A BLUELINE PARTNERSHIP WITH BRAINX

Integrating Neuroscience and Education to Produce a New Framework for Achieving Mastery in Online Learning Environments

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Overview

The first part of this paper examines how neuroscience research, when combined with education research, can provide a useful framework for understanding how students learn information to the level of mastery. For the purpose of this paper mastery is defined as the long term ability to effectively use information to produce a desired result.

The second part of this paper examines how this framework for mastery can be used to design an effective online learning system. The research was used to design the BrainX System, which accelerates the process of achieving mastery for all learners.

Based on interviews with 455 top educators, the Grunwald Research Organization concluded that the biggest opportunity for computers to add value to the education process is to provide personalized instruction that meets the individual needs of every learner (Grunwald 2004). In so doing, the computer can provide the benefits of a one-to-one model of instruction coupled with research based mastery learning strategies.

Models of Instruction

The public school classroom and most online learning systems employ a one-to-many model of instruction. All students hear the same lecture or are presented with the same online learning content at the same pace, regardless of their prior knowledge of the subject matter or leaning ability. Research demonstrates that a one-to-one model of instruction, often referred to as individualized instruction, is superior to the one-to-many model. For example:

1. By using individual instruction learners can increase their learning speed and decrease the time it takes them to complete a course of instruction. In many cases students can complete classes three to seven times faster if they receive individualized instruction versus group classroom instruction (Gettinger 1984).

2. Questions are one of the most powerful learning tools, yet in most classrooms the average student only asks 0.1 questions per hour (Grasser & Person 1994). Individualized instruction gives each learner the opportunity to ask or to respond to as many questions as are necessary to facilitate the learning objective. The result is that in individualized instruction environments learners end up asking or answering as many as 120 questions in an hour.

3. Students in individualized tutoring environments may exceed the performance of students taught in a classroom by up to two standard deviations (Bloom 1984).

Problems with Instructor-Based Individualized Instruction:

INSTRUCTION:

Unfortunately, funding makes it impractical to provide individualized instruction in a public school. In addition, the effort required to properly implement the best one-to-one strategies puts a huge burden on a teacher. For example, proper implementation of spaced memory reactivation requires extensive, ongoing data analysis of each student's records. This analysis will determine the ideal day for the next study session and the best content for the student to study in each study session.

Computers are capable of providing a true one-to-one environment and implementing labor intensive strategies like spaced memory reactivation. However, the effectiveness of computer based learning is dependent on good software designers who are careful to incorporate all of the research proven strate-

Understanding is just the first step on the path to mastery.

gies for accelerating learning and avoid learning detractions (Fletcher 2003).

Software designers must begin with a clear understanding of the goal. The goal of learning software is to use a one-to-one approach to take each student from their current knowledge and skill level down the fastest and most efficient path to mastery. For the purpose of this paper mastery is defined as the long term ability to effectively use information to produce a desired result.

Learning a Complex Process

Consider the process the brain uses to master a skill like hitting a baseball with a bat as an example of mastering a subject. Typically, the learning process begins by giving children instruction and actual demonstrations on how to stand, hold the bat and properly swing. Children quickly understand what they should do and can even give a verbal recap of the skill just learned. In other words, they have memorized the facts. But stand the child up to the plate immediately after instruction and pitch to the child. The results will be a disappointed child who misses almost every pitch.

Why can't the child hit the ball immediately after instruction that they clearly understood? Understanding is just the first step on the path to mastery. The additional steps take time and require tremendous amounts of processing in the brain. To observe this process fast forward a few weeks in the life of the child when the child practices hitting the ball on different days. The brain actually writes, tests and then rewrites new information processing systems. So when photons reflecting off a speeding ball hit the child's eyes, the information is sent to the visual cortex where it is processed and then sent to the pattern recognition parts of the cortex. The changing patterns are recognized as an approaching ball which is when the new brain processing takes place. In a fraction of a second, the cortex calculates the speed of the ball and anticipates when it will cross a point in space over the plate. This information is sent to the motor cortex, and the cerebellum which work together to send instructions to the legs and feet to adjust the stance, to the hands to grip the bat tighter, and to the arms on exactly how and when to swing.

There is no program or any programmer that could command a robot to walk up to an uneven piece of ground in front of a plate, and using only visual (video) information, hit a pitch that it has never seen before. Yet, the brain of the average 7 year old is capable of writing this program.

The brain's ability to write programming for processing information is similarly engaged when a student learns a group of math facts but still cannot use those facts to solve new problems. Over time the brain uses the understood facts to write programming that allows the student to look at a math problem and instantly know the correct order of operations that is needed in order to accurately solve the math equation.

This understanding of the brain's ability to write new programming calls for a new metaphor for learning that is rooted in programming.

Knowledge is Built vs. Programming Metaphor

For years cognitive scientists and educators have used a metaphor that knowledge is built to explain learning to students. This gives the impression that the result is a structure. In most cities students have very little exposure to the actual construction process. They experience buildings as structures that are built one time and last for a long time. The built metaphor may cause students to ask if I understand this knowledge today the building must be complete, so why do I need to rebuild (study) the structure again tomorrow and the next day and the next week? This may be one reason that the vast majority of students dramatically overestimate how much they will remember from material they learned on a specific day.

For students, things that are built are made up of physical, tangible parts that are combined to form the structure. The structure does not contain anything that was not a physical component. This may lead to the misconception that knowledge is the accumulation and proper combining of memorized facts.

In contrast to construction, today's students have lots of experience with programs – they see them start out with version 1 and get better over time as new, more powerful versions are released. They understand that the programs use input - their key strokes or mouse movements - simply as a part of the programming's processing. They experience facts - a car in a video game or a rule for how many levels must be achieved before winning- as just an input used in the programming, not the program itself.

The programming metaphor helps students understand that learning is a process whereby the brain writes a program for processing thought and input to produce various results. Knowing that programs get better over time helps students understand that they have to work repetitively over time to refine their knowledge and skills so that their brain will function more efficiently.

Challenges of Online Learning

The challenge of creating online learning systems is to design a program that starts a student's brain with the correct input, at the right time, so that it takes the student down the fastest path to mastery. For educators and programmers, this process begins with an understanding of memory, the physical structure of the brain, and the role of emotions in learning.

Memory

The understanding of memory in the human brain has changed radically in the last century. Early theorists thought of memory as a warehouse of stored information (Eichenbaum & Cohen 2001). This warehouse was thought to be located in a specific region of the brain. This theory held that memories were stored the brain like facts are stored in books. Memories would be written in specific regions where they could be searched and accessed like looking up a reference item.

In the first half of the last century, many researchers thought of memory as a switchboard (Eichenbaum & Cohen). This view states that different parts of the brain are hardwired to other parts. When a stimulus is received it connects a circuit and produces a predetermined response. This view was popular with early behaviorists who believed that behavior could be changed by rewiring these connections through conditioning.

Lashley (1963) demonstrated the error of both of these beliefs by teaching a 'maize solution' behavior to rats to the point where the rats were experts at navigating the maize. Then he made cuts in different parts of the brain in an effort to disconnect the memory center from the response or the stimulus response circuitry. Despite numerous configurations of the experiment, Lashley's subjects were still able to perform the learned behavior. This demonstrated that memory was not located in one place (warehouse theory) nor was there one connection between a stimulus and an action (switchboard theory). Modern brain scans confirm that while different parts of the brain have specialties, memory is spread throughout the brain, leading to the question of types of memory and an explosion of "term coining."

Terms for different types of memory include short term, long term, working, declarative, non-declarative, etc. Each of these terms imply that memory is a stand alone function that can be identified and defined. Recently, Eichenbaum and Cohen have proposed that memory is a sub-function of information processing. Therefore, there could be as many different types of memory as there are information processing functions (Eichenbaum & Cohen).

The Eichenbaum-Cohen theory is supported by brain scans that demonstrate that learning produces physical changes in the brain. The area of change is dependent, in part, on the area where the learned information is processed. For example, taxi drivers in London have been shown to develop larger hippocampuses, the longer they are on the job (Burgess & O'Keefe 2003). The hippocampus is the location where the brain processes physical directions that are involved in finding ways to get from one location to another. It is not just that a map is stored. In a feat of complex processing, the brain actually writes a sophisticated program that allows the driver to account for a number of variables like traffic conditions, weather, and special events in the city, and then figures the best route from their current location to where the customer wants to go. In addition, the brain develops a calculation system to estimate the time it takes to make the trip.

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The Physical Structures in the Brain

This physical part of the human brain has many parts and structures. The cerebrum is the outer part of the brain that looks like a folded mushroom. It accounts for 85 percent of the total weight of the brain and is the source of all higher thinking functions. It is also the location of memory, although there is no specific portion of the cerebrum that is dedicated solely to memory.

The limbic system is located in the center of the brain under the cerebrum and is the primary center of motivation and emotions. It is also a critical component for the formation of memories. The major components of the limbic system are the limbic cortex, hippocampus, and amygdale.

Even though different parts of the brain have different functions, at the cellular level, each of the parts are made up of the same types of cells. These are neurons and glial cells.

Neurons have three major components which are:

1. The cell body
2. Dendrites which receive information and carry it to the cell body
3. A single axon which transmits impulses away from the cell body

Even though neurons stimulate each other and work together to produce incredibly complex functions, they never actually touch in the way a wire touches a connector. Instead, neurons interact with one another by sending chemicals between the microscopic gaps between the axon of one neuron and the dendrite of another neuron. These gaps are called 'synapse' and they are extremely important to memory.

When a synapse is initially stimulated there is a short term increase in efficiency which lasts several minutes and then fades. This increase in efficiency is called 'short term potentiation'. If the same synapse is repeatedly stimulated, the synapse will split to form additional synapse and this increases the efficiency of the connection for a longer time period (Colicos & Goda 2001). This durable increase in efficiency is called 'long term potentiation'.

The brain contains a billion synapses in every cubic centimeter of brain tissue. Large groups of neurons create synaptic connections that are called 'neural networks'. Like using a keypad to enter a phone number, these neural networks, when properly stimulated, produce memories and thoughts. So stimulating one group of neural networks produces the thought of a green apple and another a red apple.

However, this model of neural network stimulation has one problem. It works well when there is a relatively close connection between the neural networks but, what if the networks are too far apart for short term potentiation to occur? Until recently, this question stumped neuroscientists. Now it is believed that a long overlooked cell is the answer. Astrocytes (a.k.a. glial cells), which outnumber neurons by a factor of nine to one, were originally thought to function solely as support cells. In this role they insulated and supported neurons to make them more efficient, by providing nutrients and oxygen.

An advantage that astrocytes have is they can commute over relatively long distances within the brain (Fields 2004). An analogy is that neurons act as telephones that communicate through hard wired synaptic connections in the brain. If this is true, then astrocytes are the brain's cell phone network that can broadcast by sending chemical signals only to other astrocytes that have the their receptors properly set to receive the specific signal. This means that astrocytes in one part of the brain can activate astrocytes in another part of the brain to coordinate the activation of different neural networks.

Astrocytes in an individual's brain may someday also give us a better understanding of creative genius. For years, scientists that have studied Einstein's brain have been frustrated by its lack of any remarkable features. This may be because they were looking for the wrong type of cell. Most experiments compared the number of neurons per centimeter in Einstein's brain to samples of brain tissue taken from the average population and found little difference. However, it has recently been discovered that Einstein's brain contained an unusually large number of astrocyte cells. This might account for his ability to connect seemingly unconnected items to construct new ways of looking at complex issues.

Putting This all Together for Learning

Memory begins with some type of sensory input. In the case of academic learning, this input usually enters the brain through the visual and/or auditory systems. Teachers and textbook authors have long recognized that the goal of instruction is to help the student gain an initial understanding of material by connecting new information with a student's existing information. But, what does this initial understanding look like in the brain?

Candy Apples

When a teacher describes something that is new to a student – say a candy apple, they describe it in terms that the student knows which stimulates existing neural networks. In this case, the brain's network of a green apple is stimulated along with the brain's network of red candy and, before long; the brain connects the two networks to form an entirely new network that is a combination of the two existing networks. Each network can be stimulated on its own, producing the thought of a green apple, a stick, or red candy. On the other hand, they also can be stimulated together to form the memory of a candy apple.

These neurons, astrocytes, and synapse are not the 'candy apple' memory itself; they are simply the hardware component of memory. There is a "software" component that causes us to be able to see a mental representation of the candy apple in our mind. The mind itself has not been physically located in the structures of the brain by any researchers to date.

As stated earlier, synapses that are stimulated together temporarily improve the efficiency of their connections (short term potentiation). The same is true when neural networks stimulate large groups of synapses that connect to form a new thought or memory. This newly formed efficiency of connection between neural networks is called a 'memory trace'. Just like individual synapses, the multiple synaptic interactions that are stimulated to form the memory trace fade if they are not properly reinforced. This is why initial understanding of material is not enough.

The Role of Emotions

Emotions are a force multiplier when it comes to memory formation. In other words, if a learner is intently focused on the material being studied or emotionally stimulated by the material, the strength of the memory trace will be greatly enhanced.

Even the emotional value of specific words has an impact on memory. Words with emotional impact are much more likely to be remembered than words with neutral impact. In addition, the context of the words (the rest of the sentence or paragraph) is much more likely to be remembered when the sentence contains emotionally charged words vs. emotionally neutral words (Kensinger & Corkin 2003). This finding is important because it suggests that emotions serve to increase not only the likelihood that an emotional experience will be remembered, but also the amount of details that one will remember about that lecture or reading.

Emotions gain their memory enhancing power from a small part of the brain called the ‘amygdale’, which releases special memory enhancing hormones when it is stimulated by emotions. People often need to remember lessons that produce strong emotional reactions because not remembering the lesson might result in harm or death. For example, a child who runs out in the street and is frightened by a car that shrieks to a halt, barely missing him. The child bursts into tears from the fear that the experience produced. The hormones released into the brain by this negative emotion produce a strong memory that running into the road is bad.

Stage One: From Memory Trace to Long Term Memory

We know that the formation of long term memories requires the physical change of an enormous number of connections. Like the growth of a muscle, these changes take time. In fact, they sometimes take years to fully form (Eichenbaum & Cohen). However, there are still some questions surrounding where and how a memory trace is stored when first activated to form an initial understanding, and when it is written into a new process and stored in long term memory. Some researchers believe that a memory trace starts out in one part of the brain, the hippocampus, and then is transferred to the cortex (LeDoux 1998).

Howard Eichenbaum of Boston University, a leading researcher in this field, rejects the idea that memories start out in one part of the brain and are transferred to another. He believes the following:

> *‘I think of the information as always in the cortex and “indexed” or otherwise connected to other information in some way by the hippocampus. So, the cortex always has the items stored as modifications of its perceptual (or other) representations, and the hippocampus has the indices. For some time the hippocampus is required to link the items in episodic memories. Over time, the links are established in the cortex itself, so the hippocampus is no longer required.’ - Howard Eichenbaum*

Stage Two: Integration Into Information Processing: Long-Term Memory

Over time, the memory trace is reworked and configured so that it can be incorporated into the brain’s processing system and stored in long-term memory. Much of this reconfiguration process starts during the first night’s sleep after the initial understanding has been formed. This contradicts early research on sleep, which failed to show a connection between sleep and the formation of long term declarative memories (Shebilske et al. 1999). This error was due to the researchers focus on the rapid eye movement phase or REM sleep.

In a study proving the connection between sleep and memory, one group of participants learned a new task and was kept awake for 8 hours prior to a test; they showed little or no improvement in retention when taking the test. Another group was

allowed to sleep in the 8 hour period after initial training. This group showed a significant increase in their test scores (Marquet, Smith & Stickgold 2003).

Researchers have now determined that sleep is critical to the formation of long term memories of declarative information (academic information is one form of declarative knowledge). However, instead of REM sleep being the critical component, it is Slow Wave Sleep (SWS) that affects declarative memory. It appears that while a person sleeps the hippocampus reformulates the memory. This seems to aid in the memory consolidation process, presumably by making the memory easier to integrate into existing neural networks.

The real value comes from rehearsing the verse on several different days.

Another critical factor in sleep is the uptake of acetylcholine. When people are awake, neurons in the brain secrete acetylcholine. As this chemical builds up in the brain, it slows the thinking process and makes people feel tired. One of the reasons a cup of coffee in the afternoon is effective is that it blocks the inhibiting effects of acetylcholine. As people sleep, the neurons reabsorb the acetylcholine which is critical for the consolidation of memories. Students who are given drugs that block the uptake of Acetylcholine during sleep experience a sharp drop in memory consolidation. Two groups of students were taught the same novel material. One group was given an acetylcholine uptake inhibitor prior to going to sleep and the control group was given a placebo. When they were tested, the group that had been given the uptake inhibitor had very little recollection of what they had been taught the previous day, while the control group did quite well on the memory test (Gais & Born 2004).

The need for this reformulation process during the first night's sleep means that there is a limit to the memory's longevity that can be formed on the same day that the memory is learned. For example, learning a poem and rehearsing it a dozen times on the same day is of limited value. The real value comes from rehearsing the verse on several different days. The memory consolidation process requires that a student's existing neural networks be changed to incorporate the new information. This necessitates physical changes to the brain, which require time and repetition to occur. Memory becomes stronger with repetition just like a muscle becomes stronger with repetitive exercise. The brain grows new neural connections in much the same way that a muscle grows new muscle fiber to become stronger. For both the brain and the muscle this physical change takes time, and only so much change can take place during a period of time (Underwood 1968).

The process of consolidating information into long term memory can have three possible outcomes:

1. The process is completed and strong memories are formed.
2. The process may not be completed, resulting in the memory fading away (much like an old photograph fading away).
3. The memory only partially consolidates, with only part of the information recalled (like an incomplete drawing). This is evident in students who study using a set of multiple choice questions with plausible distracters. Often the students remember all of the answer options but forget the cue that tells them which is the correct answer.

Using this understanding of neuroscience, the next step is to look for research studies conducted by education researchers that examine the results of testing different learning strategies with actual students.

Education Research

One of the oldest findings from education research is the power of the 'spacing effect'. The spacing effect helps in the formation of long term memory by using timed intervals between the presentation and re-presentation of material being studied (Bjork 1994; Mizuno 1997; Russo & Mammarella 2002).

There are two distinctly different spacing effects. The first is 'intra-lesson spacing' where material is re-presented in the same study session. Several studies have demonstrated the effectiveness of asking the same question a second time in the same study session. The effectiveness of this strategy is directly proportional to the difficulty the student had in answering the question the previous time it was asked. The more difficult the question was to remember and answer, the greater the benefit of intra-lesson spacing (Shebilske et al. 1999; Mizuno 1997).

'Inter-lesson spacing' generally refers to study sessions on different days, although the term is occasionally used to refer to different study sessions on the same day. Numerous studies have demonstrated the effectiveness of inter-lesson spacing (Shebilske et al. 1999).

The effectiveness of the spacing increases with the increase in the days between study sessions (Bahrick et al. 1993). Researchers tried different intervals of 14, 28, and 56 days. The results indicated that the longer the interval, the greater the retention. For example, 13 re-training sessions spaced at 56 days were able to produce retention similar to 26 sessions spaced at 14 days. In one long term study, students who learned information using spaced study sessions could still remember the material nine years later. Unfortunately, this long term research only had 4 participants so the results, while interesting, are not conclusive.

The best outcome from inter-lesson spacing is achieved if the same set of questions is repeated in each session(Mizuno). This is a departure from traditional programmed learning strategies that continue to change the questions on a given topic. This supports the theory of memory traces because using different questions would create new memory traces, instead of reactivating and thereby strengthening the already forming memory trace.

The key factor determining how well a memory consolidates is in what way, and how often, the memory is reactivated. The best way to reactivate memories is with questions. Extensive research shows that learners who use questions to study dramatically outperform learners who merely re-read information, or use any other type of study technique (Brothen & Wamback 2000; Krank & Moon 2001; Thalheimer January 2003).

Research also shows that the best types of questions to use are fill-in-the-blank and/or short answer format. These types of questions produce a much greater recall effect when compared to multiple choice questions (Glover 1989; Renquist 1983). This effect is probably due to the fact that having to recall the answer causes the brain to reformulate the memory and reactivate the complete memory trace. A multiple choice question simply requires a student to recognize the correct answer.

Research has also shown that multiple choice questions can actually have a negative impact on learning. For a multiple choice question to be effective, the other choices (the distracters) need to be plausible. Once material has been completely mastered, it is easy to reject even plausible distracters. However, in the delicate process of consolidating long term memories, distracters are dangerous. This is because in the consolidation process, the brain is open to additional associations. When the student reads the plausible distracter, the brain cannot help but form an association between the question and the wrong choices. In the emotional stress of an actual test, a student may become confused because he remembers that the wrong choices (distracters) on the test were in some way associated with the question, but loses the cues required to remember the correct answer (Skinner 1968).

Therefore, contrary to the method used by many test prep companies, the best way to study for a multiple choice exam is not to take several simulated multiple choice practice exams. It is rather, to answer questions about the information that will be covered on the test using fill in the blank or short answer question formats. When the student sits for the actual exam they will recall the correct answer and the distracters will appear foreign because they have never before been seen.

Other Research on the Value of Questions in Learning

A technique involving questions that has proven effective at increasing time-on-task for all students is the use of no penalty questions. This means that the questions used during the learning phase do not have a negative effect on the final grade (Garver 1998). One of the best ways to accomplish this is to let the student evaluate their own answers to study questions. They evaluate their answers after being shown the correct answer. Self evaluation gives the student more control over their learning environment, lowers frustration, and eliminates any hint of a penalty.

The important role that emotions play in memory consolidation was discussed in the brain research section of this paper. It turns out that at least two areas of education research also confirm the important role of emotions. These research areas are: Frustration & Control and Self Efficacy.

Frustration and Control

Practice and time spent on task are two of the most important components of learning (Bell & Kozlowski 2002; Brown 2001). Researchers at the MIT media lab used computer based instruction programs to demonstrate the role frustration and control had on learning. The lower the level of frustration and the more control the students felt they had over their learning environment, the more time they spent on task. Students who were given the most control over their learning environment felt the least amount of frustration and spent twice as much time-on-task as students who had little control over their learning environment. (Kort, Reilly & Picard 2002).

Self Efficacy

Motivation can be affected by social affiliation and interdependence (Stevens & Fiske 1995). Motivation is also driven by a learner's belief in their ability to learn (Schunk & Pajares 2002). This belief is referred to as 'self efficacy'. The higher self efficacy a student possesses, the more time that student will spend on task. For example, students with high self efficacy spent more time-on-task when they encounter a difficult problem because they believe they have the ability to learn and solve the problem. Conversely, students with low self efficacy quickly give up on a difficult problem because they believe that they are not capable of solving the problem or learning the material. In short, both of these emotional beliefs become self fulfilling.

The BrainX eLearning System and the Process of Learning

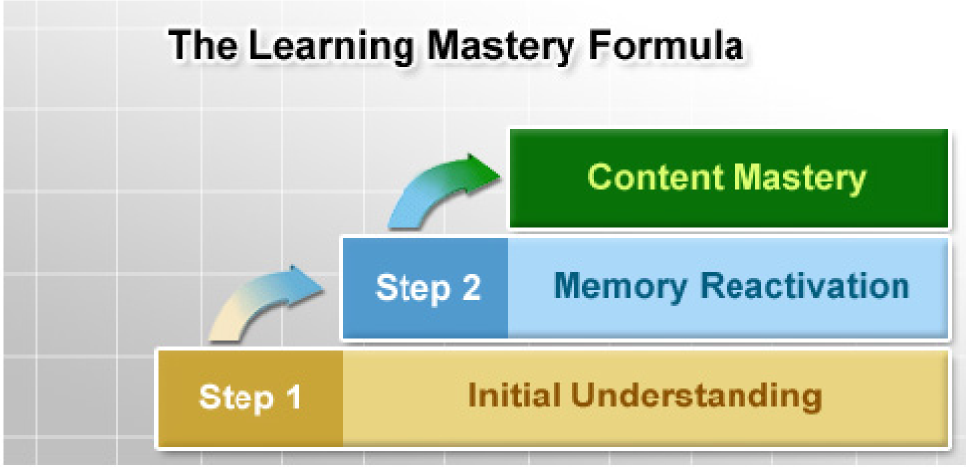
The following is an explanation of how each critical component of the preceding research on the process of learning has been incorporated into the BrainX eLearning System.

Connection and Control

Learners feel in control of their learning environment right from their first minutes on the system when they are given the opportunity to pick their own Personal Digital Tutor from a list of real people who have been digitized. The Digital Tutor options include different ethnicities, gender and occupation. They include professional athletes, TV personalities, teachers and people from other walks of life that are interesting to learners. The Digital Tutor greets the student each day with different messages that reinforce good learning strategies and improve the learner's self efficacy. In addition, the Personal Digital Tutor provides built in accountability. The Tutor monitors the students work to make sure they are making adequate progress. Optional settings empower the Personal Digital Tutor to contact the learner by e-mail if they don't log into the system at the appropriate times. If a student gets too far behind, the Digital Tutor can alert a designated classroom teacher or parent, so that additional intervention can take place.

Mastery Model

The diagram below is a visual representation of the two distinct stages of achieving mastery of academic information.



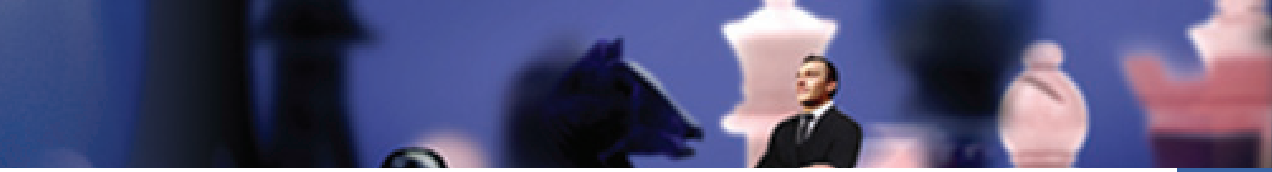
The learning of academic information is a two-step process. First, learners gain an initial understanding of a subject, possibly by reading a book or listening to a lecture. To start the Initial Understanding stage, the learner is asked to write a short statement about what they currently know about the topic that is going to be covered in the subsequent lesson. This is called a Record What You Know question. Next, the system provides instruction in a way that matches the needs of each learner. These needs fall into three areas:

1. **Content**. One-size-fits-all lessons actually fit no one. They are too advanced for some students, leading to frustration, and too basic for others, leading to boredom. The BrainX System uses an artificial intelligence based Digital Tutor which uses an assessment to determine a student's current knowledge level and will customize the lessons for each student.
2. **Presentation**. The key for the most efficient learning is to have the best presentation method based on each student's needs. Some students learn faster if they read material, others if they read along as the material is being read to them. Still, others learn best if their lessons include video. Many English Learners retain material better if they can read and listen to lessons in their native language and then in English. The BrainX System gives the learner many choices between several different presentation options.
3. **Control**. While a lesson is being presented, the learner is actively processing the information in that lesson. Each student has different processing needs. Some students need to reread sections; others need to utilize graphics in order to process material. If they don't have the control required to make these individual adjustments, they get frustrated and that impedes the learning process. The BrainX Digital Tutor gives each learner complete control over the lesson presentation environment.

Memory Reactivation

The Proper Use of Questions

Research indicates that studying with question-and-answer sessions is the best way to accelerate the memory consolidation process. The BrainX System uses a special question type called a 'Learning Question'. Learning Questions are comprised of



up to five elements:

- > > A question formed around a main idea or key term.
- > > An answer that forces the learner to recall the most important part of that main idea or key term in the context of how that idea or term needs to be used.
- > > Hints and other memory helpers when needed.
- > > An explanation of the answer.
- > > References indicating the exact source and location of the material for further study.

In the majority of situations, the most effective Learning Question format is either fill-in-the-blank or short answer. As stated earlier in the paper, the research shows that multiple choice questions are not desirable for use during the memory reactivation process. Multiple choice questions can be used in tests that are given after the material has been mastered with no ill effect on material retention.

Self Evaluation Study Sessions

Self evaluation through study sessions increases retention of information and time-on-task. The BrainX eLearning System has been designed around a simple and effective self evaluation technique. The Digital Tutor presents a question to and is answered by the learner. The learner then requests the correct answer from the system. The learner then compares his answer to the correct answer and evaluates his response. The learner can select one of the following self-evaluation choices; my answer was: Correct/Easy, Correct/Hard, or Incorrect. Once the learner has evaluated his answer, the next question is displayed. The study session continues in this manner until all of the questions in the Knowledge Base have been answered or the learner ends the session manually.

The Digital Tutor in the BrainX eLearning System uses prompted assistance, which is more effective than forced assistance.

Inter-lesson and Intra-lesson Spacing

The BrainX Digital Tutor uses artificial intelligence to build an optimum re-questioning algorithm to calculate the most efficient inter- and intra-lesson spacing for each student. This algorithm takes into account not only if the student got the question correct or not but how difficult it was for the student to answer the question. At the end of each Study Session, the Personal Digital Tutor uses another algorithm to determine the best day for this student to repeat this set of questions. In this way, the system takes each student down the most efficient memory reactivation path, resulting in mastery in the shortest amount of time based on inter and intra-lesson spacing methodologies.

The tutor is sensitive enough to adjust the reactivation schedule to accommodate the full range of possible learners. For example, it has been used effectively with special education high school students who function at a second grade level, to experienced doctors studying for the Internal Medicine Board Review Exam. The adaptive nature of the Personal Digital Tutor means that both of these learner groups are presented with material at a level and pacing that is just right to challenge them, but not too difficult that they cannot meet the challenge.

Time Management

In the BrainX System, learners who do not have one or two hours of time to study each day can then take advantage of small periods of 5 to 20 minutes to study. With traditional study techniques, effectively using these short periods is difficult because learners need time to determine what to study and get into the proper mindset. With the BrainX eLearning System, students log on and the Digital Tutor immediately picks up where the learner left off when they closed their last session.

Proper Use of Assistive Information

The Digital Tutor in the BrainX eLearning System uses prompted assistance, which is more effective than forced assistance. Explanations of answers, hints, and text references are available to learners as they need them, but using these assistive devices is not obligatory.

Student Summaries

To demonstrate that information has been truly mastered, and not just memorized, at the end of each lesson the learner is asked to summarize what they have learned. The Digital Tutor only asks for this summary after the learner has demonstrated mastery in the study session. If this system is being used in a setting where the learner has a live teacher or tutor, this evaluation is sent to the live teacher or tutor for evaluation.

Summary:

The success of the BrainX system shows that neuroscience research, when combined with education research, can provide a useful framework for designing effective online learning systems.

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About the Author:

Bruce Lewolt

Bruce is an author, innovator in learning practices, and holder of a US Patent for his proprietary online learning technologies, that are based in research from the cognitive sciences. He is co-author of the Simon and Schuster audio book called, 30-Days To A More Powerful Brain, and a frequent presenter at education conferences.

With over 20 years of experience in new product development, Bruce brings a unique perspective to enhancing performance that is informed by the latest research from the fields of neurobiology, cognitive psychology, education, and computer science.

Bruce began his career as a software architect specializing in expert systems and artificial intelligence. This led to a curiosity of how people learn, and ultimately, to his in-depth research on what the best practices are that separate the most successful students from those who do not learn as effectively. He discovered that the most significant predictor of academic success was not raw intelligence, but rather the systematic application of a set of strategies that Bruce named “Expert Learning Strategies.” In 2003, Bruce codified these strategies in his book, Getting A’s: Secrets Expert Learners Use To Get Straight A’s. The book teaches how to increase personal performance by becoming expert learners. The methods work. Bruce’s strategies have helped thousands of students go from C and D students to A students.

Bruce continued his research in the specialized area of the neurobiology of learning. Working with some of the best neuroscientists and cognitive psychologists in the world, Bruce quickly realized that although the expert learning strategies he had researched earlier were effective, there were even better, more efficient ways to learn based on research into how the brain organizes information. This inspired his design and development of an e-learning system, which uses intelligent learning agents to help anyone learn any subject matter in the most effective way. This technology was granted one of the most extensive U.S. patents ever approved in the area of online learning.

Summary:

The success of the BrainX system shows that neuroscience research, when combined with education research, can provide a useful framework for designing effective online learning systems.

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