# Brain Research and Implications for Engineering Education

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## Abstract

*Cognitive Engineers view learning as a process in which information is obtained, stored in long term memory and successfully recalled when needed.. Minor changes in the preparations and delivery of course content provide for increased opportunity for learning and application of engineering concepts. Discussed are predominant methods of information acquisition; learning modalities, hemispheric dominance, hierarchies of learning, schema theory and explicit vs. implicit memories. Introduced are instructional design strategies for improving probability of learning whether by traditional delivery or electronic means.*

## Introduction

As educators, we can no longer afford to teach the best and lose the rest. We must, instead, stimulate and refine students' critical thinking skills. We can no longer harbor the thought that if the student would "try a little harder", he/she could learn as we prefer to teach - and we usually teach the way we ourselves were taught. We must rethink the learning process.

## Information Acquisition

Once material is presented, information is processed through the senses and into what is commonly referred to as Short Term Memory (STM). Information in STM is lost within 15-30 seconds, if not rehearsed. From STM the information is then passed to Long Term Memory (LTM) which is considered permanent. Information successfully transferred to LTM is theoretically never lost but may be irretrievable.

## Learning Modalities

Students are primarily exposed to new material in a visual or auditory mode. In some cases, a kinesthetic approach is used. Rarely used in the more formal learning scenarios are the olfactory and gustatory modalities (although they are used in some classes such as chemistry when working with certain chemicals).

A simple way to test students for their preferences in regards to auditory, visual or kinesthetic modality of presentation is to ask them to "Write the word 'cat'" on a piece of paper [1]. The paper, however, must be placed on your forehead while you write. If the word 'cat' is printed correctly, the student is primarily a visual learner. If the word 'cat' is written cursively, the student is primarily an auditory learner. If the word 'cat' is written inverted or backwards, the student is primarily a kinesthetic learner. It is our experience that most engineering students and instructors will test as visual learners.

A study performed by Jacoby and Dallas indicates that when the modality of presentation and testing of the material matched, performance of the students improved [2]. When material presentation and testing modality do not match, performance decreases. So many times, as educators, it is our narration as we are writing on the board that is of prime importance in the thought processes we are trying to teach. We then expect primarily visual learners to hear us accurately, remember what we say, and then perform visually and kinesthetically with a written test.

## Hemispheric Dominance

In most people, one hemisphere of the brain specializes in tasks suited to a sequential/analytical paradigm such as logical reasoning and planning. The other hemisphere deals with global applications of visual imagery, dreaming, and coordination. Typical lectures and textbooks effectively stimulate the analytical hemisphere dominated individuals. The global hemisphere dominated person prefers interactive activities such as labs or working in groups.

While there are written tests which can be administered to students to determine whether each is an analytical learner or a holistic, global learner, there is an easier method based on the experimental results obtained by Dr. Jerre Levy [3]. For approximately 99% of the right handed population, those whose hand is in line with the arm when writing, the right hemisphere is used for spatial relations and global style learning and the left hemisphere for analytical processes and language skills is

dominant. 56% of the left handed population, those who write with the hand curved to the inside at an angle with the arm, have the same lateralization as the right handed people described. For the rest of the population, the hemispheric lateralization is reversed. Dr. Jerre Levy performed experiments that revealed that the inverted hand position is a "biological marker" indicating that the hemisphere for specializing in language and analytical abilities is on the same side as the writing hand [4]. Typically, in the literature, the left hemisphere of the brain is considered to be the site for verbal and analytical abilities.

The lateralization of our skills can affect many of our personal preferences of interaction and reaction. For example, some students may sit on the left side of the class so that the right eye may more easily transfer mathematical material to the left side of the brain and then sit on the opposite side of the class for a music appreciation course.

## Learning styles

Within the framework of the left/right hemisphere dominance, exists the learning cycle. Kolb's Model of Experiential Learning, based on an original study of 1,933 people between the ages of 20 and 60, sections learning styles into four major groups [5]. Kolb is especially relevant to the engineering educator as much of his research was performed at MIT and many of his subjects were engineering students and practicing engineers. The four types of learners are called (1) Divergers (2) Accommodators (3)Convergers (4) Assimilators.

Each student has a preferred learning style that affects his/her abilities and information retention. Educators also have individual preferences for learning (and thus teaching) that may or may not complement the students in the class. Most engineers and math majors have the learning styles of Convergers and Assimilators, respectively. Retention of information increases as students are coerced to use the other learning style modes in addition to the preferred one. Information retention can be increased to 90% by incorporating all the learning style methods. To be an effective and efficient learner, students must become involved, listen, generate ideas, and act on their decisions. As educators, we must provide opportunities for all of these aspects within the context of the course [5,6].

Research into location of brain functions indicates that the methods preferred to learn are biologically based. Learning patterns and methods are initiated shortly after birth and are fairly rigid by the time a person leaves elementary school.

Some characteristics of learning styles and preferences may be gender specific. For instance, women tend to verbalize while solving mathematical problems while men tend to think in terms of the abstract variables and verbalization is minimal.

## Hierarchical and Schema learning

Exceptional memories may be the result of extremely efficient encoding and retrieval skills. The degree of organization of the information in LTM has a direct effect on the ability to retrieve it. One of the more efficient ways to organize material is through the use of hierarchies. For example, once a Schnauzer is identified as a type (subcategory) of dogs, more information regarding the dogs category may be transferred to the category Schnauzer.

Another method of categorizing information is by the use of schema, or clusters [7]. Each schema represents a different type of problem solving capability or skill. When confronted with a situation or problem that needs to be dealt with and solved, the memory is searched for a relevant schema to aid the solution. Once the correct schema is activated, the appropriate solution techniques are accessed. Schemata exist for everyday problems such as how to fill up a car with gas or how to solve a particular type of math equation.

## Explicit vs. Implicit Memories

Kandel and Hawkins [8], describe two primary types of learning:

1. Explicit (Declarative) requires a conscious effort to notice details and memorize the process. Usually the information is stored in categories with associations created between elements of the various categories. Successful recall of the information depends on having a strong cue with definite associations relating to the stored information. The sought-for information is then "matched" to what is needed. This information is thought to be stored in the Temporal Lobes and is the information that an amnesiac cannot remember.

2. Implicit (Nondeclarative) does not require conscious effort or participation and remains intact even if damage to the temporal lobes occurs. This information cannot be "looked up" or matched. It is automatic knowledge that is triggered by an already encountered, specific event. It includes information learned by repetition priming and skills such as writing.

## Instructional Design Strategies

As the instructors, we have the capability and the responsibility to ensure that learning has occurred. Employing tactics that have foundation in this research makes sense. For many of us this will require a fundamental change in the way we do business. It may mean a change in philosophy for outcomes in our classes. Try setting the goal that *every* student in our class *earns* an A. With that mental model, we can change how we provide opportunities for the students to learn.

## Information Acquisition

In order to facilitate migration of information from STM to LTM, episodes of rehearsal of the information are required. Provide opportunities for this rehearsal to take place. Asking students to put concepts into their own expressions, whether written, oral or physical, provides opportunity for them to process the information in ways other than just listening to what we have said.

## Learning Modalities

Accommodating different learning modalities requires a major paradigm shift. The first thing we should do is assess what our own learning modes are. We tend to teach the way we learn. Once we are aware of how we are teaching, it will become easier to add techniques that enrich the other learning modalities.

Next, make it a point to find out what modalities are favored in each student. In subsequent conversations with a student, we can use verbs that help build a connection with the student. Auditory learners will perk up their senses when you use words such as “listen” and “hear.” A visual learner will benefit from hearing us use words such as “look” and “see”, as well as by our providing a sketch or showing the written word. Kinesthetic dominance will respond to a demonstration in which students participate and to words such as “build” and “do.”

Auditory learners often find note-taking a distraction. We need to not interpret this lack of activity as lack of interest. The activity is taking place within the brain of the auditory learner. Some students may benefit from taping lectures and playing them back for review.

Take time to point out what we are doing to facilitate learning through different modalities. The students must be encouraged not only to know what their dominant learning modes are, but also should consciously develop skills for learning through the other modalities to enrich their learning ability.

## Hemispheric Dominance

Content is useful to those students who are analytical learners. Concept is the goal of global learners. In order to develop both sides of the brain, opportunities must be provided that involve practical projects for teams of students to solve.

The difficult part is ours. Where are these problems? Clearly, we are preparing engineering students to solve problems in their careers, so there ought to be a large pool of contemporary problems from which to draw. In addition, students may benefit from defining their own problems within the constraints of the course objectives and time allowed.

With clearly stated, viable problems, motivated students will research, create, test, analyze, revise and demonstrate solutions. Our job changes from lecturer to coach, from filter of the best students to motivator, from disseminator of information tospawner of curiosity.

## Learning Styles

Each of the types of learners have their perceiving and processing dimensions. Bernice McCarthy has developed 4MAT, a scheme for touching each type of learner by planning a lesson that reaches each of the styles of learners [6].

Divergers need help connecting their experience of the world to the content of courses. In general, school has been a frustrating experience and courses are perceived as isolated rather than an integral part of the entire curriculum. Provide opportunities for left hemisphere students to analyze and reflect about the experience in your class and create that experience for the right mode students.

Assimilators ask “What?” Their goal is conceptual understanding. These are the students for whom school has worked well. They have been considered the best achievers and have won the awards for scholarship. They do not need concrete examples to understand concepts. For those right mode students who share this dimension, we must provide opportunities for analysis. For the left mode, we need to implement a part of the lesson for skill development.

Convergers do well if we design a place in the lesson to practice. Left modal learners may practice defined "givens", while right mode students will need an opportunity to incorporate themselves into the information . Then they may answer the question “How?

Accommodators must have an opportunity to test the relevance of the content. They must be given

opportunity to relate to other experiences. Answering the question "What if?" is paramount with this group.

## Hierarchies of Learning

Perhaps the most important outcome of this field of study is that teachers often forget that they had to progress though the hierarchy to learn the material the first time. We tend to minimize our experiences in learning and want to just "tell" students the answers. A key technique for helping students to reach each level of learning is to implement a "wait time" for responses to your questions. We need to provide time for students to process the new information and synthesize a response.

A seemingly blank stare may not indicate no brain activity, but just the opposite. While we are waiting for a response, time seems to pass quickly and we fear "losing momentum" in the lesson. However, we must become comfortable with the fact that at that moment the best learning may be happening *inside* our students' heads. Take this time to process the next part of the lesson, or to review student's names. Generally, if a student needs more help in clarifying what is expected, that student will become aware of and then uncomfortable with the silence and ask for help. Place the onus on them for getting the information they need to answer the questions. It may be that everything they need is already in their minds and just needs time to become organized into coherent thought.

## Schematic Learning

Schema theory tells us that the "better" students may not have extraordinary memory storage capabilities as much as efficient search and retrieval skills. Connections may be better established by providing a framework for students to use to examine incoming information. Five helpful questions which students might use for lesson summaries are: What happened? How is this the same as something I already know? How is this different? How will I use this information? When will I use this information?

## Explicit vs. Implicit Memories

The classroom setting that provides support for all types of learners promotes the creation of explicit memories as opposed to implicit. Input is more efficiently organized and stored. More associations can be built between new and previously stored items in the manner that best suits the student. Information can be reinforced using visual, auditory and kinesthetic modes to create more varied associations. Distinctive retrieval cues can be thought of and implemented. Given multiple associations and retrieval cues, maybe one of them will work successfully when the information is next needed.

## Making the Changes

A common response to these suggestions is that we cannot do all this and still cover all of the material in the course. A moment of heresy: Content may not be the most important part of your courses! Concept is generally more useful in problem solving. Content changes rapidly, generally in the way it increases. Many of us are teaching ideas which did not exist when we were doing our undergraduate work. Yet, we managed to master them. We must trust the students to get the content. We must do the job of *motivating* them to search for it.

We need to teach students to become life long learners. Helping them to identify how and why they learn will be most useful in that endeavor.

These concepts may be quite foreign to us at the beginning. Try to adopt one new technique each class. Do not try to do all of these at one time. But do implement these strategies. Rejecting this new way of teaching is asking "Which students will we teach ?"

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## Biographies


Kathleen M. Harmeyer is president of Exper-Tech, an educational technology firm specializing in instructional design and development of educational multimedia titles

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