Teaching and Learning of Surgery

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Significant insights into how we teach and learn have been made over the past 50 years. And, even though it has been one-half of a century, it is only now that some of these insights are being incorporated into mainstream medical education. A significant insight and one of the most widely accepted learning concepts garnered from an intensive study of how our minds function has been that of cognitive load.

Cognitive load theory and its supporting hypotheses were conceived in the mid 1950s. On September 11, 1956 at a symposium organized by the "Special Interest Group in Information Theory" at the Massachusetts Institute of Technology, Miller relates that participants became convinced that experimental psychology, theoretical linguistics, and computer simulation of cognitive processes were pieces of a larger whole.[1] Future activities seemed to suggest a need for the progressive elaboration of themes expressed in the symposium along with a coordination of the disciplines involved. Many names were given to this interdisciplinary exploration of information technology including cognitive studies, information-processing psychology, and cognitive science, but none became widely accepted.

Nomenclature was standardized in 1976 when the Alfred P. Sloan Foundation, interested in the new field of neuroscience, sought to bridge the gap between study of the physical brain and study of the cognitive mind. Foundation members selected the term "cognitive science" to describe fields that represented both brain and mind. A Sloan Special Program in Cognitive Science was created to explore this interest.

The several disciplines originally involved in cognitive science included psychology, linguistics, neuroscience, computer science, anthropology, and philosophy.

Cognitive load theory posits the presence in memory of 2 main components. 1) working memory and 2) long-term memory.[2–5] Human cognitive architecture includes a working memory of limited capacity and duration and a long-term memory effectively infinite in duration and capacity holding many schemas of information and knowledge.[6]

Working memory, which is conscious memory, appears to be located in the prefrontal cortex and parietal areas and is concerned with the amount of information the brain can hold and manipulate at one time.[7]

Working memory can be defined as a brain system, which actively holds information in the mind to do verbal and nonverbal tasks, such as language comprehension, learning, and reasoning, and to make it available for further information processing. It is a brain system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks.[5,8]

Working memory is limited in capacity and duration. Early work in humans suggested that, in general, young adults could hold 7 discrete pieces of information in working memory, plus or minus 2. And, for most cognitive learning, duration of working memory was short and tended to last up to a few minutes.[2] In addition, working memory is one of the cognitive functions most sensitive to decline in old age.[9]

Working memory is thought to be composed of a central executive and 2 subcomponents. One subcomponent is for processing visual-spatial information (images); the second subcomponent is for processing auditory (speech) information. It is presumed that these subcomponents process information in relative independence of one another.[4]

In a physical sense, working memory is a short-term potentiation of neural connections in the brain that can become long-term memory through a process of rehearsal and meaningful association. It seems likely that the process of long-term potentiation involves a physical change in the structure of brain neurons.

Long-term memory, in contrast to working memory, is not constrained by capacity and has the ability to *store* virtually an unlimited amount of knowledge. The elements of information stored in long-term memory differ structurally

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and functionally from working memory. Long-term memory is thought to be composed of 2 types of memory: declarative and procedural.

Declarative or explicit memory is long-term memory that can be recalled as facts and knowledge.[10] Declarative memory can be further divided into 2 categories: (a) episodic memory, which stores specific experiences, and (b) semantic memory, which stores factual information.[11] While the entire brain is likely involved with memory, the hippocampus and surrounding structures appear to be very important in declarative memory.[12]

Procedural memory or implicit memory is memory for *how* to do things–like riding a bicycle or flying an airplane. Procedural memories are frequently below the level of conscious awareness and are retrieved for the execution of integrated procedures involved in cognitive and motor skills. This type of memory is presumed to be encoded and stored in the cerebellar cortex.[13]

The contents of long-term memory have been postulated to be sophisticated structures that permit us to perceive, think, and solve problems. These structures, which are called schemas, allow the treatment of multiple elements of information as a single unit. Schemas are the cognitive structures that make up an individual's knowledge base.[14]

Schemas are acquired over a lifetime of learning and may contain other schemas within them. Typically, individuals are not conscious of the contents of long-term memory. It is only when these contents are brought into working memory that we become conscious of the information contained within the schema.

Humans can encode and store large amounts of information for later retrieval provided learning experiences are designed to take into account the limitations of working memory and provide for ready retrieval of information from long-term memory.

Current thinking suggests that to be learned, information contained within instructional materials must first be processed in working memory. To be retained, this information must then be encoded into schema. For efficient encoding, instructional materials should be designed to reduce the load imposed on working memory in encoding that information. Current application of cognitive load theory concerns itself with techniques for reduction of working memory load so that schema acquisition is facilitated in long-term memory.[15]

Some recommendations to reduce instructional material's working memory load include:

1. Change problem-solving methods to avoid a heavy working memory load by using worked examples or goal-free problems.
2. Eliminate the working memory load associated with having to mentally integrate several sources of information by physically integrating those sources of information.
3. Eliminate the working memory load associated with unnecessarily processing repetitive information by reducing redundancy.
4. Increase working memory capacity by using auditory as well as visual information under conditions where both sources of information are essential (ie, nonredundant).[15]

Building on work in cognitive science, the American College of Surgeons, Division of Education incorporated several aspects of the relatively new understanding of learning into resident training. In particular, the college recognized the limited capacity of working memory as articulated in cognitive load theory, and recommended that educational material for surgical training be designed to reduce the level of cognitive load incurred in learning those materials.[2,16]

Another important concept in teaching and learning the surgical sciences is the role of deliberate practice in the acquisition of expert performance. It has been commonly held that the characteristics that result in expert performance are innate and transmitted genetically. Exceptional individuals in the arts, sports, music, and sciences have been felt to have talent or "natural ability" to explain their exceptional performance.[17] It was believed that because expert performance is qualitatively different from normal performance, that the expert performer must be qualitatively different from the rest of us.

This view has been challenged of late and a new account of how individuals can achieve expert performance has been advanced. More recent thinking suggests that expert performance can be achieved through learning and adaptation. Superior performance, in a real sense, can be achieved from extended, deliberate practice. There is only a limited role for innate characteristics (inherited) and "natural ability." In a sense, almost everyone has the potential for performing at a high level in a specific field if they engage in highly concentrated, consistent, long-term practice.[18]

Deliberate practice is defined by Ericsson as a highly structured activity with an explicit goal to improve performance. Deliberate practice requires effort and is not inherently enjoyable. But, deliberate practice improves performance.[18]

Deliberate practice to obtain expert performance is not short-lived or simple. It must extend over a period of time of at least 10 years duration and is an effortful activity that can be sustained only for a limited period each day. To maximize gains in performance, individuals must limit practice to an amount they can completely recover from on a daily or weekly basis.

It doesn't seem to matter whether the domain is music, science, sports, chess, or the arts. Expert performance is achieved after an extended period of time (about 10 years or about 10 000 hours for musicians) with deliberate practice, motivation, and adequate time for recovery after practice.[18]

Put another way, it is now widely held that elite performance is the product of 10 or more years of maximal effort in a field through an optimal distribution of deliberate practice. The commitment (motivation) to deliberate practice distinguishes an expert performer from the less-accomplished individual. Experts carefully schedule deliberate practice and limit its duration to avoid exhaustion and burnout. What distinguishes experts is more and better knowledge, knowledge that has been acquired over time and with effort. It is interesting that scientists and authors typically choose mornings for demanding effort while athletes use afternoons for their most strenuous workouts.[18]

A thoughtful review of the above will show that these new insights into how we learn and improve can have a profound and far-reaching impact on surgical training. For example, it would be unwise to underestimate the amount of practice needed to learn even basic skills in the surgical sciences. The use of computer simulation for deliberate practice and warm-up only touches the surface of what can be implemented.

Reducing the cognitive load of teaching methods and teaching materials will have a positive effect on a learning experience. Reducing this load has the potential to facilitate transfer of information and knowledge from working memory to long-term memory.

It would seem that early in a learning process we practice to learn a skill–it is fun. Later we learn to practice–an effortful exercise that typically, is not fun–and, eventually, we are able to learn from practice. Practice, deliberate and effortful practice, will hone skills and facilitate transfer of knowledge from working memory to long-term memory for long-term availability and for ready use.[19]

Memories need to be stabilized and consolidated after initial acquisition.[20] Consolidation of memories has been identified to have 2 specific processes. Synaptic consolidation, which occurs with the first hours of learning, and system consolidation, where hippocampus-dependent memory becomes independent of the hippocampus over time ranging from weeks to years.

Preparing physicians for the 21st century will require change and it will be challenging, but it is necessary and it is doable. Using knowledge gained from the cognitive sciences, concepts can be taught, practiced, and assessed in the context in which they will be used. These new insights into how we learn must be shared with learners as well as teachers.

The American Medical Association (AMA) has joined the effort to introduce bold innovation in medical education by incorporating new understandings of how we learn. In a statement on accelerating change in medical education, the AMA will focus on:

- Partnerships that create, implement, and evaluate new methods of medical student education;
- Focused attention on flexibility, individualized and social learning, achievement of competencies and professionalism in physician education;
- Promotion of exemplary methods to achieve patient safety, performance improvement, and patient-centered team care in medical training.

The AMA will accomplish in the next 5 years:

- Define criteria for focused change in medical student education, using a structured review process that includes the Council on Medical Education and new and established partners;
- Establish partnerships with select medical schools and health care systems to develop innovations supporting new, flexible, and outcomes-based education across the continuum.

At the same time, the AMA will continue to shape graduate medical education (GME):

- Working closely with ACGME and Residency Committees on GME standards;
- Supporting federal and state-level advocacy that addresses GME and workforce issues.[21]

The acquisition of practice skills can be safely absorbed without implementation of the old dictum "see one, do one, teach one." Increasingly sophisticated simulation and virtual reality tools will enable students and practitioners to safely develop practice skills without endangering patients. These same tools will also help provide nonbiased assessment so that demonstration of mastery can be validated before progression to the next level. Assessment drives learning.[22]

Finally, it must be noted that when taken as a whole, human memory is not static; it is not immutable; it is not like printed words in the pages of a book. On the contrary, verbal learning needs repeated use and reinforcement.[19]

All of the above reinforces the observed facts that human memory is fragile and, in many instances, unreliable. It is subject to deterioration and distortion. (Witness the spate of criminal justice cases overturned when laboratory or other nonrefutable evidence contradicts human memory.) In point of fact, we are just beginning to understand how our minds work, and this understanding will have profound implications for teaching and learning.[19]

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