Working memory and mental workload

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It is remarkable how little educators seem to know about how the mind works. I suppose one could advance the argument that they need not know; the inner processes of the mind have little bearing on ordinary curriculum decision-making. But I beg to differ. One parsimonious definition of learning is that it amounts to changes in long-term memory—no more and no less. If that is the case, then it would seem fairly important to find out how one goes about changing long-term memory.

Before we get into the substance of this editorial, then, a brief primer on how the mind works, beginning with profound apologies to those who may well view this as simplistic. We begin with sense organs, of which the most obvious in an educational setting are eyes and ears (though touch really matters in the operating room). These sensory inputs communicate with long-term memory through “working memory”. (It used to be called short term memory, but that is too static a term). Working memory in turn is viewed as having several components—a “phonological loop” to process auditory information, a “visual spatial sketchpad,” an “episodic buffer” and a “central executive” (Baddeley 2006). While hypothetical constructs (they’ve never been seen on MRI) they are based on decades of experimentation. It is here that conscious memory operates—from the deliberate rehearsal of a telephone number to the mental calculations of a multiplication. Although there are 4 components, there is an overall severe limit on capacity, amounting to 7 ± 2 “chunks”.

Working memory then communicates with long-term memory, both in retrieving information from memory and in inputting new information to memory. The operation of LTM is quite remarkable. Somehow, we are able to access exactly the information we need in very short time intervals, despite the fact that our brains are operating at the snail—like pace of a few hundred milliseconds per operation. As I wrote in an earlier editorial (Norman 2011), the Jeopardy game of 2010 in which “Watson”, the super-duper IBM computer, beat Ken was remarkable, not because Watson won, but because Ken came so close to Watson. To beat Ken, Watson ripped through the equivalent of a million pages of text a second. Ken surely could not compete at that level. How does Ken do it? Because his memory is “associative”—each piece of information is accessed through predetermined

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associations. It's a bit like the little magnifying glass in the corner of the Mac screen, which also works on associations that are identified at input. But the mind is more dynamic than that. Every retrieval strengthens the associations.

Well, what does all this have to do with education anyway? As it turns out, a lot. Two papers in this volume have “Mental Workload” in the title. Both are referring to the serious limits that working memory may place on two important judgment tasks—clinical decision-making, and rater judgments. While speculative, in that no one has conducted studies in which performance of clinicians and raters is measured concurrent with measures of basic cognitive variables like size of working memory, both papers rely extensively on our understanding of the human mind.

Tavares and Eva (2013) begin with the perceptual process and how high perceptual load can impair ability to detect stimuli in the environment. They then go on to explore the processing of information and how, with complex processing demands, working memory can be overloaded and lead to impaired judgment. In doing so, they draw heavily on cognitive load theory, which is derived directly from consideration of the limit of working memory (van Merriënboer and Sweller 2010).

Byrne (2013) proposes that current “dual processing” and “schema” models of clinical reasoning have as a central but perhaps unrecognized component mental workload and the inherent limitations of working memory. In this conceptualization, expertise is associated with increasing use of schemata and System 1 processing, which reduce mental workload. While much theorizing (Croskerry 2009) suggests that errors result from cognitive bias originating in System 1, in fact, consideration of the limits of WM may lead to a different direction, namely that, in the face of distractions that occupy WM (cognitive load), one may be better off relying more, not less, on System 1. Indeed, Byrne argues that a major component of expertise is a highly refined System 1.

But these two areas do not come close to exhausting the areas where WM may affect teaching and learning. As we indicated earlier, WM contains one component where visual processing occurs. This may well be an important determinant of learning spatial relationships like anatomy, explaining why several studies have shown a relationship between anatomical learning and spatial ability (a component of intelligence) (Garg et al. 1999) and between initial surgical skill and spatial WM (Hedman et al. 2007).

Another area where WM may be implicated is in the acquisition of cognitive and motor skills. One dramatic aspect of pedagogy that has emerged over the past few years is the notion of “deliberate practice” (Ericsson and Charness 1994; Ericsson 2004), which has been used as a justification for simulation-based instruction (McGaghie et al. 2011). Taken literally, the position is that mastery derives entirely from repeated deliberate practice with feedback. The figure of 10,000 hours of practice¹ has been popularized by Gladwell (2008). But even here, working memory is operative. While there is no question that mastery requires hard work and extensive practice, more recent characterizations have shown that there *are* individual differences in time to mastery, related in part to intelligence, which is, in turn, related to the size of working memory (Hambrick and Engle 2002; Meinz and Hambrick 2010).

One of the most visible contributions of cognitive science to medical education is in the realm of e-learning, Cognitive Load Theory (van Merriënboer and Sweller 2010; Mayer 2010), which has been applied extensively in instructional design, directly derives from the notion of a working memory of limited capacity. Acknowledgment that this is a major

¹ One wonders if the 10,000 h mantra would have become so successful if the computed number was, say, 7365.

constraint on learning dramatically refocuses pedagogy away from issues like “high fidelity simulation,” “learning in context” and “authentic assessment” to a recognition that the educator must consider simplifying the learning environment, “reducing extraneous load” to optimize learning. The effects of these manipulations are not trivial; Mayer shows that interventions directed at simple effects like removing (yes—removing) animation and using audio rather than text (to use both visual and aural aspects of WM) can have large effect sizes, of the order of 1.0.

The title of Mayer’s article says it well, “Applying the science of learning to medical education”. He begins by neatly summarizing the argument from cognitive science, “When the goal is to foster learning, it might be useful to understand how learning works” (p.544). Just as medicine advances treatment by understanding mechanisms of disease, we have the potential to greatly influence the effectiveness and efficiency of instruction by better understanding the nature of learning. The articles by Tavares and Byrne advance us in this direction.

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