Working Memory, Cognitive Load, and Emotions

Yael Gampel

Bentley University

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Dr. William Gribbons

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Working memory is a short-term mental workspace that synthesizes perceptual information from the senses and existing knowledge from long-term memory (LTM), influencing cognitive load and emotions. Its notable characteristics of being dynamic, time-constrained, and limited capacity allow for quick access and adaptation to changing information for continuous updates (Jonides et al., 2005). Evolved for survival, working memory helps us retain sensory information "long enough to make appropriate (or inappropriate) decisions," (Carruthers, 2013; Coolidge & Wynn, 2020). Today, it allows us to "reason, solve problems, [and] speak and understand language" (Jonides et al., 2005). Given its significance in relation to cognitive load and emotions, designers should eliminate complexity in products to reduce mental fatigue and performance errors and improve emotional response and learning (Sweller, 2023). This essay explores the interplay of these factors, followed by an evaluation of the Dentrix Dental Management Software through the lens of working memory.

Working Memory

Working memory is considered a conscious, short-term storage system with a finite capacity. Unconsciously, however, it can be influenced by readily accessible knowledge stored in LTM or perceptually salient, attention-grabbing stimuli (Slevc, 2011). Retrieval of information from LTM relies on cues, aligning with the spreading activation theory that describes a network of concepts connected based on their relations (Logie & Cowan, 2015). This processing system, commonly understood as multiple subprocesses, is most notably explained by psychologists Baddeley and Hitch's Working Memory Model. They outline three main major components: the central executive, the phonological loop, and the visuospatial sketchpad" (Baddeley, 2000).

Central Executive

Baddeley described the central executive as the command center of the mind, a critical component that controls and regulates cognitive processes (Wu & Was, 2023). This component acts as a central hub that oversees various functions such as LTM activation, task management, task switching, and selective task attention or inhibition (Hartley & Speer, 2000). Wu and Was (2023) describe these as higher order activities called complex functions, which comprise basic component functions like "shifting between tasks, updating information, and inhibiting irrelevant information" (Wu & Was, 2023). The central executive control is conditional on our metacognition, as we continually assess and refine our memory contents. The central executive also relies on past experiences stored in LTM "to understand the present and model the future before selecting an action" (Baddeley, 1992).

Phonological Loop

Baddeley (2000) describes the phonological loop as a cognitive processing station evolved for speech perception and production. It comprises a phonological store for “verbal and acoustic information” and an articulatory loop for rehearsal, playing a crucial role in encoding and recalling information (Baddeley, 2000). Baddeley explains that auditory information decays after a mere few seconds unless rehearsed in the articulatory loop (2000). Notably, the efficiency of rehearsal is influenced by “emotional valence,” as sounds with a stronger emotional impact require fewer repetitions for memory encoding (Coolidge & Wynn, 2020). The phonological loop works alongside the visuospatial sketchpad, helping to facilitate encoding and retrieval.

Visuospatial Sketchpad and Episodic Buffer

In his model, Baddeley (2000) describes the visuospatial sketchpad to as a temporary store for visual and spatial information. This mostly conscious system operates in tandem with pre-attentive processes, such as detecting and grouping visual stimuli, aiding in mental imagery and working to store those representations (Logie, et al., 2015; Carruthers, 2013). When used in conjunction with the phonological loop, such as by verbally stating or rehearsing the name of a visual stimuli, it strengthens the encoding and recall of the stimuli (Coolidge & Wynn, 2020).

The episodic buffer is a fourth component of Baddeley’s model that was later amended to explain the multimodally coded information of memory storage. This component combines data processed in LTM and subsidiary cognitive systems “into a unitary episodic representation” (Baddeley, 2000). Because of working memory’s limitations, the episodic buffer is assumed to control strategies to help in remembering, “utilizing the attentional capacity of the executive to capitalize on prior learning” (Baddeley, 2007).

Limitations and Strategies of Working Memory

A focal point of working memory’s constraints is its capacity, emphasizing the need for the brain to prioritize valuable information “to maximize memory utility and prevent the negative consequences of forgetting” (Murphy & Castel, 2022). Psychologist George Miller (1956) introduced that our working memory can hold 7 (+/-2) items of information, reducing to two or three items when actively processing rather than holding information (Sweller et al., 1998). Attention is allocated to the information we deem most important, whether consciously through rehearsal or unconsciously through perceptual salience (Jonides et al., 2005). However, researchers have noted that there is an incongruency between the constantly changing information of the sensory environment and the need for our working memory to stabilize this information for retention, highlighting the significance of attention-based rehearsal (Jonides et al., 2005).

Memories are also influenced by proactive and retroactive interference. Proactive interference occurs when old memories hold more weight during the learning of new information, while retroactive interference arises when newly learned information interferes with old memories (Murphy & Castel, 2022). This not only underscores the volatility of working memory but also reveals that we have a system of memory selectivity, essential in the management of the influx of information in our daily lives and ensuring our daily functioning and survival.

Further, working memory's time-constraint describes that information rapidly decays when it is not rehearsed, becoming inaccessible after around 30 seconds (Cowan, 2013). Decay depends on "how well the information is consolidated in working memory," prompting the use of conscious strategies to strengthen rehearsal, improve retrieval, and limit decay (2013). Interestingly, stronger emotional attachments are more resistant to decay (Coolidge & Wynn, 2020). Mnemonics, or "strategies for encoding information with the sole purpose of making it more memorable," include prominent methods like chunking and the method of Loci.

Chunking is a grouping technique commonly used by memory experts but can even be used in daily life, like when memorizing a phone number. It involves data compression into "3 or 4 meaningful units," reducing cognitive load and allowing "more information to be stored in the available capacity" (Cowan, 2013; Norris & Kalm, 2020). Researchers suggest that chunks in working memory are prompted by their pre-existing representations in LTM (Norris & Kalm, 2020). Another helpful strategy for strengthening memory is the method of Loci, which relies on spatial relations between physical locations (e.g. loci) to create a familiar mental space for organizing and recalling memories (Qureshi et al., 2014). This allows us to encode and repeatedly access a dense amount of information, even facilitating metacognitive regulation of one's own learning style (Qureshi et al., 2014). Contrary to the misconception that a skilled memory has a larger capacity, experts in memorization excel because they are more practiced using strategies that minimize their cognitive load and allow for more working memory usage (Sweller, 2023).

Cognitive Load and Emotions

Cognitive load is the "resources needed to perform a task" (Redifer et al., 2019). It can be impacted by multitasking or split-attention tasks, resulting in poor performance (Biondi et al., 2020). Additionally, if new information doesn't fit into existing mental models or schemas, the demanding process of accommodation might take place, increasing load. Sweller (2023) identified three types of cognitive load: intrinsic, extraneous, and germane.

Intrinsic load refers to the mental effort required by the "natural complexity of information being processed" (Sweller, 2023). The task or material itself generates this baseline load, and therefore cannot be influenced by information design. Extraneous load pertains to the presentation of information and the cognitive resources it demands (Sweller, 2023). When we try to store more information than our capacity allows, storage into LTM is hindered, resulting in mental fatigue and impacting learning and task performance (Tzafilkou et al., 2021). To enhance learning efficacy, product designers should minimize this load by reducing the elements we have to encode or removing unfamiliar and taxing information that requires accommodation.

Lastly, germane load refers to the mental resources people use to promote learning and improve their performance, aiding in the production of accurate mental models of learned information (Klepsch et al., 2017). This load involves metacognitive regulation, and having a higher germane load means more engagement in the learning process, suggesting that this should be fostered in design (Klepsch et al., 2017). People can deepen their learning by “actively connecting new information with existing schemata” and employing memory strategies previously mentioned (Klepsch et al., 2017). Importantly, negative emotions are more likely to be experienced when a task demands a higher cognitive load.

Many researchers agree that working memory is essential for controlling emotions through reappraisal, regularly preserving and modifying information in the pursuit of a goal (Adamczyk et al., 2022). The two most common emotions associated with working memory and load are anxiety and motivation, as they significantly impact the quality of experience and performance outcome. For instance, anxiety can lead to mental fatigue, “impairing the processes of working memory and allocation of attention resources” (Atiomo, 2020) However, anxiety can also be good, with research showing that “it motivates students to avoid failure and put more effort in terms of attention” (Tzafilkou et al., 2021). Additionally, motivation enhances learning performance and achievement, encouraging engagement and rewarding feelings (Redifer et al., 2019). Designing products that minimize cognitive load, foster positive emotions, and maintain user attention is critical for a safe and enjoyable user experience.

Case Study

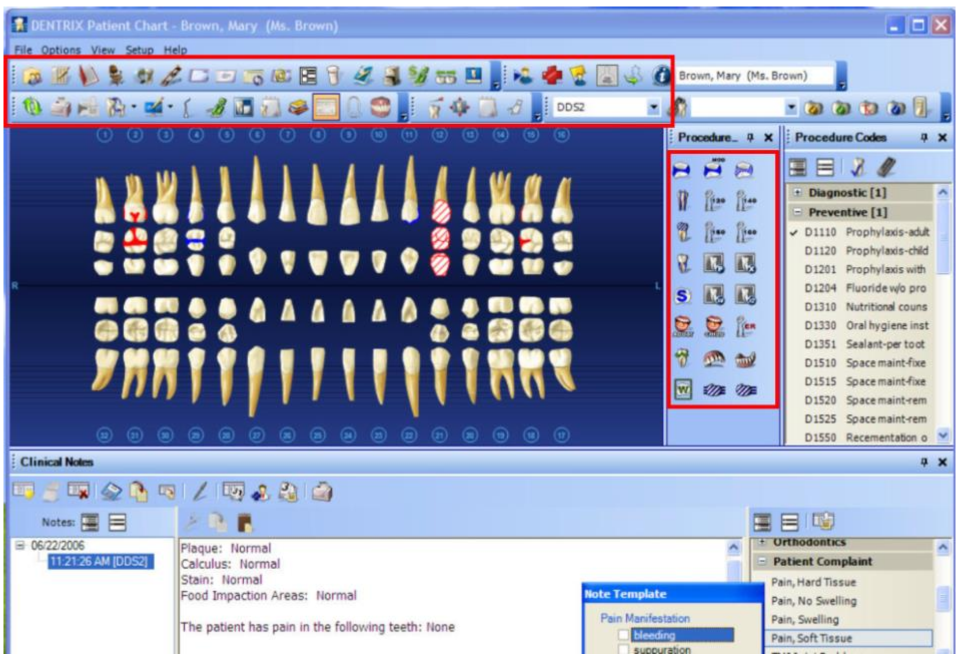
Dentrix, a dental practice management software, serves as a crucial tool for clinicians in managing patient details, health records, appointment scheduling, and prescriptions. Although widely used across many dental clinics, Dentrix has an overwhelming interface, potentially impacting the accuracy needed in a higher-risk healthcare environment. The following explores usability issues that might discourage clinicians from adopting Dentrix, along with recommendations to improve them.

Dental Graphics Chart

Within the graphics chart in Figure 1, there are many icons presented that lack clarity regarding their purpose. For an expert of this software, these icons may be easier to identify as they are stored in their LTM from prior experience. However, for a novice user learning on the job, this can be a slow and arduous learning process, potentially leading to anxiety and errors. In fact, the likelihood of errors also increases for experts using the software at the end of a long, fatiguing day. This high extraneous load becomes particularly problematic in health-related tasks and may even diminish the effectiveness of high priority icons.

Figure 1

Patient Chart



Note. The red markings highlight the numerous icons that may affect working memory efficacy.

To address this issue, I recommend streamlining icons into higher level categories, displaying only high-priority ones on the main screen. Additionally, adding clear labels next to the icons will help facilitate quicker processing within working memory and the efficient transfer of information into LTM. This will also reduce extraneous load and anxiety, improving comprehension and accurate decision-making.

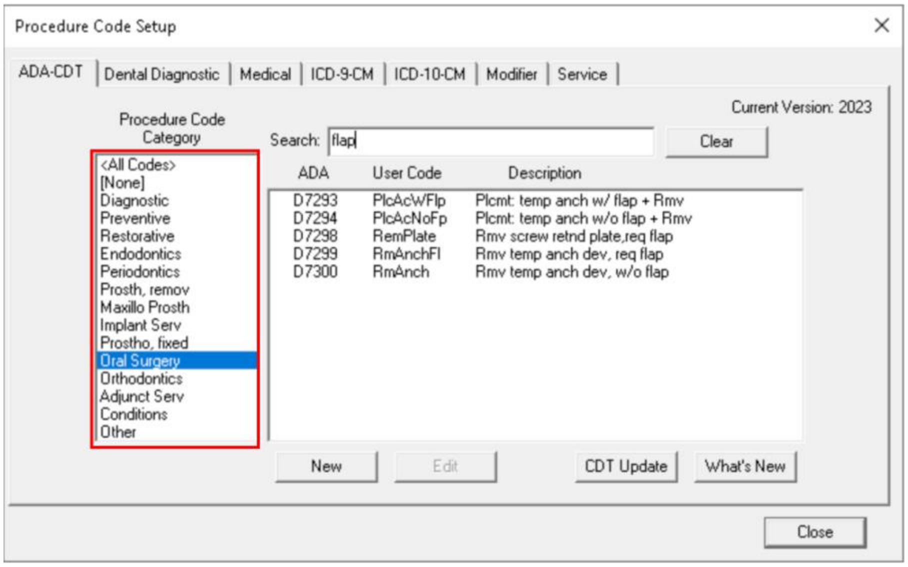
Procedure Code Page

Within the Procedure Code page (Figure 2), multiple codes can be seen which are important for accurately setting up a procedure based on the diagnosed issue or action to be taken.

The abundance of options may overexert working memory's capacity, resulting in inaccurate or inefficient task completion. For novices or even elders, selecting the correct code becomes a more challenging task, as the codes' complexity and poor organization more strongly impacts memory.

Figure 2

Procedure Code Categories



Note. The red marking outlines the procedure code categories that illustrate poor readability and cognitive load implications.

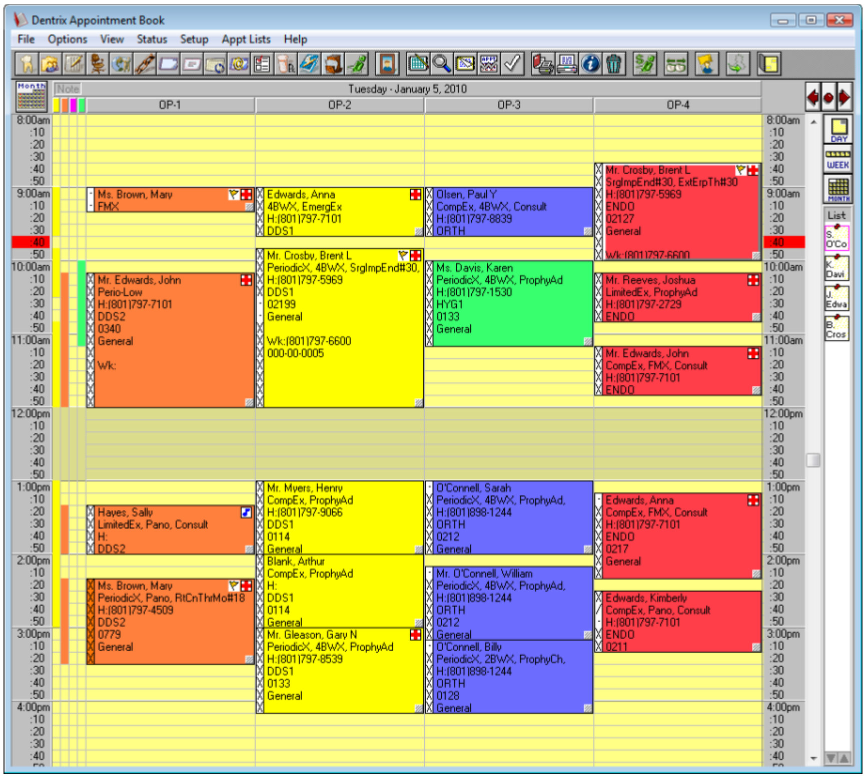
Although intrinsic information of the codes can't be changed due to its standardization by the American Dental Association (ADA), I suggest reducing extraneous load by visually differentiating the categories. More specifically, increasing the list spacing will allow for easier reading and encoding of the information. Further, by prioritizing common codes in a top section and ordering the other categories alphabetically, the interface will be optimized to minimize cognitive load, allowing clinicians to quickly and easily find the appropriate codes when needed. A notable advantage of this feature is its search functionality, allowing users to input key characters associated with the procedure for quick retrieval, minimizing unnecessary searching.

Appointment Book

At first glance of the Appointment Book (Figure 3), the highly saturated colors can overstimulate the eyes, distracting users from important elements and potentially straining working memory when processing information. A lack of attention may lead users to miss or forget important appointments due to the lack of visual salience compared to the surrounding elements. The overwhelming visual stimuli may also cause frustration and anxiety.

Figure 3

Appointment Book Schedule



Note. The absence of markings in this image is intentional, as a red outline would be hard to distinguish against the colorful backdrop.

To alleviate cognitive load on working memory, I recommend changing the vibrant mix of colors to a more minimal color all around, such as white. To differentiate between the physicians, the colors can be retained for users' familiarity with them but can be simplified through outlining the boxes with those colors or incorporating a colored tag or small symbol within the box. This can facilitate quicker information processing through reduced mental fatigue, thereby enhancing users' ability to encode and recall scheduling details.

Conclusion

In summary, working memory facilitates the integration of new perceptual data with prior knowledge to make sense of the information we learn. Exceeding its capacity increases cognitive load, reducing learning efficiency and increasing the risk of errors. This, along with the negative emotions heavy load may evoke, underscores the importance of simplifying informational complexity and providing guidance for successful user experiences in product design.

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