi-modal learning environments. The following chapter will give you an overview of CLT, common effects from cognitive load both from the 1998 model and current research, approaches to overcome those challenges, and general practices to aid you in developing message design with a focus on cognitive load.

Memory

Before discussing Cognitive Load Theory, it is essential to include a discussion of memory and how it is utilized to process information. Memory is defined as how information is encoded, stored, and retrieved by the brain (Mellanby & Theobald, 2014, Baddeley 2000, 2003). Many believe that cognitive theory was the first to introduce short-term memory, or working memory, and long-term memory concepts. Still, evidence suggests that William James, in the late 1800s, was the first to describe these two different terms regarding memory (Mellanby & Theobald, 2014). Later, Baddeley introduced the concept of sensory memory, completing the three most common memories recognized by researchers in cognitive psychology and neuroscience: working memory, long-term memory, and sensory memory. Information Systems Theory similarly views the memory retention process as a computer processes information

(Richey et al., 2011). Data is first received in the sensory memory for a brief time. Then, if attention is made to the working memory, the information is quickly moved to working memory or rejected. Next, the data is encoded and stored within working memory, which will be further discussed later in this chapter. Finally, if the information is well-rehearsed, it moves to long-term memory via encoding and storage and can be retrieved at will. These three memories are illustrated in Figure 1.

Figure 1.
The Memory System from an Information Systems Theory Viewpoint.



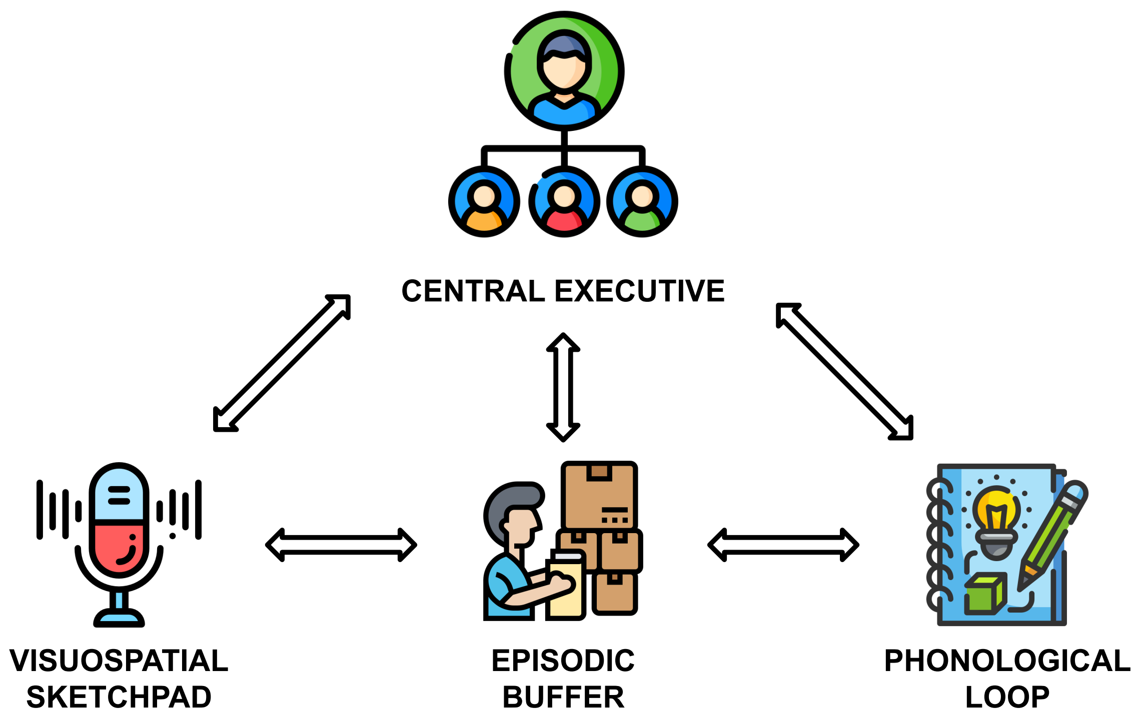
Note. Adapted from *The instructional design knowledge base: Theory, research, and practice,* by R. C. Richey., J. D. Klein, & M. W. Tracey, 2010, Routledge. Copyright 2010 by Routledge.

Working Memory

Working memory, sometimes referred to as short-term memory or the mental workspace, is the central processing center of the brain for the encoding of information in the memory system. This processing center has been widely studied as a center with limited capacity, or load, that simultaneously manipulates and stores information for brief periods (Alloway, 2009; Anmarkrud et al., 2019, Mellanby & Theobald, 2014). Baddeley and Hitch introduced this

idea of a limited capacity system in 1974 (Baddeley, 2000, 2001, 2003, 2017). Their multicomponent depiction of working memory has stood as the foundation for decades of research in working memory. Although Baddeley's model has changed some over the years, it consists of four key components: central executive, phonological loop, visuospatial sketchpad, and episodic buffer (Baddeley 2000, 2003). Their relationship to one another is illustrated in Figure 2.

Figure 2.
The Current Model of Working Memory



Note. This figure has been designed using resources from Flaticon.com. Adapted from "Working memory and language: An overview" by A. Baddeley, 2003. *Journal of Communication Disorders, 36*(3) (https://doi.org/10.1016/s0021-9924(03)00019-4)

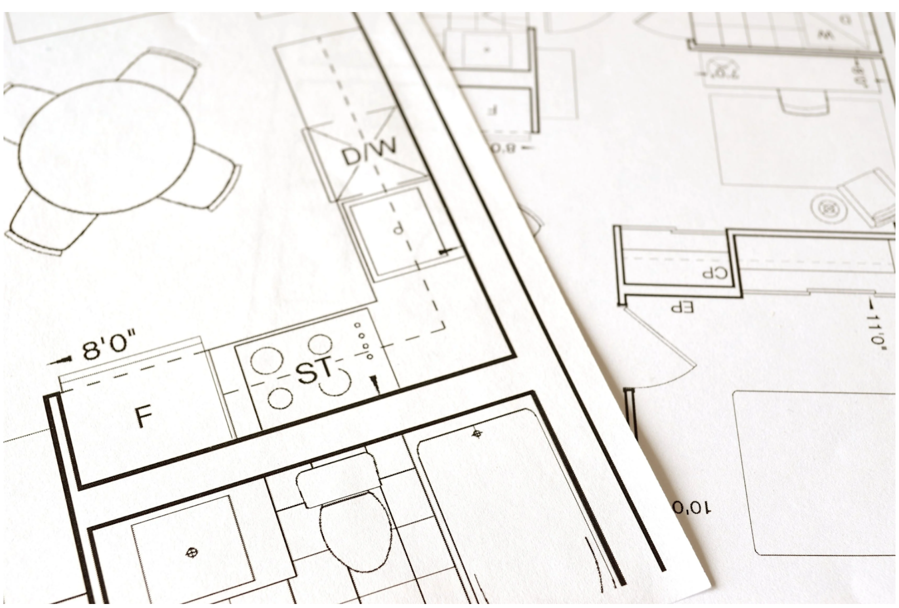
The central executive component is considered the essential element of working memory. It regulates the flow of information, attention, and coordination of the other three subcomponents in the working memory system. Baddeley (2000) suggests that it is not a storage location for memory but a processing unit. Metaphorically, it acts as a supervisor with three assistants, making the decisions about what deserves specific attention and what can be ignored within its limited capacity (Baddeley, 2017). Additionally, the central executive functions as a link to long-term memory from the three subsystems, as well as codes for time and place (Anmarkrud et al., 2019).

The phonological loop serves as the "assistant" for the part of memory that interacts with the spoken and written material (Anmarkrud et al., 2019, Baddeley 2000, 2003). The phonological loop consists of two parts: the phonological store is where information is stored in a speech-based form, and the articulatory control process allows us to repeat cues verbally in a loop. An example of this is the common phrase "phone, wallet, keys," which helps one remember their essential items before leaving home (see Figure 3). However, in the same respect, one can overload the loop with too much information, for example, watching a recorded interview with background music (Emory, 2019).

Figure 3.
A visual representation of the use of the articulatory control process with the phrase "phone, wallet, keys."

The visuospatial sketchpad “assistant” serves as the part of memory that interacts with the visual and spatial information, similar to how the phonological loop interacts with the central executive (Baddeley, 2003, 2017; Sweller, 2008). The visuospatial sketchpad allows for the visual, spatial, and possibly kinesthetic encoding of information, such as the layout of your residence. In the previous example, when your home was mentioned, it was highly likely that a design of your home, either in pictures or diagram, was brought from your long-term memory into your visuospatial sketchpad for use in your working memory (see Figure 4). In the same way that the phonological loop can be overloaded by too much information, so can the visuospatial sketchpad (Baddeley, 2003). Vredeveldt et al. (2011), for instance, found that closing one’s eyes reduces load and improves performance on eyewitness memory recall because cognitive resources are no longer needed to focus on observing the current environment. Using this previous example of the layout of your home, if you were to close your eyes at this moment, you would be more able to easily recall an accurate image of your home and items within and around it.

Figure 4.
A visual representation of the use of the visuospatial sketchpad to recall the layout of a home.



The last subcomponent of working memory is the episodic buffer "assistant." This memory component was not initially considered in Baddeley and Hitch's understanding of working memory. The episodic buffer was added later when they described how the subsystems interact with each other (Baddeley, 2000). This component serves as a "buffer" or interface between the subsystems, long-term memory, and others (Baddeley, 2000). Unlike the central executive, the episodic buffer is more concerned with the storage of information than attention control (Baddeley, 2003). Episodic buffer can package all of the information from multiple components, or sources/chunks, when necessary - hence "episodic" (Baddeley, 2000, 2003). This "assistant" is similar to when you order from your favorite online retailer, and a variety of different items (e.g.visual, spatial, phonological information) are packaged and sent to you, (e.g. long-term memory) (see Figure 5).

Figure 5.
A visual representation of the use of the episodic buffer for the packaging of information and knowledge.

Long-Term Memory

Long-term memory serves as storage for all of the central information executive and episodic buffer deemed necessary to store; a.k.a. learner knowledge. Long-term memory is not just a vault of information but also organizes and assists in recalling critical pieces of information during the learning process (Baddeley, 2017; Mellany & Theobald, 2014). Schema is a crucial component to the use of long-term memory in the learning process. A schema refers to how information is organized in long-term memory and aids in comprehending, storing, and retrieving new knowledge (Richey et al., 2011; Van Merriënboer & Sweller, 2005). Paas and Ayers (2014) state that learners with more knowledge or schema, working memory "space" limitations practically disappear compared to those without prior knowledge or schema. As a result of this schema, the working memory can handle more complex materials or problems that exceeded its capacity before the development of the schema (Driscoll, 2018; Paas & Ayers, 2014).

1998 Cognitive Load Theory Model

Developed in the 1980s by John Sweller, Jeroen J. G. van Merrienboer, and Fred Pass, Cognitive Load Theory (CLT) aims to explain how learner's information processing load generated by learning tasks can affect their ability to process new information and develop knowledge within their long-term memory (Skulmowski & Xu, 2021; Sweller et al., 1998). Sweller et al. (1998) describe the load on working memory in three ways - intrinsic cognitive load, extrinsic cognitive load, and germane cognitive load. Additionally, they suggest that load on working memory was a limited resource. If the cognitive load were increased beyond what a learner was capable of, their learning would be significantly impacted. This model assumed that a learning material's complexity was based upon the number of information components and their connections with one another, known as "element interactivity" (Skulmowski & Xu, 2021; Sweller et al., 1998). Though still relevant today, many early studies only focused on traditional classroom learning and concentrated on

decreasing the extraneous load of non-digital sources (Skulmowski & Xu, 2021).

Intrinsic Load

Intrinsic load is simply defined as informational complexity, including the number of items, their comprehension difficulty, and their interaction with one another (Anmarkrud et al., 2019; Emory, 2019; Sweller et al., 1998, 2019). Some tasks will have inherent difficulty based on the task, e.g. three-digit multiplication compared to single-digit addition, regardless of how the instruction is presented. Thus, when more items are grouped, a higher cognitive load is placed on the individual completing the task (Anmarkrud et al., 2019; Emory, 2019; Sweller et al., 1998, 2019). Although intrinsic load can be minimized to a degree based on instructional design practices, as the name suggests, it cannot be entirely removed as it is also heavily based on the learner's prior knowledge (Anmarkrud et al., 2019; Skulmowski & Xu, 2021).

Extraneous Load

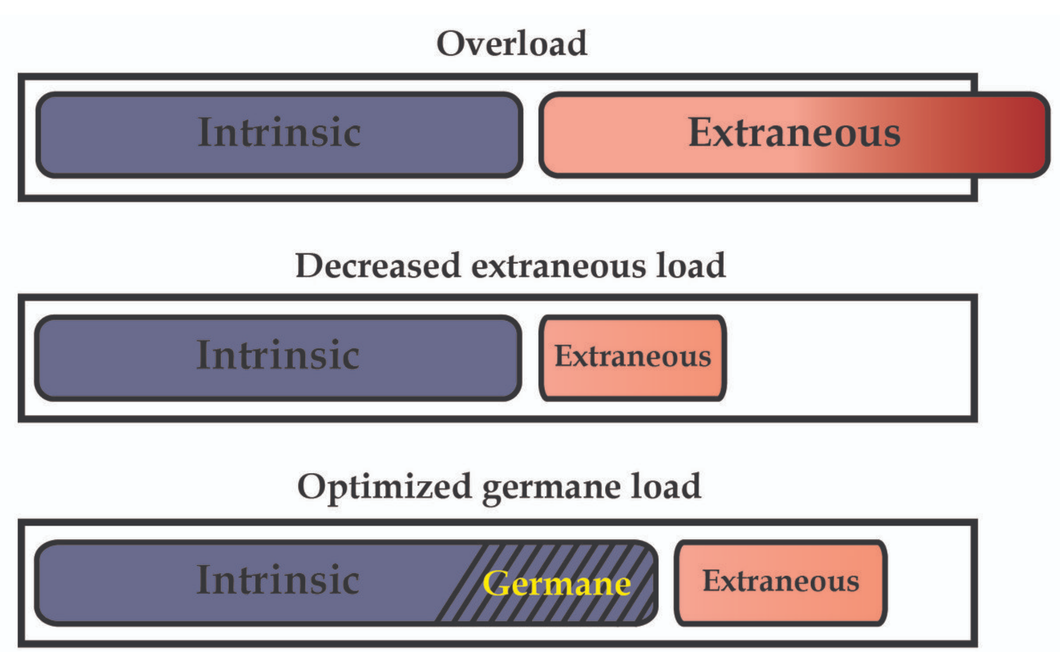
Where instructional message design choices cannot influence intrinsic load, extraneous cognitive load can be affected (Anmarkrud et al., 2019; Emory, 2019; Sweller et al., 1998, 2019). Extraneous load is not concerned with the complexity of a task or information provided but in the manner in which it is provided and what types of learning activities accompany it (Anmarkrud et al., 2019; Sweller et al., 2019). Germane load is increased with data that distracts from the intrinsic load. For example, if an instructor were teaching basic English to students learning English as a second language, it would not be helpful to share a complex quote from William Shakespeare with them as it would confuse them more than instruct. Additionally, if that same instructor were teaching English but put the text in a font that was hard to read or in colors that were difficult to see, the load placed on those students would be challenging for those having to sort through the information. Thus, design choices can substantially affect

learning by increasing or decreasing extraneous cognitive load (Skulmowski & Xu, 2021).

Germane Load

Germane load is considered the cognitive resources devoted to the processes forced on generating and storing new knowledge into long-term memory (Skulmowski & Xu, 2021, Sweller et al., 2019). This falls more in line with Baddeley's (2000) episodic buffer of working memory and schema development. In the 1998 model shown in Figure 6, the germane load had an additive relationship with the other cognitive load components; for instance, if the other two load components were too high, then no learning would take place due to lack of cognitive resources (Sweller et al. 2019). The most controversial cognitive load, germane load, is described in the following model and has since been changed to germane processing.

Figure 6.
Additive relationship between Intrinsic, Extraneous, and Germane Load



Note. From "Managing Cognitive Load with Authentic Language Materials" by A. Inkster, n.d., *Connecting learning sciences to educational technology: Theory, evidence, and practice.* (https://wiki.its.sfu.ca/permanent/learning/index.php/Managing_Cognitive_Load_with_Authentic_Language_Materials) C.C. BY 4.0

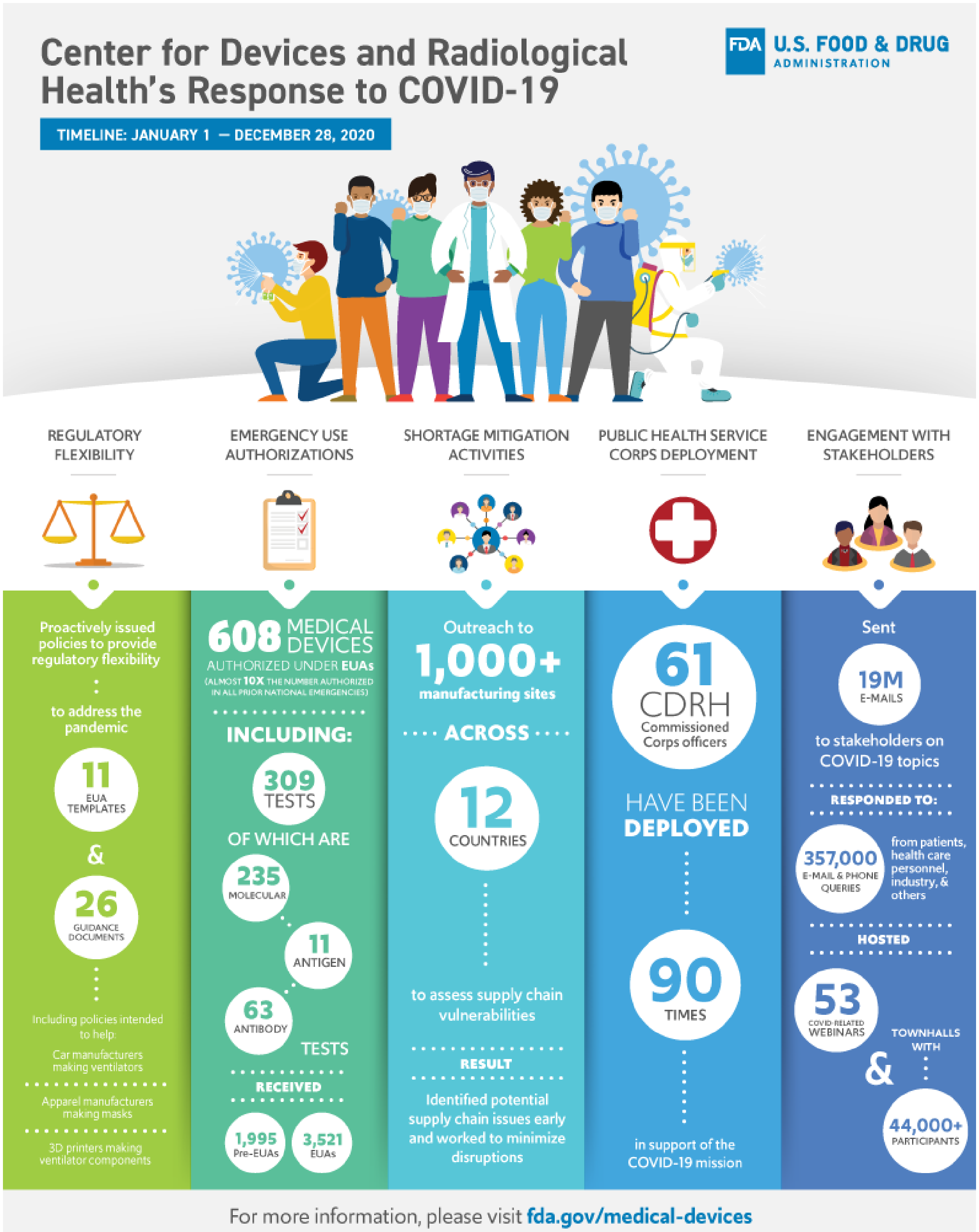
2019 Cognitive Load Model

Some of the characteristics of germane load were abandoned by Sweller et al. (2019) in their revisit of CLT. They no longer asserted that germane load contributed to the total cognitive load but instead "redistributes working memory resources from extraneous activities to actively direct relevant [resources] to learning by dealing with information intrinsic to the learning task" (Sweller et al., 2019). This means an increase in germane load no longer contributes to cognitive overload and can no longer be assumed detrimental to the learning process or performance (Skulmowski & Xu, 2021). An intrinsically complex message design can be very useful as long as the learner can focus their germane resources (see Figure 7).

The primary purpose of CLT is to optimize learning complex information and tasks by efficiently using the relationship between a limited working memory and unlimited long-term memory (Paas & Ayers, 2014; Sweller, 2019). The goal of instructional design and message design is to lower the cognitive load so that learning can occur without cognitive overload. In the following sections, we will explore various effects of cognitive load, their challenges and introduce methodologies that can reduce the cognitive load placed on learners through instructional message design.

Figure 7.

Example of cognitive load in an infographic.



Note. This infographic is a great example of keeping extraneous cognitive load low and relevant content high. The intrinsic load may also be high, but the load is manageable as the learner reads through the graphic from top to bottom. From "Center for Devices and Radiological Health's Response to Coronavirus (COVID-19): Infographic" by U.S. Food and Drug Administration, 2020, https://www.fda.gov/medical-devices/coronavirus-covid-19-and-medical-devices/center-devices-and-radiological-healths-response-coronavirus-covid-19-infographic

Instructional Effects

The following six effects were outlined in the original 1998 paper and have been further studied in the past few decades. These specific effects were summarized as they found a reduction in the cognitive load of instructional content (Sweller et al., 2019). In this section of the chapter, we will address the effect itself and include design methodologies and takeaways to reduce cognitive load. Additionally, these effects will depend upon the learner's expertise level (Kalyuga et al., 2003, Emory, 2019). Later in the chapter, we will discuss the issue of the reversal effect, in which the positive result can be minimized or reversed in some high expertise learners (Kalyuga et al., 2003, Sweller et al., 1998, 2019).

Goal-Free Effect

Referred to as the reduced goal specificity effect or no goal effect, the goal-free effect is when problem-solving questions or situations are posed to the learner without a specific goal outlined by the instructor or designer (Sweller et al., 2019). For example, a learner is posed with a question where two trains are traveling toward one another with specified velocities from a set distance apart. Still, the problem statement is undefined, such as, "Calculate as many variables as you can." As a result, the learner cannot move from a problem state to a goal state as no end goal was defined. In this specific example, this cognitive load could be reduced by stating the following problem

statement, “In km, at what distance from Train A’s starting point will the two trains pass each other?” Thus, the end goal is defined, and the learner can move from the problem state to a goal state.

Items for Designers to Consider:

- What is the intent of the message/problem/task?
- Clearly define goals for the message, problems, or activities.
- If multiple goals are required, clearly communicate each goal that the learner must achieve.

Worked Example

Like goal-free problems, worked examples aim to reduce the cognitive load by introducing new concepts to problems through example work (Sweller, 2019; Sweller et al., 2019). In addition, worked examples provide a full problem-solution that learners can study and replicate. This is most commonly used within science, technology, engineering, arts, and mathematics (STEAM) fields and has applications outside of STEAM through examples of citation guides, essay examples, artistic methodologies, etc.

Items for Designers to Consider:

- Worked examples assist in the reduction of cognitive load best for low-level expertise learners.
- Worked examples should not require the learner to integrate different sources of information mentally.
- Worked examples should contain explicit guidance through the problem or task.

Completion Problem Effect

One failure of worked examples is that they do not require the learner to study them. The completion problem effect is one solution to that failure (Sweller et al., 2019). Completion problems build upon goal-free problems and worked examples by beginning the process of

completing a problem-solving activity and then requiring the learner to complete the activity with a specific goal for completion. This effect lends itself to the guidance fading effect in which guidance from the instructor is slowly removed from the learner as the learner grows in the expertise (Emory, 2019; Sweller et al., 2019).

Items for Designers to Consider:

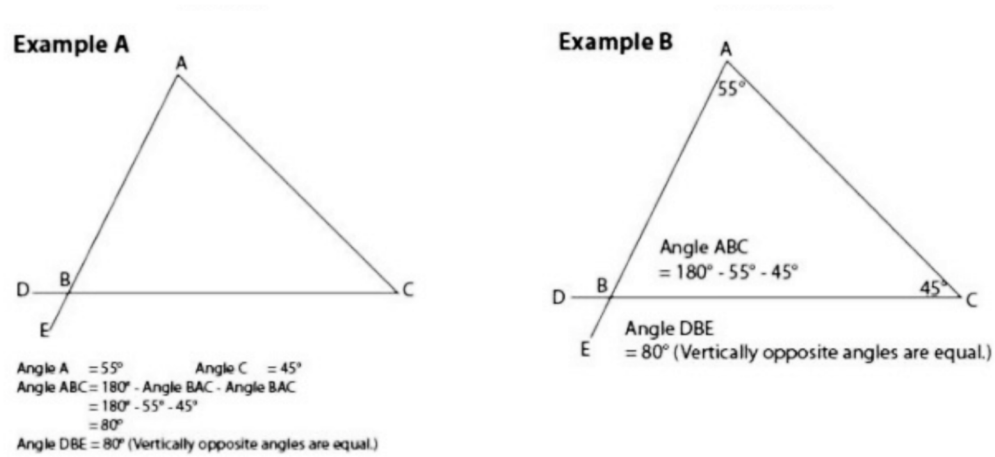
- Vary the level of guidance throughout the problems given in course/message design, starting with heavy guidance and then taper to little to no guidance.
- Provide explicit guidance when addressing new topics.
- Blend between goal-free, completion-problem, and worked examples within your design.

Split-Attention Effect

The split-attention effect stems from when a learner must draw from multiple sources in order to learn a concept (Emory, 2019; Sweller, 2019; Sweller et al., 2019). This effect is easily mitigated by integrating multiple sources into one source. Consider the following example in Figure 8. Combining all the information into the problem, the load placed on working memory is much less for learners.

Figure 8.

Integration of information in Example B eases problem solving as compared to Example A.



Items for Designers to Consider:

- When creating a message, is the message content in multiple locations or one easy-to-read source?
- Will combining the message into one source become cluttered or overwhelming?
- If possible, a singular source of information is superior to multiple sources when information is needed to be considered simultaneously.

Redundancy Effect

The redundancy effect in the 1998 model was highly focused on the traditional in-classroom teaching style. When considering the redundancy effect, the original effect draws a heavier cognitive load in conventional media. Sweller et al. (2019) suggested that incorporating multiple presentations of the same information causes increased cognitive load. Newer studies show that by looking at a cost-benefit analysis of some media, some redundant information is proving helpful in working memory and the development of long-term memory (Kirschner et al., 2011; Skulmowski & Xu, 2021).

Skulmowski & Xu (2021) reported that very subtle forms of redundancy, e.g. keywords or short phrases, can increase learning.

Items for Designers to Consider:

- Am I replicating the same information exactly? Is it necessary?
- More is not better.
- But, a little can go a long way.

Modality Effect

The modality effect is very similar to the split-attention effect in which information is split between multiple sources (Emory, 2019; Sweller, 2019, Sweller et al., 2019). However, modality does not seek to simplify the information, as split-attention does, but improves the working memory's processing by incorporating multiple modalities. For example, if a text and diagram are required to be combined for consideration and the text is short, then the text should be recorded or spoken rather than written (Sweller, 2019). For fixed situations, infographics provide an excellent opportunity to lessen the cognitive load for complex subjects, such as in Figure 8 (Dunlap & Lowenthan, 2016; Emory, 2019, Van Merrienboer & Sweller, 2010).

Items for Designers to Consider:

- Focus on engaging the learning quickly
- Use audio overlay for short text
- Low and mid-levels of interactivity can promote learning

These six effects from the original 1998 model, as well as others that have arisen throughout the past few decades of research, are all aimed at the reduction of cognitive load.

Reduction of Intrinsic Cognitive Load

The following practices, though not specifically outlined by Sweller and his colleagues, do address the reduction of cognitive load by reducing the intrinsic cognitive load to increase the functionality of working memory.

Cueing

Designers can use cues to point the learner toward important parts of the information to be received through color, font, arrows, illustrations, and so forth (Richey et al., 2011). These items along with the proper use of white space can cue learners toward the flow of information and highlight valuable data. This is true of animated media as well with the use of cuts, transitions, highlights, camera angles, etc. Used in an intentional manner, these cues will provide learners with guideposts in the development of their long-term memory and learning.

Chunking

As previously mentioned, working memory is limited, chunking breaks down large amounts of information into groups or chunks of information (Richey et al., 2011). For example, recall your phone number - you most likely used chunking. For many North Americans, phone numbers are in this format XXX-XXX-XXXX, where 10 digit numbers are broken into three smaller chunks. Another example is the often taught scientific method in secondary education, where students learn the steps to proceed through a basic experiment. Instructional designers can use the same techniques when developing messages to break large blocks of information into smaller blocks for lower cognitive load and better processing through a learner's working memory.

Scaffolding

Scaffolding is similar to chunking in that information is broken down into smaller chunks, but where chunking is one set of information into smaller chunks. Scaffolding builds upon itself (Richey et al., 2011). Think back to when you learned to read or taught someone to read, first you learned the alphabet. Then you learn how those letters sound when speaking them, then small words, followed by larger words, more complex sentence structures, and so on. By introducing concepts, piece by piece, instructional designers can reduce the cognitive load placed on learners.

Advanced Organizers

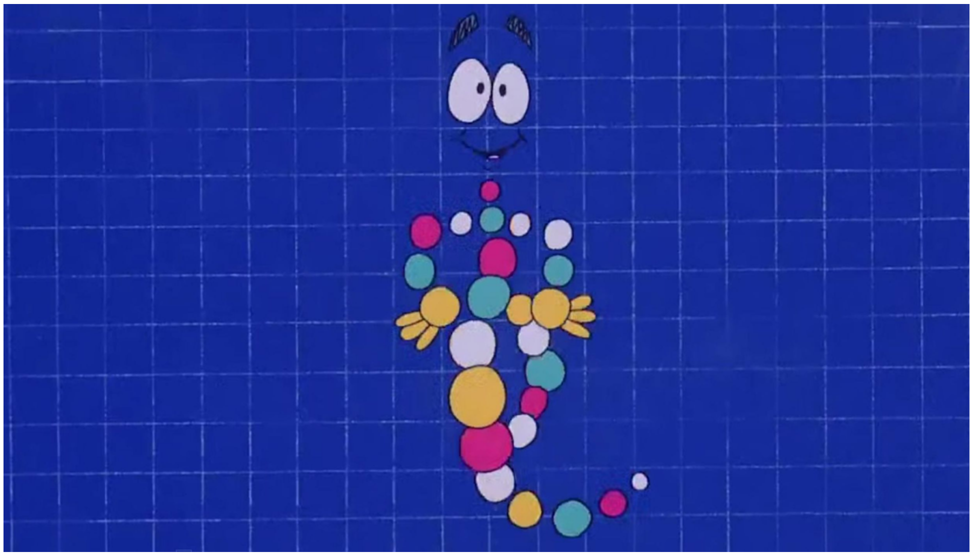
Advanced organizers provide learners with higher levels of information in a more generalized format (Richey et al., 2011). Providing these materials in advance allows the learner to recognize what they currently know, what they will learn, and what they will need to do to get to that level. In a sense, it is preemptive scaffolding. Advanced organizers aim to introduce a topic and illustrate the relationship between learned information and future knowledge. They can be as simple as a minimal graphic to as detailed as a narrative to promote the learner's engagement with the materials.

Emotional Design

A new shift in the cognitive perspective of design is emotional design. This approach introduces positive emotions to the learner and thus increases engagement from the learner (Skulmowski & Xu, 2021). Emotion design includes the addition of enjoyable design elements, anthropomorphizing nonhuman entities, adding warm colors, and so forth. These new studies confirm that the design choices are helping to increase retention, transfer, comprehension, and motivation while also lowering the perceived difficulty of the learning material (Skulmowski & Xu, 2021). For example, in Figure 9, I would posit that "Mr. DNA" from the movie *Jurassic Park* is

well-remembered by many, if not all, who have seen the movie and is an example of these new and emerging studies.

Figure 9.
Mr. DNA from "Jurassic Park" as an example of emotional design



Note. From "Chosen one of the day: Mr. DNA from *Jurassic Park*," by C. Enlow, 2018, *SYFY Wire* (https://www.syfy.com/syfywire/chosen-one-of-the-day-mr-dna-from-jurassic-park)

Conclusion

Learning requires both the use of limited working memory and unlimited long-term memory. To make the best use of the limited resource of working memory, one must apply the concepts of cognitive load to all aspects of information communication and message design. Without considering the load placed on the learner, designers and instructors may overload their learners and hinder the long-term development of knowledge. The history of Cognitive Load Theory is long, but it is not over. Discoveries are being made every

year, and the understanding of cognitive psychology and neuroscience is ever-changing.

New research calls for a reevaluation of the current Cognitive Load Theory to address the cost-benefit of an increase of extraneous load versus an increase of germane resources (Skulmowski & Xu, 2021). As the world continues to develop further into a more technologically based society, CLT will need to grow and change.

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