References Barb Oakley Presentation

General information on forming memories

- For a complete history of Hebbian learning, see (Sejnowski, 1999).
- Although not a rigorous source, an overview of the most recent findings related to how dendrites emerge and meet axons can be found here: https://en.wikipedia.org/wiki/Dendritic_filopodia.
- Recent overview of memory and consolidation processes: (Runyan, Moore, & Dash, 2019).

Working memory, long-term memory, and retrieval practice

- Overviews of current conceptions of working memory: (Cowan, 2017).
- Retrieval practice is important for learning: (Jeffrey D Karpicke, 2012; Smith, Floerke, & Thomas, 2016).
- Students need to be taught the importance of retrieval practice: (Robert A. Bjork, 2018; Jeffrey D Karpicke & Grimaldi, 2012).
- The importance of working sample problems: (Chen, Kalyuga, & Sweller, 2015).
- Active retrieval promotes meaningful learning: (Jeffrey D Karpicke, 2012).
- Retrieval practice produces more learning than elaborative studying with concept mapping: (J. D. Karpicke & Blunt, 2011). On a side note, one recent study incorporated retrieval practice *with* concept mapping: (O'Day & Karpicke, 2020). Surprisingly, it didn't help.
- Review of neurocognitive architecture of working memory: (Eriksson, Vogel, Lansner, Bergström, & Nyberg, 2015). There are dozens of different definitions of working memory. See (Baddeley, 2003; Cowan, 2017; Turi, Alekseichuk, & Paulus, 2018).
- Increase in size in working memory with age, and the distribution of working memory sizes in the classroom after (Gathercole & Alloway, 2007), page 7, by kind permission of Professor Susan Gathercole, Department of Psychiatry, University of Cambridge.
- (Alloway & Alloway, 2010) explains that working memory is a relatively pure measure of a child's learning potential and indicates a child's capacity to learn, while academic achievement and IQ tests measure knowledge that the child has already learned. (Shipstead, Harrison, & Engle, 2016) observes: "The strong correlation between working memory capacity and fluid intelligence is due not to one ability having a causal influence on the other but to separate attention-demanding mental functions that can be contrary to one another but are organized around top-down processing goals." By fluid intelligence, Shipstead means the ability to reason through and solve novel problems, as opposed to crystalized intelligence, which refers to the ability to put learned knowledge to use—the classic example of this is vocabulary.
- The creation and strengthening of neural links in long-term memory can extend their working memory on that topic: (Cowan, 2019; Ericsson, Hoffman, Kozbelt, & Williams, 2018). (What Ericsson terms "neural representations" is largely synonymous with our terminology of "sets of neural links.")

- Something that looks like working memory increase seems to occur within a specific area of practice: (Baddeley, Eysenck, & Anderson, 2020). As Baddeley notes “This is an area that is certainly worth further investigation, but I would not buy shares in it just yet!” p. 92.
- Reviews of the consolidation process: (Runyan et al., 2019; Tonegawa, Morrissey, & Kitamura, 2018).
- The hippocampus and concept formation: (Mack, Love, & Preston, 2018).
- Learning involves retrieval practice: (Jeffrey D Karpicke & Grimaldi, 2012).
- Learning involves two fundamental learning systems, in this case, the hippocampus and the neocortex: (McClelland, McNaughton, & O'Reilly, 1995). (This is a classic paper in the field.)
- Indexing theory—the key idea behind our understanding of how the hippocampus helps us learn—was originally proposed in (McClelland et al., 1995). The index code idea was elaborated to explain how a small number of neurons in the hippocampus supports reinstatement of recent memories in the neocortex. Recent confirmatory research (Mao et al., 2018) found that “Indexing theory proposes that, each time an animal has a unique experience, the hippocampus creates a unique pattern of neural activity that it sends to the rest of the cortex. That unique pattern acts like a context code and is stored in different regions of the cortex, along with the raw data the regions are responsible for encoding, such as shapes, sounds and motion. If the hippocampus recreates that index, it will simultaneously appear in all the cortical regions involved at the time, thereby retrieving the individual parts of the experience to create an integrated memory.” ((University of Lethbridge press release, 2018).)
- As you go up the hierarchy of cortical areas in the neocortex to get from the sensory periphery to the hippocampus at the top, the representation is transformed in each layer, and becomes more and more abstract. What the hippocampus gets is just a shadow of what is in the neocortex, which has all the details in all of the layers. If the feedback from a very small number of neurons in the hippocampus can activate many billions of cells in the neocortex, that is exactly like an index.
- Although not a rigorous source, an up-to-date, fairly readable description of memory consolidation processes can be found at: https://en.wikipedia.org/wiki/Memory_consolidation.
- Hippocampus turns to repeat new learning to the neocortex: (Runyan et al., 2019; Wamsley, 2019).
- 15-minute period of eyes-closed rest following learning enhanced the memory: (Wamsley, 2019). See also (Craig, Ottaway, & Dewar, 2018).
- Rest during wakefulness may be critical: (Wamsley, 2019). (Reference within quote omitted.)
- New synapses are formed during sleep: (Yang et al., 2014). There is also evidence for decreases in synapse strengths during sleep: (De Vivo et al., 2017); Some synapses are also pruned during sleep: (Li, Ma, Yang, & Gan, 2017).
- Sleep helps fix memories: (James W Antony & Paller, 2017; Dudai, Karni, & Born, 2015; Himmer, Schönauer, Heib, Schabus, & Gais, 2019).

- Retrieval as a fast route to memory consolidation: (J. W. Antony, Ferreira, Norman, & Wimber, 2017).
- Learning often involves pulling information out of the brain: (Agarwal & Bain, 2019) p. 28.
- Sleep and the growth (and pruning) of synaptic connections: (Himmer et al., 2019; Niethard & Born, 2019).
- (Owens, Stevenson, Hadwin, & Norgate, 2014) found that students with a good working memory did better, the more stress they felt. But people with a bad working memory did worse with more stress. The study hypothesized that more stress acted as an additional load on working memory, which didn't bother those with large capacity working memory because they had enough capacity—but affected the performance of those with lesser-capacity working memory. The authors concluded that work needed to be done to reduce the stress of those with lesser-capacity working memory. But it's perhaps likely that those with lesser-capacity working memory didn't prepare properly, and so of course they were more stressed. If this latter supposition is true, then stress reduction techniques would just make students with lesser working memory capacity feel better, but wouldn't do a anything to help their test scores.
- With too many options, it's easy to get lost (cognitive load theory): (Mayer, 2004; Sweller, 2016).
- The value of deliberate practice: (Ericsson et al., 2018).
- Extra effort strengthens the learning and interrupts forgetting: (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). (This is the seminal meta-analysis that showed the effectiveness of distributed practice).
- Sleep and mind wandering help during spaced repetition: (van Kesteren & Meeter, 2020).
- Hippocampal and neocortical interactions in memory formation: (Wang & Morris, 2010) (This now-classic paper is exceptionally important.)
- It's common for students with lesser-capacity working memory to struggle with math: (Clark, Pritchard, & Woodward, 2010; Raghubar, Barnes, & Hecht, 2010).
- Reading comprehension is directly related to working memory capacity: (Carretti, Borella, Cornoldi, & De Beni, 2009).
- Practice preferentially helps students with lesser capacity working memory: (Agarwal, Finley, Rose, & Roediger, 2017). Reform mathematics educators observe that student-centered approaches are effective in part because they offer more representations in memory. The challenge is, if those multiple representations are not well embedded in long-term memory, they simply become more confusing for students with lesser-capacity working memory. It's important to note that there can be effective or ineffective teaching using either student-centered or teacher-directed approaches.

Expertise reversal effect

- (Chen, Kalyuga, & Sweller, 2017)
- (Kalyuga & Renkl, 2010)

Differentiation

- For an extensive guide to incorporating differentiation into a classroom, see (Heacox, 2017).
- For an in-depth explanation on what differentiation is and isn't as well as the role of the teacher and strategies for managing a differentiated classroom, see (Tomlinson, 2017).

Direct instruction

- For a broad overview, of direct instruction see (Dehn, 2008) p. 303, who cites three metanalyses to conclude "Direct instruction is considered one of the most effective instructional methodologies for students with working memory deficiencies." More recently, see (Morgan, Farkas, & Maczuga, 2015)—this massive study involved 3,635 teachers and 13,883 first grade students attending 3,635 classrooms in 1,338 schools. For a more general discussion of direct instruction versus discovery learning and the impact of these approaches on students, see (Klahr & Nigam, 2004).
- As noted in (David C. Geary, Berch, & Koepke, 2019) "…meta-analyses conducted by (David C Geary et al., 2008)—and consistent with the results from Project Follow Through ((Stebbins, St. Pierre, Proper, Anderson, & Cerva, 1977))—indicated that students with difficulties in mathematics benefit from teacher-directed instruction ((R. Gersten et al., 2008)) that may help compensate for domain-general deficits." See also (Fuchs et al., 2013) and (Russell Gersten et al., 2009). There is also a large body of literature involving the benefit for novices of the "worked example effect," whereby initial guidance using worked problems helps novices (which encompasses those with lesser-capacity working memory) more than providing no guidance. See for example (Chen et al., 2015; Ramón y Cajal, 1989; Stockard, Wood, Coughlin, & Rasplica Khoury, 2018).
- The tougher the material, the more a direct instruction approach is needed: See (David C Geary & Berch, 2016) p. 240, where the authors note: "we have suggested that structured, explicit, teacher-directed instruction should be most effective when acquiring secondary skills that are remote from supporting primary systems and that take place in a species atypical, classroom context where the goal is oriented toward acquiring knowledge for its own sake." [Italics in original.] Interestingly, 2012 PISA achievement versus teaching style reveals a pattern supportive of Geary and Berch's supposition. The better the PISA scores, the more likely the country is to use direct instruction. (Mourshed, Krawitz, & Dorn, 2017).
- Good references for direct instruction: (Boxer, 2019; Engelmann & Carnine, 1982; Estes & Mintz, 2015).
- Lesser-capacity working memory benefits from direct instruction: (Stockard et al., 2018).

Declarative and procedural learning

- Dyslexia as a disorder related to the procedural system: (Ullman, Earle, Walenski, & Janacsek, 2020).

- Higher declarative processes: (Evans & Ullman, 2016; Takacs et al., 2018; Ullman et al., 2020).
- Humans have enhanced transitions from declarative to procedural performance: (Schreiweis et al., 2014). See especially figure S7 in the supplemental section.
- Learning through one system can inhibit learning in the other: (Freedberg, Toader, Wassermann, & Voss, 2020; Ullman et al., 2020).
- "The development of II automaticity is associated with a gradual transfer of control from the striatum to cortical-cortical projections from the relevant sensory areas directly to the premotor areas that initiate the behavior." (Ashby & Valentin, 2017). The declarative/procedural learning systems are an example of what are call "layered architectures," with multiple control loops working on different time scales. Coauthor Terry has a project to understand how the brain manages mountain bike trail riding. As this project shows, most humans can safely stay on the trail without crashing because of "diversity-enabled sweet spots" (DESSs) in the brain. Basically, a variety of axon lengths help provide feedback at different layers and levels of the interwoven network of neurons in the brain, helping to create control that is both fast and accurate despite being built from components that are individually slow or inaccurate. (Nakahira, Liu, Sejnowski, & Doyle, 2019).
- The declarative and procedural learning systems and their location and information flow in the brain: (Ashby & Valentin, 2017).
- Procedural and declarative links are deposited in two different places in the neocortex: (Ullman, 2020).
- The habitual and goal-directed aspects of the procedural system:(Redgrave et al., 2010).
- How rapidly the shift from learning a concept declaratively to learning that concept procedurally proceeds seems to depend on FOXP2. The declarative system is affected, for example, by BDNF or APOE. (Ullman, 2020). Dopamine-related genes appear to affect procedural learning (Wong, Morgan-Short, Ettlinger, & Zheng, 2012).
- Declarative learning and developmental disabilities: (Evans & Ullman, 2016; Ullman et al., 2020).
- Indications of improved procedural learning in autism spectrum disorders and Tourette's: (Takacs et al., 2018; Virag, Janacsek, Balogh-Szabo, Chezan, & Nemeth, 2017).
- Overlapping parts of the brain that do procedural processing and that do arithmetic: (Evans & Ullman, 2016).
- Proceduralization of math: (Evans & Ullman, 2016).
- For a good relatively recent introduction to the concept of desirable difficulties by the foundational researchers in the area, see (R. A. Bjork & Bjork, 2019; Robert A. Bjork & Kroll, 2015). Desirable difficulties, it should be noted, relate to both procedural and declarative learning: (Soderstrom & Bjork, 2015).
- That procedural and declarative sets of links may connect if they relate to the same concept is tackled in a theory called "semantic processing": (Xie, Wang, Wei, & Ye, 2019).

- Apropos declarative learning, "…'deep" conceptual understanding and explicit statements of concepts are not the same thing": (David C Geary, 2007) p. 69. (Dunbar, Fugelsang, & Stein, 2007).
- Learning through one system (eg, declarative) can inhibit learning through the other (eg, procedural): (Freedberg et al., 2020; Ullman, 2020)
- Reading delayed when non-procedural-system-based approaches are used (popular articles): (Goldstein, 2020; Lemann, 1997)

The value function and insight into our understanding of the procedural system

- A history of our understanding of deep learning networks such as those of the procedural system: (Sejnowski, 2018).
- Dopamine, updated: Reward prediction error and beyond (Lerner, Holloway, & Seiler, 2020)
- The challenge of reinforcement learning: (Sutton, 1992) (This paper is a classic in the field)
- Basal ganglia circuits for reward value–guided behavior: (Hikosaka, Kim, Yasuda, & Yamamoto, 2014)

Interleaving and varied practice

- The importance of interleaving was first discovered with relation to procedural learning. See (Steven C. Pan & Bjork, In press) for a review.
- Benefits of interleaving on Spanish-language verb conjugations: (Steven C. Pan, Tajran, Lovelett, Osuna, & Rickard, 2019).
- Interleaving area, volume, and perimeter calculations: (Carvalho & Goldstone, 2019).
- Interleaving helps learners retain information better than blocking: (Soderstrom & Bjork, 2015).
- Interleaving benefits learning to write letters: (Ste-Marie, Clark, Findlay, & Latimer, 2004).
- The value of interleaving somewhat similar materials: (Brunmair & Richter, 2019).
- The variability effect: (Likourezos, Kalyuga, & Sweller, 2019).

Dan Willingham

- *When Can You Trust the Experts*: (Willingham, 2012)

Santiago Ramón y Cajal

- Ramón y Cajal's reflections on his success: (Ramón y Cajal, 1989), p. 309.

The history of scurvy and its more general implications

- These two blog posts are fascinating! (Cegłowski, 2010; Slime Mold Time Mold, 2022)

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