# The New Science of Learning and Why Students Forget Their Economics So Quickly

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## Abstract

The human brain has automatic, built-in abilities to filter and discard information so that the vast majority of the information that enters our senses is deleted. Consequently, the result is that teachers need to understand, model, and program student learning to work in harmony with these natural abilities. New discoveries in the 'science of learning' that employ multi-disciplinary work in psychology, neuroscience, machine learning, and education have shown us how the human brain works. Furthermore, studies of child development, plasticity of the human brain, and computational approaches to learning have contributed to new understandings of how we learn and how long-term memory is formed. The most important of these findings are:

1. Learning is computational and probabilistic, using Bayesian Logic. 2. Learning is fundamentally social in nature. 3. Designated brain circuits link perception and action. 4.The human hippocampus and REM sleep collaborate to form and store long-term memories.

In addition, we present the implications of this research for the teaching of economics and also present practical techniques that can be incorporated into classroom teaching to help students study more efficiently and improve student learning.


## We Think, Therefore We Forget

The human brain is bombarded with enormous amounts of information every second. To ensure its continued function and survival, it employs automatic and innate abilities to filter and discard the vast majority of this information. As a consequence, teachers need to understand, model and program student learning to work in harmony with the natural tendencies of the human brain. Additionally, the teaching of economics is particularly challenging in this regard because of its goal of explaining complex frameworks of reference, in contexts most students are not currently experiencing in their real lives.

Studies of learning development, human brain plasticity, and computational approaches to learning are contributing to new understandings of how we learn and how we form long-term memories (Metltzoff et al. 2009). Four critical findings from this research inform this paper:

(1) Learning is computational and probabilistic, using Bayesian Logic. Humans are born with computational skills used to infer language structure, cause and effect, as well as basic statistical regularities and co-variations. This Bayesian model of probabilistic thinking challenges both Skinnerian reinforcement learning and Chomsky's "nativist" model of an inborn facility for grammar and syntax (Gopnik 2004). In early childhood, humans learn actively, testing their environment through observation, hypothesizing, experimentation, conclusion, and the incorporation of feedback.

(2) Learning is fundamentally social is nature. Parents, peers, and teachers offer social cues about what and when to learn, in formal and informal learning environments. Because of the social nature of learning, interpersonal interaction among students at any age increases the quality and amount of learning. At the extreme positive end of interactive learning, in instances where tutoring involves active learning strategies, students test up to two standard deviations above classroom teaching limited to passive learning strategies (Meltzoff et al. 2009; *e! Science News* 2009).

Benjamin Bloom ("Bloom's Taxonomy") calls this the "2 Sigma Problem". Bloom contends that the goal of the teacher should be to create teaching/learning conditions under large group instruction that allow the individual student to achieve the same level that he/she would under individual instruction by a skilled tutor (Bloom 1984; Guskey 2007).

(3) Designated brain circuits link perception and action. The same "mirror neurons" that allow readers and television viewers to identify and share an emotional connection with both fictional and real characters by entering a state of "suspended disbelief" are activated in real life. Damasio and Meyer (2008) demonstrated that both acting yourself or watching others act has the same effect on the brain and activates the same areas of the brain. In addition, active learning produces faster and more satisfying results through imitation, shared attention, and prompting of empathic understanding.

(4) The hippocampus, primarily during rapid eye movement sleep ("REM" sleep), processes short-term memories and sends their components to various and specific parts of the brain for long-term storage. Multiple retrieval or strong emotional content (or both together) strengthen the path to long-term memory. As a matter of fact, they are the *conditions precedent* for the formation of long-term memories. Furthermore, the neurotransmitter that motivates the formation of and controls the persistence of long-term memory is dopamine,

the brain's "reward chemical" (Rossato et al. 2009; Shen et al. 2008). Finally, long-term memories, as we shall see below, do not actually exist at all in any one place in the brain, but are actually *systems* of neurons connected together. (Neuroscientists say, "Neurons that fire together, wire together".)

These findings have an immediate application in opportunities to improve adult student learning. However, to fully understand the new research, we need to take a short tour of the human brain - how it works, thinks, emotes and forms memories – and the resulting implications for designing adult learning strategies. It is also important to understand that the disciplines of economics and psychology, as a deliberate methodological protocol, view the brain as a "black box". In economics, the basic formulation of this protocol is in the discipline's fundamental object of study ("revealed preferences") and in the dictate that it is impossible to compare interpersonal preferences. In psychology, it is the experimental methodology of subjecting the participant to some sort of stimulus and observing what response is elicited. However, neuroscience – and more specifically neuroeconomics – by examining the internal mechanisms of the brain has yielded valuable insights into why we act the way we do (often "irrationally"), how we learn and how we apply that learning to daily existence.

## The Human Brain: Physical Makeup

At the macro level, neuroscientists conceptualize the structure of the human brain as the "Triune Brain". This model follows the evolutionary development of the human brain, which did not fundamentally change its older parts as it evolved from reptile to mammal to primate but instead added additional, more advanced layers on top of the older parts.

The oldest and most primitive part of the brain is located in the middle of the brain and is called the Midbrain or "Reptilian Brain". It consists of the brain stem, the cerebellum and other primitive parts. The midbrain manages the body's basic life-sustaining physiological processes, including respiration, heart rate, sleep patterns, and other basic instincts. We still share this brain structure with modern-day reptiles and clearly reptiles are capable of nature's basic imperatives: hunting prey, eating, mating and having offspring.

The second layer of the brain is known as the Limbic System and it sits on top of and around the midbrain. The limbic system is the emotional driver of the brain. Its structures, which include the ventral striatum, the amygdala, the hippocampus and the insular cortex, are the source of the primitive emotions and feelings of excitement and fear and pain but they also control reward seeking and loss avoidance, two of our most important survival mechanisms.

Finally, the third system in the brain is the Cortex, which is the largest part of the brain. This area is generally viewed by anthropologists as having evolved in mammals and primates in order to handle increasingly complex social relations in larger and larger groups (de Waal 2005, 2009). Therefore, the cortex is very adept at social relations. We must also single out a very special part of the cortex, known as the Prefrontal Cortex, which is at the front of the human brain (behind the forehead). This area of the brain is the ultimate seat of the executive function in primates – the go or no-go decision. It is also the area involved in abstract thinking, mathematics, planning, calculation, learning and strategic decision-making.

At the micro level, the human brain consists of a complex structure of approximately 100 billion neurons, each having on average approximately 1,000 connections (called "synapses") with other neurons for a total of 100 trillion inter-connections or "synapses" (Silver and Kanichay 2008). The amazing thing is that when we are born, we have essentially all the neurons we will ever have. The actual growth of the human brain from infant to adult consists solely of the original neurons growing connections to other neurons in the brain. Neurons communicate signals within the neuron cell itself via electrical impulses and across the synapses between neurons via molecular neurotransmitters such as glutamate, noreprinephrin, dopamine and serotonin. (See Figure 2.) The brain automatically and unconsciously processes sensory inputs from auditory, visual and somatic nerves and constructs these inputs into a *gestalt* (whole), thereby recognizing objects. It also learns how to process walk, talk, reading and math and how to create music, poetry and philosophy.

The brain is fragile but also constantly active and dynamic. As we learn, neurons in the brain form, strengthen, and redirect their connections. It is these intricate and extensive connections that create learning and memory, not the growth of new neurons. As a matter of fact, the brain only grows new neurons in two small structures – the hippocampus and the olfactory bulb. This fragile, incredibly complex and constantly dynamic machine is what we humans use to learn.

## The New Science of Mind

Integrative theoretical models for understanding the human brain (Cohen 2005) posit that although the parts of the human brain are all interconnected and work together, the brain is best not thought of as a homogenous unit, but as a 'Society of Minds' (Minsky 1986) with each part allocated a specific task or tasks. For example, the emotional brain, consisting of the ventral striatum, the brain stem, the amygdala and the anterior insula, processes information very quickly and unconsciously, hence the lay term of "gut reactions." On the other hand, the neocortex and prefrontal cortex are slower but they enable a person to consider and act on abstract goals and principles. Moreover, the "conscious brain" can override the "emotional brain", for which we use the term "free will". However, the prefrontal cortex has some very severe limitations. It can only remember up to four things at one time and can only focus on and compare two items at one time; adding a third item causes it to automatically "drop" one of the first two (Koechlin and Hyafil 2007; Buschman et al. 2011). This constraint is a central concept in decision theory and it also has immediate applications for learning economics, especially in proscribing multi-tasking while learning.

Neuroscientists have identified five instinctual motivational drives corresponding to the reptilian and mammalian instinctual brain circuits (Solms 2006, 42): 1. Seeking rewards and pleasure. 2. Anger and defensive aggression–but not predatory aggression. 3. Aversion to danger and loss. 4. Reaction to sudden or imminent danger, including threats to the individual and to socially relevant group members. 5. Comprehension of rules that allow the individual to survive and prosper in a group setting.

Since recent research has shown that emotion and motivation are *necessary conditions* for the formation of long-term learning, involving the limbic system, understanding such instinctual motivations is essential to the process of teaching (Rossato et al. 2009; Shen et al. 2008).

The last two decades of the twentieth century have seen a marked increase in interdisciplinary research combining philosophy, psychology and psychoanalysis with new findings in brain biology and dramatic advancements in molecular biology (Kandel 2006, 69). This has revolutionized our understanding of the brain and mind. According to Kandel (2006) four principles sum up the results of this interdisciplinary research: 1. Mind and brain are inseparable. That is, 'mind' is a set of operations carried out by the brain. 2. Each mental function is carried out by neurons and interconnected neural circuits in several regions of the brain. This is true both of the simplest reflexes and the most creative acts of language, music and art. 3. Interconnected circuits are made up of the same elementary signaling units: nerve cells are found in all mammals and even lower forms of life. 4. Nerve cells or neurons use specific molecules (called "neurotransmitters") to communicate with each other at various speeds.

These principles can be used to inform teaching strategies that will improve students' ability to retain and process complex information in economics courses. We contend that instructors who are at least familiar with the biology of the brain will be able to successfully combine teaching strategies with students' inborn natural inclinations to encourage successful learning behaviors.

## The New Science of Learning

In other inter-disciplinary research, findings in neuroscience, developmental psychology and machine learning are now merging to create the basis for a new science of learning. These findings hold the potential to radically transform our educational methods, as they explain the importance of language and social interaction in both formal and informal learning environments (Meltzoff et al. 2009; Kording 2007) and the importance of recognizing that teaching should engage multiple learning styles and intelligences (Gardner 2006).

In a study examining the influence of social processes on the development of the basic method of statistical learning, Kuhl (2007) discovered that infants can learn a foreign language rapidly if interacting with an adult during naturalistic play. However, exposure to the same auditory input at the same age and for the same duration via television or audiotape produced no similar learning, a phenomenon called 'social gating' (Meltzoff et al. 2009; Kuhl 2007). Further, in studies involving toddlers with autism spectrum disorders ("ASD"), Kuhl and her team (2005) discovered a clear correlation between such disorders and a preference for non-speech sound bites. Children without ASD overwhelmingly preferred speech-like sound bites ("motherese"), while the ASD children preferred non-speech sound bites. Furthermore, the degree of preference for the non-speech snippets corresponded to the severity of the autism symptoms and accurately predicted developmental delays (Kuhl, Coffey-Corina *et al.* 2005).

So, learning is social and there are three social skills that form the foundation of human development - imitation, collaboration, and empathic understanding (Metlzoff et al. 2009; de Wall 2005, 2009):

*Observation, Imitation, and Modeling* engage hard-wired fundamental neural mechanisms. Social learning theory (Bandura 1977) posits that people learn through imitation and assessment of behavior effectiveness, which the brain encodes as a guide for future action. Learning becomes a continuous interaction with the environment, fed by attention, retention, reproduction of actions and motivation. As we mentioned above, in studies comparing study strategies, students who used reflection and imitation in tutoring sessions tested two standard deviations above students who relied strictly on classroom lectures (Meltzoff et al. 2009).

*Collaborative Learning* relies on an objective common ground that the teacher and student can observe together. Instant feedback from the teacher or tutor allows students to improve learning by communicating, comparing and contrasting different conclusions. As early as infancy, humans project their own experience onto other people. Collaborative learning is thus complementary to imitation and a basis for social learning (Meltzoff 2007; Tomasello et al. 2005). The human brain is on a continuous quest to handle increasingly complex social relationships among increasingly larger groups of people (Chapais and Berman 2004; de Waal 2005, 2009; Dunbar 2004). In addition, the theoretical framework of distributed cognition (Hutchins, 1995) describes work "systems" in problem-solving, informational, and computational terms. The implication for instructional design is that students involved in "system design" and not just in memorizing information will have a stronger, clearer model of how to perform well.

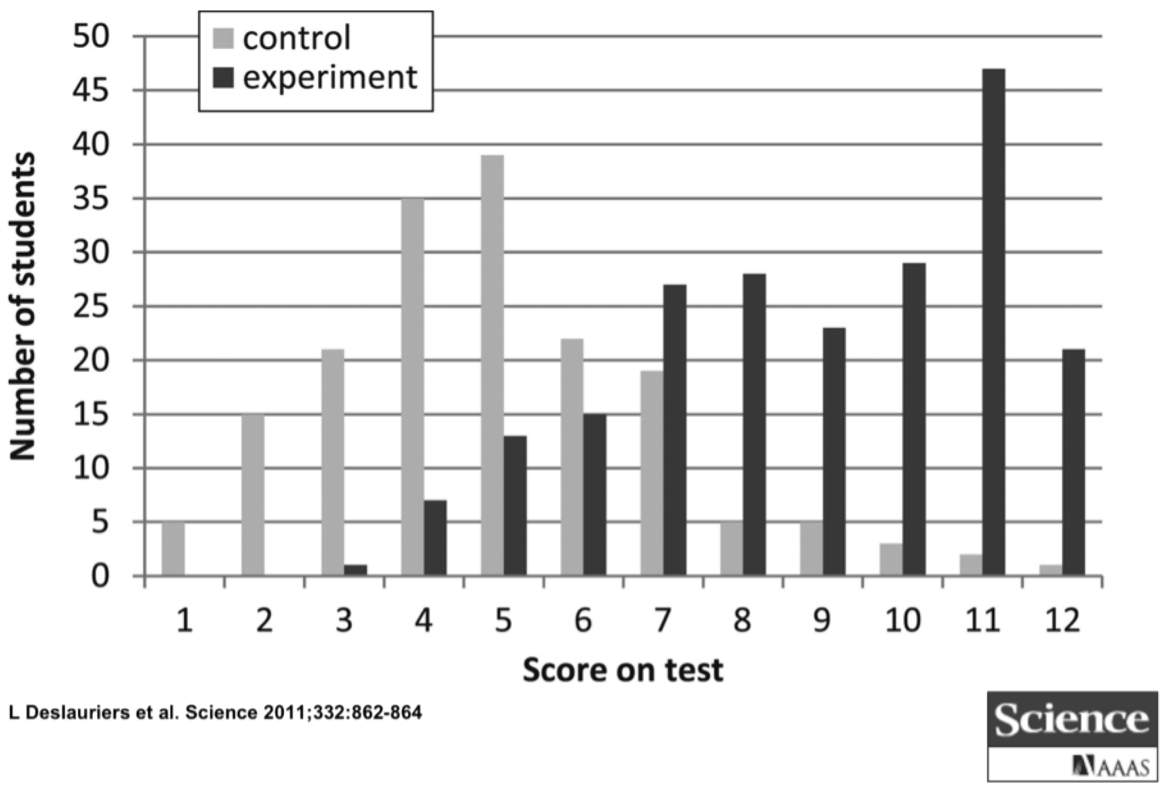
*Empathic Learning* relies on the fact that the same brain areas are activated for perceiving a pain stimulus directly as when observing someone else's reaction to that stimulus. This holds true not just for joy and pain, but also recent research has shown that "mirror neurons" in each person's brain are firing in synchronization as they are connecting in normal conversation (Stephens et al. 2010). These neural reactions are modulated by cultural experience, training, and perceived similarity between self and other (Singer et al. 2004; Hein and Singer 2008; Lamm et al. 2009). When embedded within a specific activity, context and culture, we find the same idea reflected in the concept of "situated learning" which is usually unintentional and triggers a process of "legitimate peripheral participation" (Lave and Wenger 1990).

A small, but fascinating experiment shows the importance of the social aspects of learning (Deslauriers 2011). In this study, Carl Wieman, a Nobel Prize winner in physics, trained a postdoc, Louis Deslauriers, and a graduate student, Ellen Schelew, in an educational approach called "deliberate practice" that asks students to think like scientists and puzzle out problems during class. For one week, Deslauriers and Schelew took over one section of an introductory physics course for engineering majors, which met three times per week for one hour. A tenured physics professor continued to teach another large section using the standard lecture format. The results were dramatic: after the intervention, the students in the deliberate practice section did more than twice as well on a 12-question multiple-choice test of the material as did those in the control section. They were also more engaged—attendance rose by 20% in the experimental section, according to one measure of interest—and a post-study survey found that nearly all said they would have liked the entire 15-week course to have been taught in the more interactive manner. The results are presented below. (See

Figure 1.)

The “deliberate practice” method begins with the instructor giving students a multiple-choice question on a particular concept, which the students discuss in small groups before answering electronically. Their answers reveal their grasp of (or misconceptions about) the topic, which the instructor deals with in a short class discussion before repeating the process with the next concept.

Figure 1

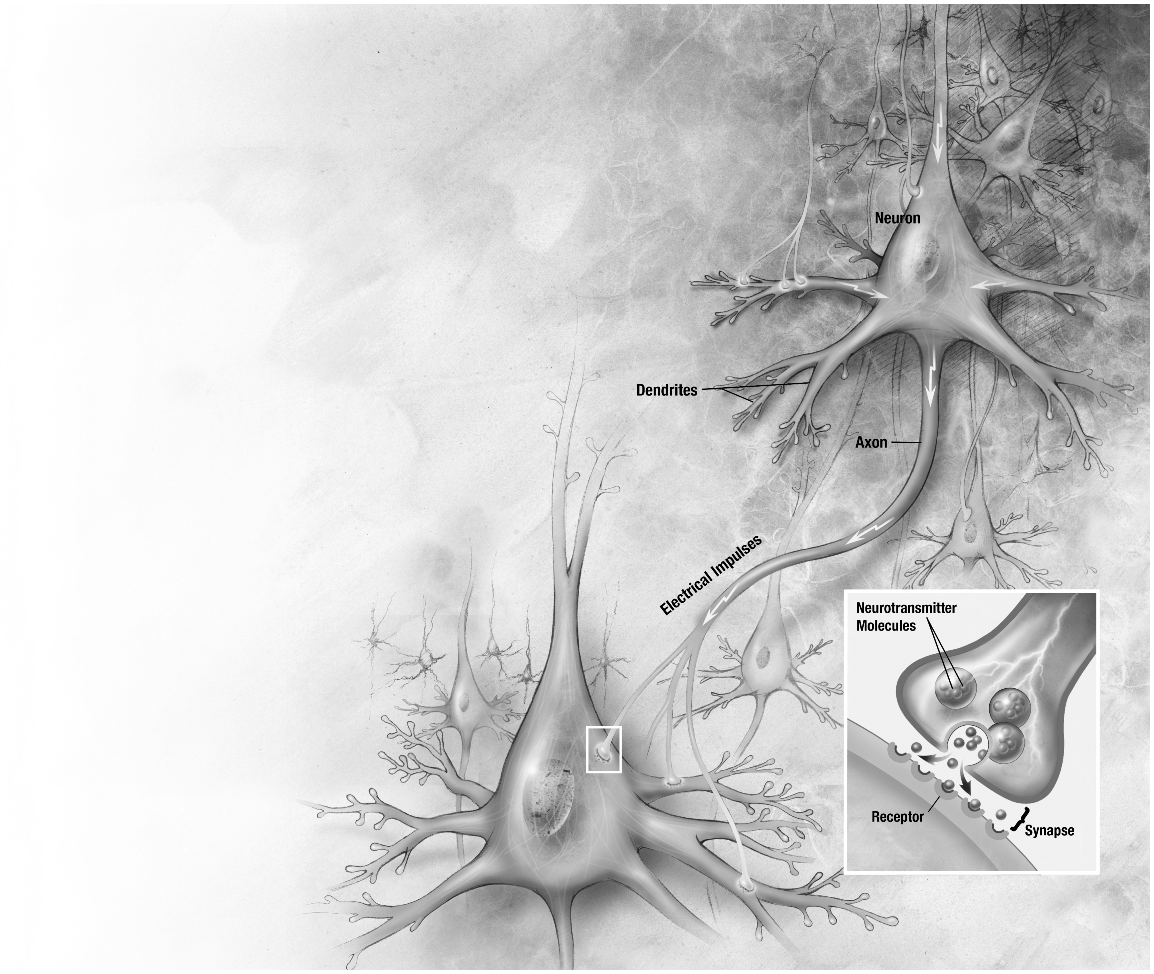



**How the Brain Learns**

As part of our survey of the human brain, let us examine in more detail how the brain learns. Using an analogy to a computer, our brains have both short-term processing memory, the equivalent Random Access Memory (“RAM”) and long-term storage memory, equivalent to the Hard Drive Disk (“HDD”). The brain mechanisms that fix something in our long-term memory or retrieve an episode or fact from our long-term memory so that we can “think” about it are actually unconscious and fairly automatic. So understanding these mechanisms has immediate implications for teaching and learning.

Within the neuron, a signal travels via an electrical current. However, communication between neurons is accomplished via chemical neurotransmitters that move across the spaces or "synapses" that occur where a specific neuron is in contact with other neurons. Neurons are constantly active, usually generating internal electrical impulses of three pulses per second. Simultaneously, neurons are sending neurotransmitter signals across the synapses at the identical pulse rate. When multiple synapses are simultaneously active, this triggers a heightened electrical potential in the next neuron down the line and the signal is passed on. When this occurs, all active synapses are strengthened so that the recipient neuron becomes more sensitive to receiving the same signal the next time. This strengthening process is termed "long-term potentiation" and it follows a common behavioral rule for learning. If two stimuli to the recipient neuron occur at the same time, they become causally associated in the brain (Aamodt and Wang 2008). Neuroscientists say that "Neurons that fire together wire together".

Figure 2.

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In order to maximize synapse usage, the brain resets or weakens every night during sleep the synapses that have not fired often during the day (called “long-term depression”), which results in forgetting. It also grows a few new neurons (called “neurogenesis”) but only in the hippocampus and the olfactory bulb, which creates new long-term potentiation (Eriksson et al. 1998) and forms new synapses, which triggers new learning. During sleep, the neuron synapses that have been especially active during the day are ‘reset’ in a process called ‘neuronal plasticity’ (Brecht and Schmitz 2008; Silver and Kanichay 2008) and information deemed by the brain to be relevant to survival is transferred to long-term memory by the hippocampus during REM sleep (Aton et al. 2009; Stickgold 2005) and stored in brain areas responsible for specific types of memory. One of the most amazing recent neurological discoveries is that memories are not stored intact in any one specific area of the brain. Rather, the hippocampus fixes long-term memories and stores them in the same brain areas that originally processed the sensory input. So, for example, the visual portion of a memory is stored in the visual cortex, the auditory portion of the memory is stored in the auditory cortex and language and math are stored in the prefrontal cortex (the logical part of the brain). Research has shown that patients with damaged hippocampus cannot form new memories, although they can remember old ones. As evidence of this, since Alzheimer's disease usually affects the hippocampus first, Alzheimer's patients immediately experience memory problems (Smith and Squire 2009).

This is why cramming and all-night study may get the student a passing grade on the next day's exam but is deadly for long-term memory. Sleep is critically important to life; not only does it give the human body a chance to rest and recharge, but it is also a time when memories are transferred from the short-term to the long-term storage areas of the brain.  Lack of sleep results in additional release of cortisol, which further inhibits neurogenesis and neuroplasticity (Aamodt & Wang 2008; *Science News* 2006; Mirescu et al. 2006).  Recent research concludes that during REM sleep the brain replays short-term memories from the prefrontal cortex at a rate of speed seven times their real-world timing and fixes ("consolidates") them in long-term memory. As a consequence, students who schedule multiple study sessions, spaced out to provide enough time for learning, filtering, forgetting, and re-learning increase the amount of learning relegated to long-term memory almost two-fold (Aamodt & Wang 2008).

The high-speed replay of short-term memories by the hippocampus is what the cortex of the brain interprets as "dreaming". Dreaming happens during REM sleep but also occasionally during non-REM sleep, and the hippocampus is occasionally supplemented by the limbic system, resulting in dreams with high emotional content—elation, anger, or anxiety (Solms 2006). The fixating activity of the hippocampus is strongly affected by the experience of emotions: strong joy, fear or pain stimuli can cause associated memories to be fixed forever in our long-term memory (Aamodt and Wang 2008), while meaningless numbers, data, and words are committed only to short-term memory and mostly forgotten after about two hours.  Consequently, generating learning environments where new information is instantly connected through a variety of neuron synapses strengthens students' ability to form long-term memories.

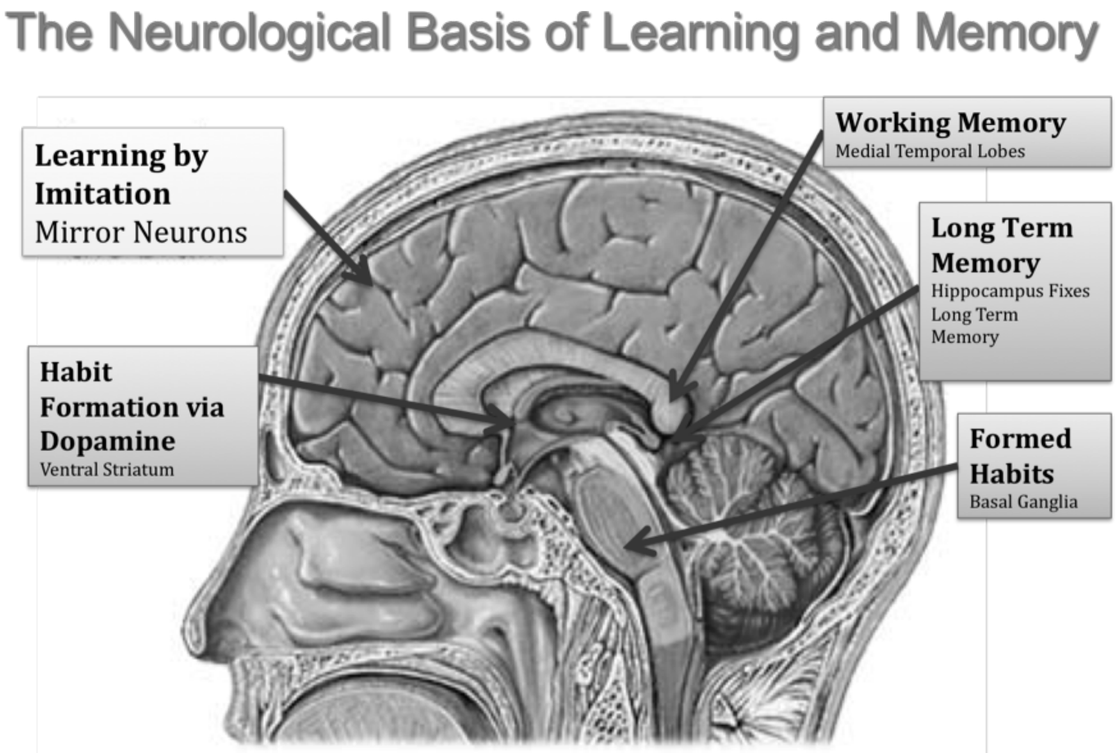
As we have said before, the human brain is bombarded with billions of bits of sensory information every minute, most of which is deleted for lack of perceived relevance to our survival. In this process, long-term memory is primarily reserved for information deemed useful for survival or success and for information with strong emotional connotations. Therefore, for  adult students, teachers must create an environment that encourages the brain to build connections between the skills and materials in the course and the students' own "survival" and emotional wellbeing. While incorporating emotional connotations into the instruction requires both talent and diligent work by the instructor, the simple ability to communicate "how and why" the material is important to the students can build relevance and emotional attachment with the content of the economics course (Karpicke and Roediger 2008).

As a result of our understanding of brain function, we can conclude that to further encourage conversion of information from short-term to long-term memory, course content should be broken down into manageable segments which can be tested repeatedly, to encourage "fixation" to long-term memory. One simple strategy is to design courses with multiple tests, instead of only one mid-term and one final exam (Karpicke and Roediger 2008). Testing may take the form of homework assignments, quizzes, debates, games, or review sessions. Adding personal motivation, anecdotes, and real world examples provides the emotional component necessary to bind this information to the long-term memory.

In summary, for deep learning and long-term memory of any subject, it is imperative to incorporate new information gradually, repeat it in timed intervals, recall it multiple times and attach emotional importance to it via humor, peer-to-peer learning and real world relevance to the students' careers.

**The Neurological Basis of Learning and Memory**

Figure 3




In a very real sense, our long term memories are actually who we "are". Observations of Alzheimer patients proves this. However, there are *only* two reasons our brain decides to remember something long term. These are multiple recall ("This must be useful".) and/or strong positive or negative emotional valence ("This must be important for survival".). We will present evidence of this below, but as a simple example of emotional valence, we all know some adult who is still afraid of spiders or dogs due to a negative childhood experience and, of course, the Post Traumatic Stress Disorder ("PTSD") of our returning veterans is familiar to all of us from media coverage.

Long-term memory formation is dependent on the strength and frequency of interaction with certain information, which the brain recognizes as important due to repeated activation of the same synapses. While the actual processes occurring inside our brain during information retrieval are unconscious and therefore inaccessible to us, we can control the way in which we interact with information, thereby "signaling" the hippocampus to fix it in long-term memory. As we mentioned above, initial consolidation to long-term memory occurs about nine hours after the first exposure, during rapid eye movement sleep ("REM" sleep)(Euston et al. 2007). Also during sleep, any weak synaptic connections are reset and lost in order to prepare the brain for the next day's information and social interaction onslaught. We cited above a number of studies showing that long-term memory is formed during REM sleep. We will add here two recent studies that have proven this at the level of actual brain neurons. Bushey et al. (2011) and Donlea et al. (2011) have recently proven that no long-term memories are formed without sleep and that without sleep all short-term memories are erased! Both these teams worked at the level of individual neurons in the brains of *Drosophilia* (fruit flies).

In the short-term, for the connections retained in the working or short-term memory, the brain uses a "library method" to retrieve information for up to a couple of days: it can "pull out" an entire volume from the shelf. For information actually retained for more than a couple of days, the brain redistributes information to the various areas that originally processed it, the visual cortex, the auditory cortex, the language cortex, etc. So, a long-term memory does not actually "exist" anywhere, but is distributed throughout the brain. When remembering, the brain will reconstruct the memory from various locations using a "crime scene reconstruction method". When this reconsolidation happens, each segment of the information happily bring along its new friends, information with which it is connected while sharing residence in the visually, auditory, olfactory, or other specialized brain areas (Medina 2008, 128). However, this process of reconstruction ("re-consolidation") always changes the memory each time it is recalled, sometimes, unfortunately, in very profound ways. This is why crime scene eyewitnesses are almost completely unreliable by the time of the trial.

**Empirical Evidence for teaching Protocols That Improve Long-Term Memory**

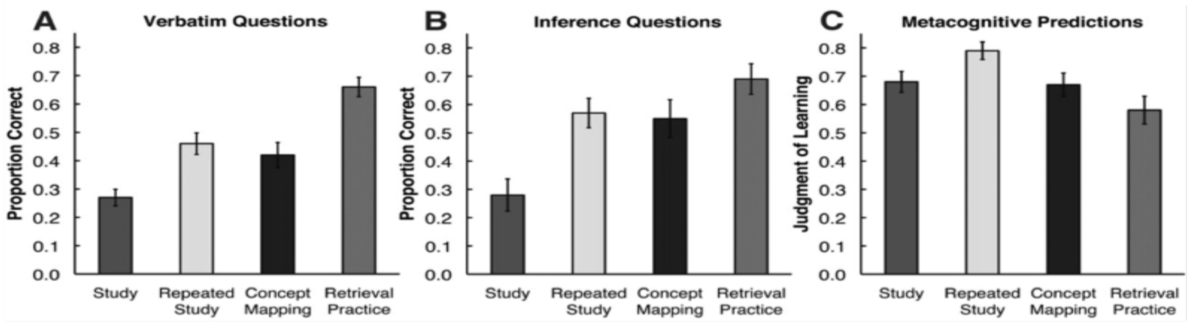
Research shows that to improve the quality of long-term memory, encoding should be an elaborate process, engaging multiple parts of the brain, much like a multimedia presentation. These elaborative learning activities are already central to contemporary education practice and one of the most highly regarded forms is "concept mapping" (Novak 2005; Nesbitt and Adescope 2006). In concept mapping, students construct a diagram in which nodes are used to represent concepts and links connecting the nodes represent relations among the concepts.

In addition, there are a number of ways to improve retrieval. First, retrieval is improved by replicating the conditions surrounding the original encoding. As an example, students should attempt to study in an environment much like the one used for testing: a quiet room, no sensory distractions, and a focused mind. However, recent research has shown that using the same study location each time does not matter. As a matter of fact, switching physical locations for studying, actually appears to help encode the information more elaborately, thereby aiding retention.

Second - and most important - the recent groundbreaking work of Jeffrey Karpicke and colleagues (Karpecke et al. 2007, 2008, 2010, 2011) has shown that repeated practice in retrieval of information produces significantly more learning than either repeated study or elaborative study using concept mapping. In Karpicke's most recent experiments (2011), he and his colleagues had undergraduate students study a science text under four conditions. The first condition was a single study session. The second group studied the text in four consecutive study sessions. The third group was taught concept mapping and, following the initial study period, used it to create a concept map while viewing the text. The final group studied the text and then practiced retrieval in a free recall test. The last group did this multiple times, but the total time period for the processes in each case was the same. The results of this first experiment, assessed a week later by both verbatim questions and inference questions, are below. Multiple retrieval proved superior to all other methods of learning.

Figure 4

**Fig. 1 Results of Experiment 1.**

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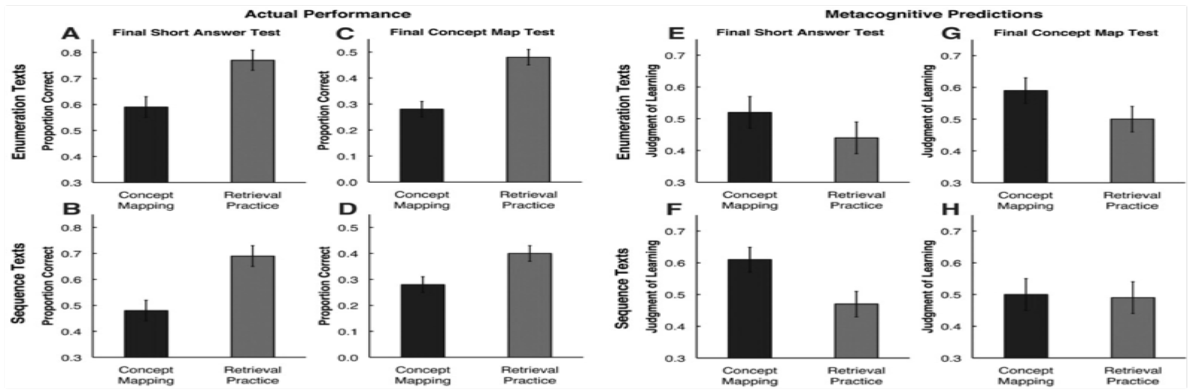
(The experimenters also asked the student to predict which method they thought would enable them to learn best, and these results are shown in graph C above, which shows that students guess wrongly as to what learning method works best for them.)

To further test the robustness of their results, the experimenters then used two different types of science texts, one that simply describe a list of concepts (“enumerative text”) and a second text that described a continuous and ordered series of events in a process (“sequence text”). The subjects (N = 120) were divided into those that did concept mapping and those that did retrieval practice. One week later, the students were randomly divided into a first group that took a short answer test and a second group that created concept maps in the exam.  The results are shown below. Surprisingly, even those that did not study by concept mapping did better in the concept-mapping exam than those who studied by concept mapping.

Figure 5

Fig. 2 Results of Experiment 2.

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## Policy Implications of the New Science of Learning

As we mentioned above, there have been a number of recent studies that provide strong evidence for the value of using our understanding of the brain to inform teaching protocols. The work of Deslauriers et al. (2011) and Karpicke et al. (2008, 2010, 2011) are some of the most important. These studies are being driven (and funded) in the interest of public policy in the areas of science, technology, engineering and mathematics (the "STEM" disciplines). The goal of this research is both to increase student achievement in these disciplines relative to our global neighbors but also to recruit and retain disadvantaged minorities in these "STEM" disciplines.

The most rigorous, comprehensive and compelling research in this area is the work of Haak et al. (2011). These authors worked with a large number of introductory biology classes at the University of Washington that contained hundreds of students – some classes had 700 students. They compared three teaching protocols: 1) standard lecture format; 2) a "Moderate-Structure Class" that involved lectures, a few daily multiple choice "clicker" questions and a peer-graded five question weekly exam; 3) a "High-Structure Class" with no lectures, but all active learning in the form of pre-class reading, pre-class quizzes, extensive informal group work in class and a weekly peer-graded practice exam. The moderate-structure class, as expected and predicted by other research, increased performance in all students over the lecture-based class. Even more compelling, however are the results of the high-structure class. This learning protocol increased all student performance over and above the moderate protocol but also decreased the achievement gap between non-disadvantaged students and disadvantaged students by forty-five percent!

We should add here that the introductory biology course was specifically chosen because out of all the STEM classes, it showed the highest achievement gaps for disadvantaged students. The authors hypothesized that this was because the exams in this course test higher-order cognitive skills that disadvantaged students are unprepared for. To examine this hypothesis, Haak et al. ranked the biology exam questions according to Bloom's taxonomy (Anderson and Krathwohl 2001) and found they were higher order and actually increased in level over the duration of the course. The high-structure class, on the other hand did not increase performance in simple rote memorization answers ("information transfer") but only in problem-solving and other higher-order learning. This deeper understanding is, of course, the goal of all educators.

In addition, a very important study just released by the National Science Foundation titled, "Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics" has good news for all teachers (Mervis 2011). This study, which focused on a number of high schools specifically devoted to math and science education, found that the methods and training of the science and math teachers is what makes the difference in science achievement, not the schools. So, the implication is that we can all create high-achievers in science.

Combining the new science of learning with research on brain biology reinforced our determination to change teaching in ways that improved student learning. While these strategies are not specific to teaching economics courses, we nonetheless applied and tested them sections of Microeconomics, Macroeconomics and Economics for Life.

*Opportunities for Multiple Retrieval and Deliberative Practice* – These are the most significant changes we have made to our teaching protocol. We use numerous methods to cause students to engage in multiple retrieval and deliberative practice. First, students must do on-line homework for each chapter (Myeconlab). Next, we have four exams instead of two in the semester. They are administered according to the logical grouping of chapters in the textbook. One action we think is important for student review is that the students hand in an answer sheet and leave the exam taking the exam with them and a copy of the correct answers so that they will review the material (which they do immediately). Further, we offer two extra credit exams after the material covered in a mid-term for the most important chapters in the book. These are take-home, open book and students are allowed to work in teams. (Each student hands in his own answer sheet.) Students receive two points added to their final grade if they score 80% or better on the extra credit exam. Prior to every exam, we have a workshop in class during which students work in groups of two on a practice mid-term exam. Also, the Teaching Assistant holds a review session outside of class before each exam.

Further, we post all our Power Point Presentations on-line on Blackboard and use Class Capture to post streaming videos of every lecture on Blackboard. It is clear to us that students take advantage of this material for review.

*Understanding vs. Familiarity* – Of course, the *first* condition precedent for learning is for students to gain a better understanding of the subject matter by connecting it with other facts and fitting the new content into an existing memory network. A student who is a passionate baseball fan will find it easier to memorize the statistics of their favorite team because of the already extant visual and auditory information and emotional connections to which the new statistics can be attached and embedded. This multimedia analogy has been demonstrated with rat experiments: when it comes to spatial memory, the 'place neurons' in the brain create a mini-replica spatial map. When rats are running in a familiar maze, hundreds of thousands of place neurons in their brains fire exactly at each spot in the maze and only at that spot, signifying to the rat exactly where it is in the spatial map (Aamodt and Wang 2008). Similarly, new material that can be placed in a "context map" in the brain is both absorbed more quickly and remembered long term. This is because in the brain a memory is actually a *system* of neurons firing together. (Neuroscientists say, "Neurons that fire together, wire together".)

Students often mistake familiarity with understanding. After having read a textbook chapter, the average student can look at the review questions at the end of the chapter and get an immediate feeling that they know the material, since they will recognize words they encountered in the chapter. Without taking the time to actually process and write the answer to each question, this recognition is often just familiarity and not true understanding.

*Teacher vs. Coach* - Stepping outside of the formal role of teachers allowed us to learn about students' perception of personal beliefs, values, and preferences. As coaches, we had the opportunity to talk to students about the things that "work" for them—what helps them get better results in the economics courses. We spent many office hours asking questions, listening, and offering a non-judgmental shoulder when students griped about the difficulty of grasping concepts that apparently had nothing to do with their major, their career, and their life. Students used to routinely come to us during office hours and say, “I don’t know why I got such a bad grade, I really studied a lot for this exam”. Virtually every time we explained the correct way to study, student scores improved. As a result of these successes, we now give a Power Point presentation of the methods presented in this paper to every section in the first week of class, as part of the introduction to each course. This helps to engage the students in “meta-cognition”, that is, thinking about thinking, about how their brain works and how they learn best.

*Relevance and Emotional Investment - T*he more elaborately the brain encodes information, the more it will be remembered. Lectures, student assignments, and even quizzes that approach economics in elaborate, meaningful and contextual ways will naturally help with information encoding. If the student forms a good first impression of a concept, theory, or process introduced in class, they are more likely to be interested to invest time and emotion into learning more (Medina 2008). If, according to Hollywood legend, movie producers have three minutes to grab the audience attention, teachers have about thirty seconds until students tune out if the lecture topic is boring or if they perceive it to be irrelevant to their goals.

*Tell Stories that Illustrate the Main Points* – In order to attach emotional meaning to the information, incorporate dramatic analysis – why was it funny, tragic, unexpected, or wise? Remind students that good knowledge of economics will help them be great decision-makers. Bring frequent examples where people succeed because of their deep understanding of economics. One of the authors enjoys scheduling “Freakonomics Fridays” which are 10-minute presentations of thought-provoking applications of economic principles to everyday situations and unusual topics. Numerous short You-Tube videos are available to illustrate economic realities. Additionally, we have been screening the Academy Award winning documentary “Inside Job” in our classes. The students find it riveting.

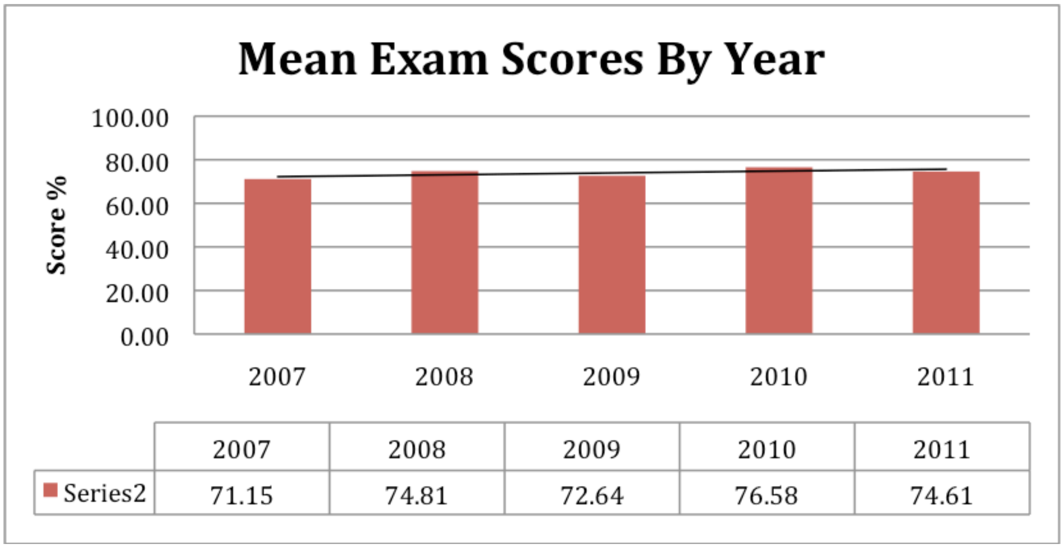
*Challenge Students via Active Learning* – Peer discussions, problem-solving, 10-minute presentations of group projects. Consider including peer learning exercises regularly. Even in large sections, this can take the form of each student turning to the colleague to their left to explain, for example, the supply and demand graph. Peer-to-peer discussions involve huge amounts of active social and emotional brain activity – one of the two critical keys to the formation of long-term memory. We cannot emphasize this enough: social learning must be a constant element of the learning experience. Further, as we have said above, teaching students to think about and reflect on how they learn best (termed "meta-cognition") also boosts learning (Flavell 1979).

As a final note, we intend, during the next academic year, to teach an entire semester's Macroeconomic Principles class using the teaching protocols employed by Haak et al. (2011), which we have described above. We will then compare the results in terms of student exam grades with the student exam grades using our current teaching methods.

## Our Empirical Results

One of the authors of this paper is a veteran at teaching Macroeconomic Principles classes. His teaching schedule has routinely included two to three Macro Principles sections in the Spring of each semester, thus we were able to look at his historical record from Spring, 2006, to Spring, 2011. These classes were taught at a major research university located in the inner city. In the Macro Principles classes, the students are composed of freshman, mainly business students, but there are also secondary education, journalism and liberal arts majors. Additionally, this university has one of the most diverse student populations in the nation, along with a significant number of disadvantaged students. Therefore, the combination of the diverse student population, the first-time exposure to economics and the fact that the vast majority are taking Macro Principles as a required course creates quite a challenge for the instructor.

The co-author gradually introduced some interactive exercises beginning in 2008, (especially on-line homework via Myeconlab) but it was not until Spring, 2011, that he added deliberative practice workshops prior to each exam, review sessions by his Peer Teacher and made tutoring available by his Teaching Assistant. We present below the mean exam grades for each year noted. We analyzed the mean exam grades for each year instead of the final course grade because each course has four to six exams throughout the semester whereas the final course grade includes some grades for special assignments and points for completing the Myeconlab homework. We felt that the exams would be a better measure of the students' grasp of the basic course material.




As you will see, there was an increase of the mean scores on the exams after Myeconlab was introduced but not an enormous increase. However, we were also able to analyze all the student evaluations for all the Macro Principles courses taught by the co-author in the Spring of each year from 2006 to 2011. Each Spring's course load included either two or three sections of Macroeconomic Principles (The number of sections is noted on the chart). The student evaluations are analyzed by computer and contain approximately fifteen questions that the students react to, graded one ("strongly disagree") to five ("strongly agree"). Apart from the demographic questions, the questions relevant to the evaluation of the instructor are:

1. Before enrolling, my level of interest in the subject matter of this course was:
2. The instructor clearly explained the educational objectives of this course
3. The instructor was well organized and prepared for class.
4. The instructor was conscientious in meeting class and office hour responsibilities.
5. The instructor promoted a classroom atmosphere in which I felt free to ask questions.
6. The instructor provided useful feedback about exams, projects, and assignments.
7. So far, the instructor has applied grading policies fairly.
8. The instructor taught this course well.
9. The course content was consistent with the educational objectives of this course
10. The course increased my ability to analyze and critically evaluate ideas, arguments, and points of view.
11. I learned a great deal in this course.

We show below the student evaluations (on a 1 through 5 scale) for virtually all his Macroeconomic Principles sections from 2006 to 2011.

**Student Evaluations in Macroeconomics Principles Courses**

**Spring, 2006, to Spring, 2011**

| Student Evaluation Question | Depart. | Spring 2006 | Spring 2007 | Spring 2008 | Spring 2009 | Spring 2010 | Spring 2011 |
|---|---|---|---|---|---|---|---|
| | Mean | | | | | | |
| Scale: 1 (Lowest) to 5 (Highest) | (Spring 2011) | 2 Sec. | 3 Sec. | 3 Sec. | 2 Sec. | 2 Sec. | 3 Sec. |
| | | | | | | | |
| 1. Prior Level of Interest in Macroeconomics | 2.1 | 1.8 | 1.7 | 1.7 | 1.8 | 1.9 | 2.1 |
| | | | | | | | |
| 2. Explained Educational Objectives | 4.1 | 4.1 | 4.3 | 4.1 | 4.6 | 4.1 | 4.6 |
| | | | | | | | |
| 3. Instructor Well-Organized and Prepared | 4.2 | 4.2 | 4.3 | 4.1 | 4.6 | 4.2 | 4.6 |
| | | | | | | | |
| 4. Conscientious in Class & Office Times | 4.2 | 4.2 | 3.3 | 4.1 | 4.6 | 4.5 | 4.6 |
| | | | | | | | |
| 5. Instructor Welcomes Questions | 4.2 | 4.3 | 4.2 | 4.3 | 4.4 | 4.4 | 4.6 |
| | | | | | | | |
| 6. Useful Feedback on Exams and Papers | 3.9 | 4.3 | 4.3 | 4.1 | 4.3 | 3.9 | 4.3 |
| | | | | | | | |
| 7. Instructor Graded Fairly | 4.2 | 4.3 | 4.3 | 4.1 | 4.4 | 4.3 | 4.7 |
| | | | | | | | |
| 8. Instructor Taught Course Well | 3.9 | 4.1 | 4.1 | 3.8 | 4.4 | 3.9 | 4.5 |
| | | | | | | | |
| 9. Content Consistent with Objectives | 4.1 | n/a | n/a | n/a | 4.3 | 4.1 | 4.5 |
| | | | | | | | |
| 10. Course Increased My Analytical Tools | 3.9 | 3.6 | 3.8 | 3.8 | 4.1 | 3.8 | 4.3 |
| | | | | | | | |
| 11. I Learned a Great Deal in the Course | 3.9 | 3.7 | 4.1 | 3.7 | 4.1 | 3.9 | 4.3 |

A few conclusions strike us. First, as the answers to question one shows, the students show a distinct lack of interest in the course at the outset. Despite that fact, we see a positive and significant increase over the time period in the evaluation of the teacher. We believe this is due to slow but increasing introduction of some deliberative practice and interactive learning to the courses.

However, the sections in Spring, 2011, show a dramatic and positive increase in evaluations of the instructor (especially as compared to the departmental means). However, the most amazing change in the evaluations in the Spring of 2011 is in the answers to questions ten and eleven. There is a huge jump in students' agreeing that the course increased their analytical skills and that they learned a great deal in the course. The only major change in the teaching protocol in the Spring, 2011, semester was the introduction of workshops in deliberative practice before each exam and review sessions before each exam. We believe this made a substantial difference in student learning.

## Conclusion

This paper attempted to review some of the brain biology aspects with immediate applications for teaching and learning in the college classroom. Research findings were interpreted through the filter of classroom communication between teacher and students. Finally, the authors suggested strategies to improve the cognitive interaction in the classroom. Understanding how the brain learns will allow us to use this knowledge to become better teacher and better students. If you will excuse the pun, to a very large extent, "the brain has a mind of its own" and this article acknowledges the limitations imposed on teachers by the need to allow students to discover how and why they learn. More details and excellent recommendations can be found in two books and one article we very much enjoyed reading: *Brain Rules* (Medina 2008), *What the Best College Teachers Do* (Bain 2004) and Teaching and Learning Strategies that Work (Hoffman and McGuire 2009). The many studies we presented show that the practical suggestions we have given really *work.* We recommend them to you.

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