**Improving Memory to Improve Academic Performance**

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By [Carl Sherman](http://dana.org/news/author.aspx?id=20900)

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The separate worlds of education and neuroscience came together around a central concern of both during a daylong symposium in New York City on “[Memory and Mind: Improving Memory and Achievement in the Classroom](http://www.learningandthebrain.com/brainsymposium.html),” co-sponsored by the Dana Alliance for Brain Initiatives (DABI) and Learning & the Brain.

Featured speaker [Eric R. Kandel](http://nobelprize.org/nobel_prizes/medicine/laureates/2000/kandel-autobio.html), a Nobel Laureate and vice-chairman of the Alliance, explicated the connection: “Learning is how we acquire information, and memory is how we store that information. Education is about enhancing learning, and neuroscience is about trying to understand how learning and memory occur. Memory is the glue that binds our mental life together.”

Kandel’s talk progressed from an overview of the pioneering neuroscience that shaped our broad understanding of mental processes to a close-up of molecular events at the heart of memory and learning.

Early attempts to understand memory were “part of the larger question that concerned 19th century science: Can any mental process be localized to specific regions of the brain?” Kandel said.

The search for an answer initially went to extremes. The hypothesis that each mental function occupied its own space on the cortical surface gave rise to phrenology, which strove to analyze personality via bumps on the skull. Doubts about phrenology led to the idea that the brain was “eqipotential”—all areas were involved in all functions.

It was through post-mortem studies of the brains of people who had deficits like aphasia that the modern concept of brain organization began to emerge: Regions are devoted to specific functions, and complex functions involve circuits that connect a number of such regions.

But where was memory? Here, it appeared, equipotentiality was the rule: Removing brain tissue damaged memory—but “how much,” rather than “where” seemed to matter.

Kandel described the central importance of the patient H.M. (Henry Molaison), whose hippocampus was removed in 1953 in an attempt to control his epilepsy. H.M.’s memories of people and events prior to the surgery were unimpaired, as was his short-term memory —he could repeat a telephone number immediately after hearing it. What he lost was the ability to form new, lasting memories (see column, "[A Fascinating Brain, in Death as in Life](http://www.dana.org/news/braininthenews/detail.aspx?id=24130)").

“We learned that to convert short-term to long-term memory requires the hippocampus: a monumental discovery,” Kandel said.

 Work with H.M clarified another key distinction: “Memory is not a unitary faculty,” Kandel said. “There are at least two forms: explicit memory for facts and events, which requires conscious recall, and implicit memory for perceptual and motor skills,” which remained intact despite H.M.’s loss of his hippocampus.

“Although explicit and implicit memory are dramatically different in the brain areas involved, the kinds of memories preserved, and the importance of conscious and unconscious processes, the molecular mechanism for converting short-term to long-term memory is amazingly conserved.”

Kandel described research, much of it his own, that had traced out this mechanism in an animal with a rudimentary nervous system, the snail aplysia. Touching one part of the snail’s respiratory apparatus, the siphon, provokes the defensive retraction of another part, the gill. An electrical shock to the animal’s tail amplifies the withdrawal reflex. Repeating the shock maintains the amplified response for days or weeks—a primitive kind of implicit memory.

Experiments with cell culture established that stimulating a sensory neuron from the siphon releases neurotransmitters into the synapse that communicates with a motor neuron to the gill, and that a “modulatory” neuron from the tail adds another neurotransmitter that transiently intensifies synaptic activity. When the process is repeated, chemical signaling moves into the nucleus, enhancing expression of genes for proteins that form new synapses.

Although the neurochemical details are different, explicit memory works pretty much the same way: short-term memory becomes long-term when genes are activated to create new synaptic connections. “The process is designed so that only things that are meaningful, enjoyable, or important are remembered,” Kandel said.

“This is what happens in the brains of your students if you are successful,” he said. “The whole function of education is to alter the brain.”

**Inside Stories**

In another presentation, [John Gabrieli](http://bcs.mit.edu/people/gabrieli.html), professor of health sciences and technology at Massachusetts Institute of Technology, explained how neuroimaging has filled in details of where and when the structures underlying learning and memory mature. “We think we’ve [taken the first steps in understanding](http://www.ncbi.nlm.nih.gov/pubmed/17676059) how declarative [i.e., explicit] memory systems develop in the brain,” he said. “We have tools to go into the brain and ask which regions develop sooner, and which act differently in the 8 and 20 year old.”

Such research has shown that turning short-term to long-term memory uses more of the brain in adults than in children. One fMRI study contrasted  brain activity when subjects recorded experiences that would later be recalled vividly to those that were soon  forgotten,  and found that in children,  increased activity was limited to the medial temporal lobe [which  includes the hippocampus and surrounding structures], but in adults, the prefrontal cortex was also engaged by memorable events.

These prefrontal areas, which encode details and textures of experience—what Gabrieli termed “the richness of memory”— grow through adolescence and are not fully mature until the early 20s.

Although long-term memories are formed in the hippocampus and prefrontal cortex, they are stored elsewhere, in knowledge-specific cortical regions that MRI studies have shown that to mature at different rates, Gabrieli said.

For example, the fusiform area of the visual cortex, which responds to faces, triples in size between ages 8 and 20, as does the parahippocampal place area, which responds to location. The lateral occipital cortex, which responds to objects, changes very little.

“Where the areas develop slowly, memory develops slowly,” Gabrieli said. “We get better at remembering faces and places, but there isn’t so much change in remembering objects.”

Fascinating as such discoveries have been, “the challenging question is how education and neuroscience will interact: When will anything neuroscientists do matter to children and teachers?” Gabrieli said. Neuroimaging may show that memory is enhanced when the amygdala is activated by emotional engagement, “but you don’t have to know anything about the amygdala to know that children learn better when they’re interested than when they’re bored,” he said.

The next few years may see more practical applications emerge, Gabrieli predicted, and pointed to research in his lab and elsewhere that is clarifying brain differences between children with dyslexia and fluent readers [see news story, "[Visualizing How We Read](http://dana.org/news/features/detail.aspx?id=31068)"].

Two other presenters focused on a faculty highly relevant to the classroom: working memory, which represents the cognitive ability to handle multiple pieces of information simultaneously, such as to add numbers or pick out rhyming words.

 “Brain imaging research shows that during a working memory task, the prefrontal cortex is working hardest,” said [Tracy Alloway](http://tracyalloway.com/), director of the Center for Memory and Learning in the Lifespan at the University of Stirling, United Kingdom.

Working memory skills develop through childhood, reaching adult levels around age 16. “But at any age, there’s a huge range,” Alloway said. “In a group of 10-year-olds, some may look like average 5-year-olds, some like 15-year-olds,”

The faculty is “a foundation of learning,” she said; it determines the capacity to process information, follow instructions, and meet classroom demands. Working memory predicts academic achievement far more robustly than IQ, and is less influenced by socioeconomic status.

It remains important in the context of special learning needs:  children with attention deficit/hyperactivity disorder, learning disabilities in reading or math, and autism spectrum disorders share a general weakness in working memory, but those in whom it is more intact fare better academically, Alloway said.

In a separate presentation, [Kirby Deater-Deckard](http://www.psyc.vt.edu/users/kirbydd), professor of psychology at Virginia Tech,    described the role of “family ecology” in the development of working memory. Children from “chaotic” households, characterized by noise, disorganization, and erratic schedules, perform more poorly on working memory tasks, which correlates with their academic difficulties, than do children from less-chaotic households, he said.

Genetics also is an important factor. Deater-Deckard cited research that found strong correlations between working memory in mothers and biological children, but not with adoptive children in the same family. Over time, similarity in working memory performance increases among genetically related family members, but diminishes in adoptive siblings. The same pattern distinguishes monozygotic and dizygotic twins.

Working memory does not improve spontaneously in children with academic difficulties, but may respond to intervention. Alloway cited [a study showing that an eight-week  training program of specially designed computer games](http://precedings.nature.com/documents/3697/version/1) increased working memory, IQ, and  learning outcomes significantly more than standard educational support. A similar program achieved substantial gains among children with dyslexia and high-functioning autism, she said.

**About Carl Sherman**

Carl Sherman is a science writer in New York City.