THE EFFECTS OF A BRAIN-BASED LEARNING STRATEGY, MIND MAPPING, ON ACHIEVEMENT OF ADULTS IN A TRAINING ENVIRONMENT WITH CONSIDERATION TO LEARNING STYLES AND BRAIN HEMISPHERICITY.

DISSERTATION

Presented to the Graduate Council of the

University of North Texas in Partial

Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

Marian H. Williams, B. S., M. S.

Denton, Texas

May, 1999

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This study examined the effectiveness of Mind Mapping (a diagram of the structure of ideas in an associative manner, using graphics, color and key words) as a note-taking device in a training course in a large, high-tech corporation, as compared to traditional note-taking. The population for this study consisted of personnel employed by a major high-tech firm, that had voluntarily registered for a Mind Mapping training class. The effect of Mind Mapping was measured by the pre-test and post-test of the control and experimental groups.

The design of the study was an experimental pre-test, post-test control group design. The statistical procedure used in this study was a one-tailed t-test to determine if there was a significant difference between mean achievement scores of the two groups. Calculations for the t-test were done using the computer program (SPSS). A level of significance of .05 was specified. The one-way analysis of variance (ANOVA) General Linear Model SPSS version 8.0 was also performed on the data. The learning style and hemisphericity of the sample was also studied using Bernice McCarthy's Learning Type Measure (LTM) and Hemispheric Mode Indicator (HMI) with respect to success in Mind Mapping to identify if there is any correlation between success in Mind Mapping and learning style or brain hemisphericity. A 2 x 4 ANOVA General Linear Model (GLM) was the statistical procedure used to analyze the scores from the LTM and the HMI.

This study determined that Mind Mapping, which is based on the brain research which shows that learning is a biological/physiological function, is an effective learning strategy that can be used in training learners how to learn. The effect of one's learning style and brain hemisphericity also play a major role in the success one has in learning and in the types of strategies used to optimize one's learning strengths and weaknesses. This study has found that Mind Mapping as a learning strategy crosses all learning styles and hemisphericity boundaries making everyone able to become a successful learner.

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The dissertation journey toward a Ph.D. is an arduous one. It should not be taken lightly, or without considerable planning, support, and financial consideration. My journey, although long and tedious, has been enjoyable, frustrating and a true immersion in the act of "learning." Like a wonderful journey into a foreign land, the dissertation process has truly been an amazing and unforgettable experience, but it is also good to be at my journey's end.

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Most of all, I'd like to thank my dad for making my life possible and giving me the great example - that life is a great journey to be enjoyed, experienced and relished.

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INTRODUCTION

Background

The new millennium will usher in a period of technological innovation, unprecedented economic opportunity, surprising political reform, and great cultural rebirth (Naisbitt & Aburdene, 1990).

> We are now in an age of instant communication. We have the ability to store all the world's information, and make it available almost instantly, in virtually any form, to almost anyone anywhere on earth. Using that ability to the fullest will change your world at least as much as the alphabet, the printing press, the steam engine, the automobile or television. Its impact will be greater than the silicon chip, the personal computer, the voice-activated word processor, fiber optics, satellites, and interactive compact video disks—even though it will make use of all these. We are coming into an age dominated by a one-world economy and a prime task of each society is to prepare all its members to reshape their own future: to develop skill and abilities needed to flourish in that one-world economy. (Dryden & Vos, 1994, p.25)

These changes have already resulted in a growing emphasis on learning (Argyris, 1991, 1993; Senge, 1990, 1992). In a rapidly changing environment, the ability of trainers, educators, and workers to utilize and understand the expanding base of available knowledge will be of paramount importance to their success. This study will show that by using certain brain-based strategies, training can be redesigned to enable learners to become more successful learners.

Three reports specifically targeted to help develop the public sector of the workforce for the 21st century are built on the premise of learning (Hudson Institute, 1987, 1988; National Commission on the Public Service, 1990). The general concept of learning has a long and full history; however, only recently has "learning" been applied to organizations. Since 1990, the number of books and articles on the learning organization has increased dramatically (Bassi, Benson, & Cheney, 1996). The term "learning organization" is seen throughout this literature and has its roots in the ideas of socio-technical systems, action research, and the work of Chris Argyris and Donald Schon (1992) on organizational learning (Senge, 1990).

A substantial amount of research has been undertaken in the areas of cognitive styles, learning modalities, learning styles, cultural differences, language differences and communication styles across cultures, and multiple intelligences. This research is the product of philosophers, anthropologists, linguists, and biologists, as well as researchers of brain functioning and neural "connectionism" (Sylwester, 1995). Additionally, information gained by neuroimaging techniques has given us new insight into the physiological changes that take place when we learn. Little action has actually been taken to incorporate this research into methods of training, much less in the design and development of learning organizations.

We must make changes in the way we learn and these changes are more urgent than changes in technology (Dryden & Vos, 1994). It is imperative that we incorporate the new research in all these areas into the way we train. We can teach learners how to learn by designing and using brain-fitting, brain-compatible instructional tools, such as Mind Mapping®, which is a Registered Trademark. We can transform workers into learners who can then direct the future of the learning organization.

This study will attempt to show that a brain-compatible learning strategy, Mind Mapping, can enable learners to be more successful learners.

Purpose of the Study

The purpose of this study is to determine the effectiveness of Mind Mapping, a brain-based learning strategy, as a note-taking device with adults in a corporate training environment. The effect of learning style and brain hemisphericity preference on success in the use of Mind Mapping will also be assessed as a tool to better understand how to aid people in becoming effective, efficient learners.

In the future, training will become devoted to teaching learners *how to learn* by using specialized thinking strategies and learning techniques, such as Mind Mapping (Gross, 1992). "Training needs to be reinvented. Training will not finish with school, nor should it be confined to those who shine academically at eighteen. Learning . . . happens all through life unless we block it" (Handy, 1989, p. 20).

In the past, people were prepared for a future with jobs in the industrial age-jobs that are disappearing daily. People now need to be preparing for the jobs of the future, jobs that will require thinking skills, not rote memorization and repetition. Mind Mapping, is a brain-based learning strategy, that will provide opportunities for learners to attain thinking skills.

This study should determine if Mind Mapping is an effective learning strategy that can be used in training learners how to learn. The effect of one's learning style and brain hemisphericity also play a major role in the success one has in learning and in the types of strategies used to optimize one's learning strengths and weaknesses. Mind Mapping as a learning strategy crosses all learning styles and hemisphericity boundaries making everyone able to become a successful learner.

Statement of the Problem

The 21st century will usher in "the learning society" and the most successful corporations will be those viewed as learning organizations. The term learning organization refers to an organization where learning is a planned, intentional process that directs the performance of individuals, teams, and the entire company (Bassi, et al., 1996). Success for employees in this learning organization environment will be dependent on their own thinking abilities. Learning will require workers to increase their thinking competencies as well as their adeptness in learning new information. Learning will be a continuous, life-long process (Gross, 1992). The matter is so important that Buzan states, "If your company does not become a learning organization, it will become a dead organization." (Buzan, 1991, p. 3).

In the past, training research and development efforts were focused on improvement of training. Now the focus should be the transfer of classroom knowledge and skills to the job situation (Dansereau, 1985). Transfer of training is the effective and continuing application of the knowledge and skills gained in training (Broad & Newstrom, 1992). This transfer of training is important because U.S. organizations spend billions of dollars each year on training and development for the employees, when approximately 90% is wasted within the first two weeks because that knowledge and training is not fully applied by those employees on the job. (Buzan, 1991; Weinstein, Goetz, & Alexander, 1988).

For U.S. organizations to remain competitive in the global marketplace they must develop highly skilled workforces. Our multi-billion-dollar training industry must be able to demonstrate that these investments pay off in improved performance on the job (Broad & Newstrom, 1992). The areas of cognition, metacognition, and the task and the learner are of prime importance and should be the focus of future research (Weinstein, 1988).

According to Howard Gardner (1991), although we have learned a great deal about learning, in most instances action to use this knowledge is not being taken. John Goodlad's (1983) study found that most instructors still used strategies that consisted mainly of lecturing and individual paper work. It is essential that instructors become aware of the new cognitive science research, embrace it, and act upon it.

The educational issue that is under consideration in this study is the lack of use of strategies that enable learners to be successful - learning how to learn, no matter what their learning style or hemisphericity preference. The focus of this study will be the brain-based learning strategy, Mind Mapping, and its effectiveness in note-taking across learning styles and hemisphericity. A thorough and comprehensive assessment of the strategy of Mind Mapping should show that it will enable people to absorb and retain much more information, thereby making training departments utilizing Mind Mapping more effective (Lewis, 1997).

Need for the Study

The need for this study is based on the fact that the future of the learning organization is dependent on each person becoming lifelong, efficient learners. A problem exists in most organizations in that most individuals do not know how to learn and that those individuals assumed to be best at learning (i.e., professionals) are not good at learning (Argyris, 1991). To resolve this dilemma, organizations must overcome their resistance to new ideas and begin to use systems thinkers, and develop collaborative learning capabilities "among different, equally knowledgeable people" (Senge, 1990, p. 14). It will become necessary to incorporate new ideas, such as Mind Mapping, into our metacognitive skills as a new learning strategy. The challenge for training professionals will be to put the concepts of a learning organization into operation through use of strategies examined by this study (Bassi, et al, 1996).

The learning strategy that is the focus of this study is Mind Mapping. A mindmap is a visual representation of knowledge. It is a diagram of the structure of ideas in an associative manner, using graphics, color, and key words. The brain-based learning strategy, Mind Mapping, is based on the translation of brain research which shows that the mind does not process information in solely list-like, linear representations.

Research into Mind Mapping as a training strategy is inadequate. Many strategies that are advocated in the curriculum literature have not been adequately evaluated (Pressley, Woloshyn & Associates, 1995). The more scientifically conducted research in learning theory has been undertaken largely by psychologists unconnected with the training enterprise, who have investigated problems quite remote from the type of learning that goes on in the classroom. The focus has been on animal learning or on short term and fragmentary rote or nonverbal forms of human learning, rather than on the learning and retention of organized bodies of meaningful material (Hart, 1983). In addition to strategy research, Hyerle (1993) suggests that areas related to maps that need to be researched are cognitive development, schema theory, cognitive styles, learning styles, cultural differences, and secondary language acquisition. There is a need for research regarding the relationship between Mind Mapping and brain hemisphere dominance and this needs to be done using a more comprehensive and reliable instrument (Mehegan,1996). In addition to the hemisphericity of the learner, Trautman (1979) suggests that further research should be done to establish better, more succinct criteria by which to determine the cognitive style and learning style characteristics of curriculum, resources, and instructional strategies.

The lack of research in the areas of Mind Mapping and its effectiveness as a note-taking device and the effect of learning style and hemisphericity on success in Mind Mapping make this a critical area for study. This dissertation study should show that brain-based strategies provide greater achievement by using both hemispheres. For training departments, learning strategies, such as Mind Mapping, can be a more successful method of instructing people how to comprehend, store and utilize information.

Hypotheses

The hypotheses for this study are:

1. Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training.

2. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across learning style as measured by the Learning Type Measure instrument.

3. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across hemisphericity as measured by the Hemispheric Mode Indicator instrument.

4. There will be no significant interaction between the learning style and hemisphericity variables.

Assumptions

The following assumptions were made regarding the study.

1. The instruction received by each participant was of equal content and quality by the same instructor, who is certified and trained in Mind Mapping.
2. Participants in neither the experimental nor the control group have had previous instruction regarding Mind Mapping.
3. No one group received differential attention during the training, thus, the Hawthorne Effect is not a factor that influences the research results.

Delimitations and Limitations

Delimitations

The delimitations that are imposed upon this study include the following:

1. This study will be limited to the study of Mind Mapping as a note-taking device.
2. Subjects for this study are from an industrial, corporate training environment.
3. This study will be limited to participants that have registered to take this course.
4. Educational level of subjects will not be considered as part of this study.
5. Gender of participants will not be considered as part of this study.

Limitations

The limitations that are imposed upon this study include the following:

6. The subjects in this study will be treated over a variety of times and settings.

7. The subjects in this study will be in the training classes as a result of voluntary registration.

DEFINITION OF TERMS

Advance organizer - Instructional activity that focuses the learner on the essence of what is about to be taught (Pratt, 1994).

Behaviorism - General term for the psychology dominant in the United States through most of the 20th century, heavily using such terms as stimulus-response, reward, reinforcement, motivation, mediation, etc. (Hart, 1983).

Brain - The main, central mass of the nervous system housed in the skull, comprising 95 percent or more of the entire human nervous system (Hart, 1983).

Brain Based - Utilizing scientific knowledge of the brain, especially the human brain (Hart, 1983). An understanding of learning based on the structure and function of the brain. Learning occurs if the brain is not prohibited from fulfilling its normal processes.

Brain-compatible - Fitting well with the nature or shape of the human brain as currently understood (Hart, 1983).

Cerebellum - The "little Brain" near the back of the neck, primarily concerned with coordinating muscular activity (Hart, 1983).

Cerebrum - The new mammalian brain, composed of two largely mirror-image hemispheres, in humans about 5/6 of the entire brain (Hart, 1983).

Concept - A general term for any consistent portion of an individual's progress in "making sense of the world"; a working hypothesis (Hart, 1983).

Constructivist theories of learning - These theories state that learners must individually discover and transform complex information, checking new information against old rules and revising them when they no longer work (Slavin, 1994).

Constructivism - A philosophy of learning that is founded on the premise that we all construct our own understanding of the world we live in, through reflection on our experiences. We use the 'rules' and "mental models" we generate in this process to make sense of experience. Learning is the process of adjusting our mental models to accommodate new experiences.

Cognitive - Related to knowledge or intellectual activity (Pratt, 1994).

Corpus callosum - Large bundle of nerve fibers forming a two-way bridge between the left and right cerebral hemispheres (Hart, 1983).

Cortex - The "bark" or outside layers of brain lobes; the gray matter of the brain in which thinking proceeds (Hart, 1983).

Hemispheres - The left and right portions of the cerebrum, roughly mirror images (Hart, 1983).

Information-processing theory - Cognitive theory of learning that describes the processing, storage, and retrieval of knowledge from the mind (Slavin. 1994).

Knowledge - Knowledge almost always takes the form of stored programs or pattern recognition (Hart, 1983).

Knowledge Structure - A hierarchy of levels, from common knowledge to higher and higher specific, detailed, technical, broad and theoretical, professional levels (Hart, 1983).

Learning - The acquisition of useful programs (Hart, 1983).

Learning Style - Tendency of an individual to learn more efficiently or effectively under a particular set of environmental conditions (Pratt, 1994).

Process of learning - The extraction from confusion of meaningful patterns, which can subsequently often be recognized by match (Hart, 1983).

Linear - Arranged in a line, or simple sequence; single path as opposed to multipath (Hart, 1983).

Metacognition - Awareness, monitoring, and regulating of one's own intellectual processes (Pratt, 1994). Knowledge about one's own learning, or knowing how to learn and monitoring one's own learning behaviors to determine the degree of progress and strategies needed for accomplishing instructional goals (Slavin, 1994).

Neuron - The specialized cell of the nervous system, which has 30 billion or more. There are a number of categories of neurons, with different shapes and functions (Hart, 1983).

Neuroscience - The study of the human nervous system, the brain, and the biological basis of consciousness, perception, memory and learning.

Pattern - An entity, such as an object, action, procedure, situation, relationship or system, which may be recognized by substantial consistency in the clues it presents to a brain, which is a pattern-detecting apparatus (Hart, 1983).

Schema, Schemata - A term used for programs which are not learned after birth but are genetically transmitted. Example: a bird "knows" how to build a nest. In humans schemata may be vague, to be refined by the culture (Hart, 1983).

Schema theory - The theory that information is stored in long-term memory in networks of connected facts and concepts that provide a structure for making sense of new information (Slavin, 1994).

Synapse - The connection between one neuron and another; actually a tiny gap across which neurotransmitters act. Since a singe neuron may connect with 10,000 or more others, synapses in a human brain run into vast numbers (Hart. 1983).

Strategy - The method, process, procedure, or technique used in instruction (Pratt, 1994).

CHAPTER 2

REVIEW OF LITERATURE

This chapter reviews and summarizes relevant literature on Mind Mapping, learning and memory, brain-based learning, the new neuroscience discoveries about the brain and how it learns, metacognition, strategies, learning styles and hemisphericity preferences. The first part of this chapter is comprised of a review of current literature and research on the various entities that affect the brain-based learning strategy of Mind Mapping. The second part of the literature review works and studies showing the effectiveness of Mind Mapping as a note-taking strategy.

Learning and Memory

The learning organization and the ability to learn will be of prime importance in the decade to come (Gross, 1992; Naisbitt, 1990; Senge, 1990, 1992; Argyris, 1991; Dryden & Vos, 1994; Buzan, 1991). By studying how we learn and how we can learn more efficiently, we can meet these growing needs. This review of the literature begins by examining what we currently know about learning and memory.

Learning and memory are inextricably entwined because without memory one cannot learn. Learning is the active process of gaining a skill or knowledge. Learning occurs when learners relate information to prior knowledge and when learners construct their own reality from sensory perceptions (Hart, 1983; Jonassen, 1987). Memory involves the processes of mental storage and the processes of locating, retaining and recalling what has been learned.

Historically, the study of the nature of knowledge and knowledge production (epistemology) and learning research looked at association, contiguity, "The Law of Effect" (Thorndike, 1913), and practice, which included multiple associations. This behavioral approach, the old traditional factory-model-of-production-view of learning and instructing, of Skinner, Pavlov, Thorndike and others, has been shown to be out-of-date and erroneous (O'Neil, 1978).

The cognitive revolution and the work of Jean Piaget slowly shifted the traditional view of training to *constructivism*. The broad-based thinking skills movement of the past 20 years has been led by the works of Arthur Costa (1991), David Perkins (1990), Edward deBono (1994) and many others (Fosnot, 1996). The constructivist theory of learning emphasizes that cognitive change only takes place when learners individually discover and transform complex information and make it their own (Brooks, 1990; Leinhardt, 1992; Brown & Duguid, 1989; Magoon, 1977; Slavin, 1994).

Constructivism is now guided by research in cognitive science (Gardner, 1985). Cognitive science became the doctrine that human behavior was more than conditioned responses, and the human mind is able to create, choose, reflect and explore the universe between stimulus and response (Resnick & Klopfer, 1989; Purves, Fitzpatrick, Katz, & McNamara, (Eds.), 1997). Presently, with all the new research on the brain and how we learn, we have the opportunity to transform training. John Bruer(1993) claims that the instructional methods based on the research in cognitive science will be as important to training as the polio vaccine and penicillin were to the world of medicine. Unfortunately, the only ones that seem aware of these breakthroughs in instruction are the researchers, not the instructors.

A contemporary view of instructing and learning based on research in cognitive science holds that, among other things: all learning, except for simple rote memorization, requires the learner to actively construct meaning; learners' prior understandings and thoughts about a topic or concept before instruction exert a tremendous influence on what they learn during instruction; the instructor's primary goal is to generate a change in the learner's cognitive structure or way of viewing and organizing the world; and learning in cooperation with others is an important source of motivation, support, modeling and coaching (Nolan & Francis, 1992).

The next step in the evolution of learning theories is the brain-based learning theory. It is based on the latest discoveries in neuroscience. The biological process of how we learn is the basis for how we instruct.

Neuroscience

Progress in neuroscience in understanding the brain as a system and communication between neurons has been amazing. A merger between the two areas, neuroscience and cognitive science, has developed to study how the human nervous system develops knowledge, learning, and memory (Hart, 1983). The physiological impact of how we learn is astounding. When you learn something new, neurons actually grow more dendrites to reach other neurons. The more you practice, the stronger these connections become.

This new field, cognitive neuroscience, draws upon new methods of inquiry and imaging that allow the human brain to be studied during life in ways never before possible. These include techniques of brain imaging and various methods to measure the brain's electrical and magnetic activity. X-ray CT (computer-assisted tomography), PET (positron emission tomography), MRI (magnetic resonance imaging), SQUID (superconductivity quantum interference device), EEG (electroencephalography) and MEG (magnetoencephalography) allow us to learn about where activity is occurring in the brain while it is performing various tasks (Barrett, 1992; Posner & Raichle, 1994).).

According to Leslie Hart (1983), the brain and how it learns has been and continues to be an ignored topic because of the traditional instructional systems started by Horace Mann in 1837 and the emphasis on the psychologists' behaviorist theories, led by Skinner. So in order to better appreciate the new research on the physiology of the brain and it's connection to learning, it is important to at least understand a few brain basics. The human brain has a virtually inexhaustible capacity to learn. This amazing 3 pound organ can store more information than all the libraries in the world (Wycoff, 1995). Each healthy human brain, irrespective of a person's age, sex, nationality, or cultural background, comes equipped with a set of exceptional features: We are all born with brains that are made up of 100 billion neurons, or brain cells, and each one can grow up to 20,000 connections, like branches on a tree. Neurons, unlike other cells, don't produce more neurons. The number of brain cells we are born with is approximately the number we have to use throughout our lives. There are about 10 billion neurons in the brain, with about 1,000,000,000,000,000 connections. The possible combinations of connections is on the order of ten to the one millionth power. As we use the brain, we strengthen certain patterns of connection. This results in a physical change in the connection itself that makes that connection easier to make next time. This is the development of memory. As a given message, or thought, or re-lived memory is passed from brain cell to brain cell, a biochemical electromagnetic pathway is established. Each of these neuronal pathways is known as a memory trace (Buzan, 1994) Repeated use keeps the track clear, thus encouraging further traffic. The more tracks and pathways you can create and use, the clearer, faster and more closely connected in time or place.

The triune brain theory (MacClean, 1978) helps explain the need to engage the whole brain in learning. Paul MacClean's (1978) triune brain theory states that there are three phases of brain development which are:

*Lizard or reptilian brain-the lizard brain is simple, geared to the maintenance of survival functions: respiration, digestion, circulation, and reproduction.

*Leopard Brain-(Limbic System) The reptilian brain extended and the leopard brain (or limbic brain) evolved, adding the animals' behavioral repertoire including the capacity for emotion and coordination of movement. This portion of the evolution of the brain yielded the general adaptation syndrome (GAS), or the fight-or-flight response.

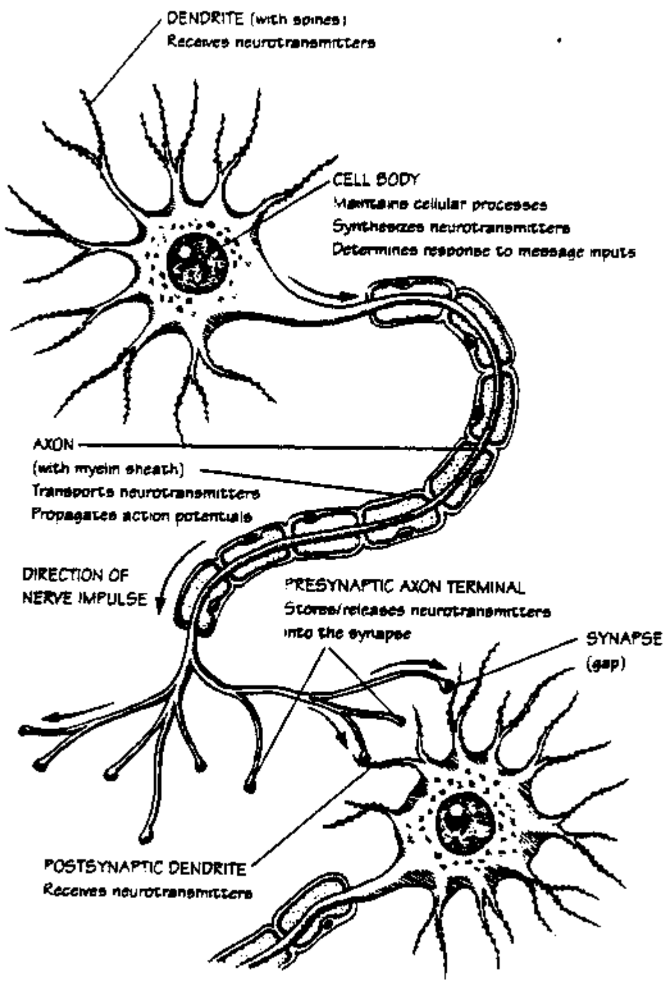
*Neomammalian or Learning brain-(Cerebral Cortex) This is the most recent phase of brain development. This phase provided the ability to solve problems, use language and numbers, develop memory, and be creative (Caine & Caine, 1994; Hermann, 1996).

All three layers of the brain interact. To instruct someone in any subject adequately, the subject must be embedded in all the elements that give it meaning. People must have a way to relate to the subject in terms of what is personally important.

The other fact that we must recognize in training is that when we learn physiological changes take place in the brain. Changes actually occur. Neurons grow dendrites. Synaptic connections are added. Our brain changes (Kandel & Hawkins, 1992).

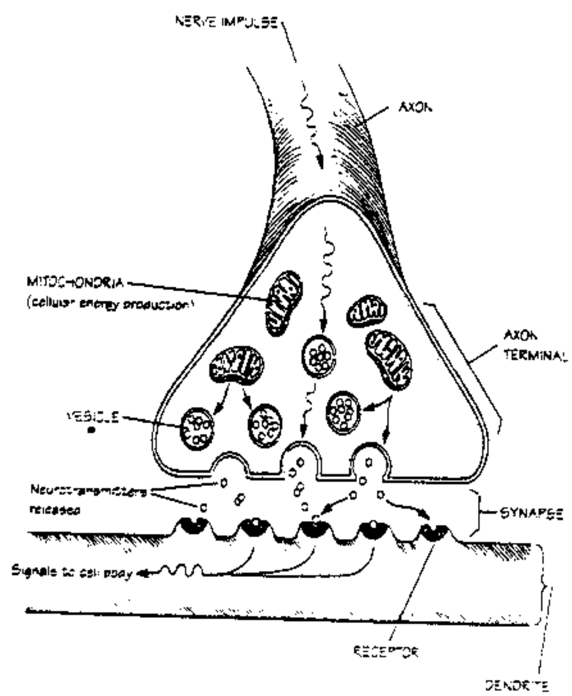
The physiological construction of knowledge occurs when the brain cell (a neuron) connects with another neuron. A typical nerve cell is composed of a main cell body (with nucleus) and two branches, one outgoing and the other incoming, that serve as communication links with other nerve cells. This outgoing branch is called the axon, while the incoming branch is called the dendrite. The receptive branches of nerve cells, called dendrites, are responsible for most of this post natal neocortical growth, and the neural network they form becomes the hardware of intelligence (Diamond, 1996). The axon and dendrite both have many connector points, so that a neuron can receive many messages through its dendrite terminals and send many different messages through it axonic terminals. As axons separate from the gray matter parts of the brain, they collect into bundles of material called nerve tracts. These tracts go from the brain to various parts of the body or to and from the spinal cord. The nerve tract that runs from the brain to the eye, the optic nerve, is made up of over 10 million different axons.

Figure 1. Functional model of a neuron (Sylwester, 1995, p. 31).



At the bottom of each axon are synapses, which are the points where the brain signals take their great leap from one brain cell to the next. The gorge across which these electrical impulses must leap is less than 2 millionths of an inch wide. The brain message takes about 1/1000th of a second to make the leap, which is about 500 times faster than a blink of an eye. Just before the synaptic gap are microscopic pockets called vesicles which contain chemical transmitters . When a message arrives, the vesicle releases its chemical transmitters (neurotransmitters) into the synapse. This release creates a chemical imbalance and the transmitters combine and create an electrical charge. This electrical charge allows the message being transmitted to leap from synapse to synapse. It is generally believed that the messages transmitted during the synaptic leap help the brain figure out what it knows (Restak, 1994).

Figure 2. Synaptic Area (Sylwester, 1995, p. 34)



While much is still unknown about the brain and how we learn, these new advances in neuroscience give us enough information to start using brain-based learning as a framework for redesigning training.

Brain-based Learning

Breakthroughs in brain research by Sperry, Ornstein, and Diamond helped us understand the split-brain, the enormous potential of the human brain, and the fact that there is rapid growth of brain-dendrites in an environment of enriched experiences.

Therefore, cognitive learning theorists have developed the information-processing theory, the dominant theory of learning and memory for the past twenty years (Slavin, 1994).

Brain-based learning involves acknowledging the brain's rules for meaningful learning and organizing instruction with those rules in mind. Brain research establishes and confirms that multiple complex and concrete experiences are essential for meaningful learning and instructing. Optimizing the use of the human brain means using the brain's infinite capacity to make connections and understanding what conditions maximize this process. In essence, learners learn from their entire ongoing experience. Content is inseparable from context. So, we as educators and trainers much search for ways to expand the quantity and quality of ways in which a learner is exposed to content and context. This process is often termed as immersion. The learner needs to be engaged in talking, listening, reading, viewing, acting, and valuing (Bransford & Vye,1989).

Research indicates that the brain functions far more optimally when engaged in challenging (but not threatening) problem solving thinking. Brain-friendly approaches to training engage the brain in higher-order thought processes, utilizing complex real-life issues and problems (Gardner 1993, 1991; Healy 1990).

The principles of brain-based learning are:

1. The brain is a parallel processor. It can perform many functions simultaneously (Ornstein & Thompson, 1984).
2. Learning engages the entire physiology. Anything that affects our physiological functioning affects our capacity to learn. Both externally and internally generated stimuli promote brain activity, resulting in increased neuronal connections or synapses. The more extensive the web of these connections, the greater the brain's capacity in the future to take in information and skills, as well as integrate them and apply them appropriately to life's daily challenges (Diamond, 1996).
3. The search for meaning is innate. The brain needs and automatically registers the familiar while simultaneously searching for and responding to novel stimuli (O'Keefe & Nadel, 1978).
4. The search for meaning occurs through "patterning". The brain functions as a pattern maker, pattern follower, and pattern sensor. From early childhood, the brain establishes patterns based on both verbal and nonverbal messages that come to us from parents and other authority figures. These patterns delineate who we think and feel we are in the world and what levels of success and fulfillment we can expect from our life experiences. The brain is constantly looking for ways to make sense of the input--to attach meaningfulness to the information--or make connections. We must search for what the learner already knows and values and how information and experiences connect.

5. Emotions are critical to patterning. The learner's feelings and attitudes will be involved in learning and will determine future learning.
6. Every brain simultaneously perceives and creates parts and wholes. Left brain, right-brain or hemisphericity is not the whole of the learning process. In a healthy person, the two hemispheres are inextricably interactive, irrespective of whether a person is dealing with words, mathematics, music or art (Hart,1984).
7. Learning involves both focused attention and peripheral perception. The brain recognizes stimuli from both its focused and its peripheral fields (Buzan, 1989)
8. Learning always involves conscious and unconscious processes. We remember our experiences, not just what we are told.
9. We have two types of memory: A semantic memory system for rote learning and an episodic memory system that does not need rehearsal and allows for "instant" memory of experiences.
10. The brain understands and remembers best when facts and skills are embedded in natural spatial memory. Spatial memory is generally best invoked through experiential learning.
11. Learning is enhanced by challenge and inhibited by threat. We narrow the perceptual field when threatened, by becoming less flexible and by reverting to automatic and often more primitive routine behavior.
12. Each brain is unique. Because learning actually changes the structure of the brain, the more we learn, the more unique we become. The ultimate capacity of the brain for

learning cannot be measured and will never be known, as that capacity increases with use (Caine & Caine, 1990).

Research tells about learning on a physiological level - the inner-workings of the brain in regard to memory, learning, and retrieval. Brain scientists have begun to identify the molecules involved in forming memories and the locations in the brain where memories are processed and stored. The latest research is forging connections between the cellular and molecular basis of memory and the brain's role in thought and behavior. Researchers have identified some of the key molecules of memory, showing how the brain converts fleeting short-term recall into mental images that can outlast color photographs.

Anything remembered has gone through three distinct phases; a learning stage, in which information is perceived by the brain; a storage stage, in which information is filed; and a retrieval stage, in which information that has been filed is recovered for uses.

Sensory memory or immediate memory allows inputs of all human impressions of the outside world into the brain through the five senses of hearing, sight, touch, taste, and smell. When someone perceives a sight or sound, it lingers in the mind in its original form for only a second or less. The impression that it makes during this time is referred to as sensory memory (Howard, 1994).

If an impression made in the sensory memory is strong enough it passes into short-term memory (STM). STM retains current thoughts for about 20 seconds. It holds new, incoming data as well as thoughts of past experiences. During the moment that they are in conscious thought, these data are considered part of STM.

Short-term memory can hold a "chunk"-an unfamiliar array of seven items at a time, plus or minus two. A technique called "chunking" can stretch this limit, by separating long pieces of information into smaller, easier to recall pieces of information.

To keep new information in STM for longer than 20 seconds, elaborate rehearsal, which is to purposely think about the information and associate it with established facts, is necessary. Rote rehearsal refers to such continued repetition of a fact in order to hold it in STM for a longer period of time.

The capacity for storage in long-term memory (LTM) is astonishingly vast and is located in the cerebral cortex (Siegfried, 1998). LTM stores information like a card catalog in a library. Items are cross-referenced. The more often an item of information is cross-referenced, the more likely it is to be retrieved when needed. The more often an item of information appears or is associated with other items, the easier it is to recall. The greater the number of associations a person can make between a new item of information and data already in LTM, the more likely that item will be to enter LTM.

Although information may be registered in short-term memory and properly encoded and transferred to long-term memory, the mind must be able to retrieve it from long-term memory in order for it to be of use. As information enters LTM, the mind classifies and organizes according to specific principles that make it easier to find later on.

Retrieval of information from LTM can be accomplished through several means. Types of retrieval are:

Reconstructive memory. According to Bartlett (1932), people do not remember accurately the way in which a story was told or an event occurred. Instead, they record information in such a way that it complies with previous personal experiences.

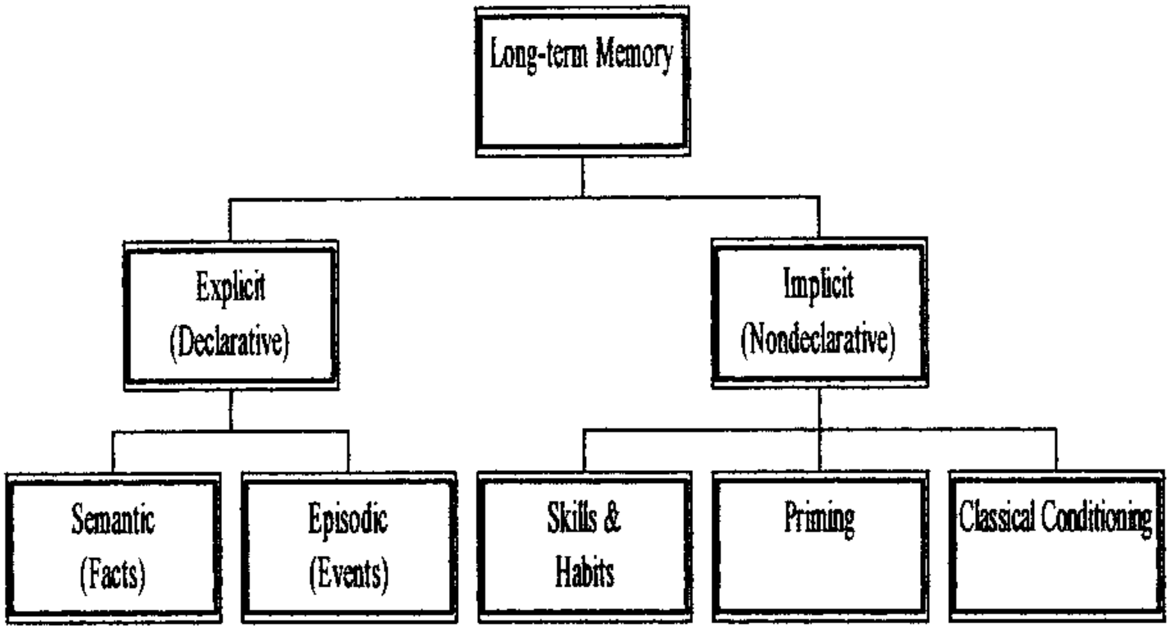
Schemas. Schemas form a basis for storing information, by establishing a framework where familiar information helps a person be better able to recognize new data and locate it in this framework in relation to similar material already stored there. This process helps to streamline the retrieval process.

Conceptual hierarchy. This helps a person to memorize information by putting it into larger categories or sets. This system or organizing items into general categories, and then further subdividing them, is an efficient memory device that the human mind uses constantly without realizing it.

Contextual cues also aid in information retrieval. A recent theory suggests that the memory of an event or piece of information is improved when the individual is surrounded by the same environmental cues that existed when it was learned. It appears that environmental cues that exist during a learning experience may activate the memory for the learned information and aid in its recall.

Learning and memory are also classified as to the types of learning or memory that occur. Long-term memory is generally divided into two broad categories: explicit (or declarative) and implicit (or non declarative) (Siegfried, 1998; Sylwester, 1995; Howard, 1994) Explicit memory involves recall of facts and events, or recognition of people, places, and things. Implicit memory is generally unconscious-involving skills and habits.

Figure 3. Types of Long Term Memory.



Explicit or declarative memory is also divided into episodic memory-very personal, intimately tied to events, and semantic memory-facts, often represented by symbols (Ausubel, 1963; Bartlett, 1932; Sylwester, 1995; Tulving, 1972). Explicit or declarative knowledge of ideas is often characterized as schemas (Rumelhart, 1980). A basic premise of schema theory is that human memory is organized semantically, or by facts. Schemas are arranged in networks (schemata) of interrelated concepts. These networks are known as our semantic network. If memory is organized as a semantic network, then learning can be conceived as a reorganization of the networks in semantic memory. These networks describe what the learner knows, which provides the foundations for learning new ideas, that is, altering and expanding the learner's semantic network through accretion, tuning, and restructuring . This process helps to streamline the retrieval process (Jonassen, Beissner & Yacci, 1993; Slavin, 1994).

The most important principle of schema theory is that information that fits into an existing schema is more easily understood, learned, and retained than information that does not fit into an existing schema. (Ausubel, 1968; Rumelhart, 1980). Schemas allow meaningful learning to occur by connecting new learning to prior learning, but this cannot occur if the learner lacks relevant prior knowledge. This connection between meaning and learning was first studied by David Ausubel (1968). Ausubel stated that the most important single factor influencing learning is what the learner already knows (Ausubel, 1968).

Learners who employ meaningful learning are expected to retain knowledge over time and they, consequently, find ways to connect new information with more general prior learned material. Learners should continuously connect what they are learning to their background and knowledge (All & Havens, 1997). When information is presented in a potentially meaningful way and the learner is encouraged to anchor new ideas with the establishment of links between old and new material, meaningful learning is more likely to occur (Irvine, 1995).

A study by Kuhara-Kojima and Hatano (1991) illustrated this clearly. College learners were taught information about baseball and music. Those who knew a great deal about baseball but not music learned much more about baseball; the opposite was true of those who knew much about music and little about baseball. In fact, background knowledge was much more important than general learning ability in predicting how much the learners would learn. Learners who know a great deal about a subject have more well-developed schemata for incorporating new knowledge. However, learners will often fail to use their prior knowledge to help them learn new material. Instructors must link new learning to the learner's existing background knowledge (Pressley, Harris, Marks, 1992).

Rote learning occurs if the learner simply internalizes knowledge in an arbitrary, verbatim fashion without making the connection between known and new knowledge. Rote learning refers to the memorization of facts or associations, such as the multiplication tables, etc. Much of rote learning involves associations that are essentially arbitrary. For example, the chemical symbol for gold is (Au) and would be more easily remembered if it were (Go or Gd). Rote learning is not "bad", but it is often "inert knowledge" or "knowledge that could and should be applicable to a wide range of situations but is only applied to a restricted set of circumstances" (Slavin, 1994, p. 214).

Procedural knowledge, on the other hand, describes how learners uses or apply their declarative knowledge. Ryle describes this type of knowledge as *knowing how*. Procedural knowledge entails the interrelating of schemas into patterns that represent mental performance which are in turn represented mentally as performance schemata (Sylwester, 1995).

Structural knowledge is an intermediate type of knowledge that mediates the translation of declarative into procedural knowledge and facilitates the application of procedural knowledge. Structural knowledge is the knowledge of how concepts within a domain are interrelated.

Semantic networks describe structural knowledge. They provide a psychological foundation for the epistemological assumptions made about structural knowledge and the inference that researchers have drawn regarding structure. These inferences that have been examined empirically provide a strong rationale for studying structural knowledge (Jonassen, Beissner & Yacci, 1993).

Hemisphericity

More than 2,000 years ago, Hippocrates, observed that our brain had two sides, a left and a right. Roger Sperry's(1968) research and findings helped mold the left- or right-brained approach. Although each hemisphere is dominant in certain activities, they are both basically skilled in all areas, and the mental skills identified by Roger Sperry are actually distributed throughout the cortex. Levy's (1983) research has confirmed that both sides of the brain are involved in nearly every human activity (Jensen, 1996). Michael Gazziniga (1992) says that events occurring in one hemisphere can influence developmental events occurring at the same time at very remote parts of the other hemisphere (Eberle, 1982). Jerome Bruner spoke of left-handed ways of knowing, which is now referred to as right hemisphere knowing. The crossover from hand to hemisphere is understandable since the right hemisphere of the brain controls the left side of the body and vice versa (Bruner, 1965; Torrance, 1977).

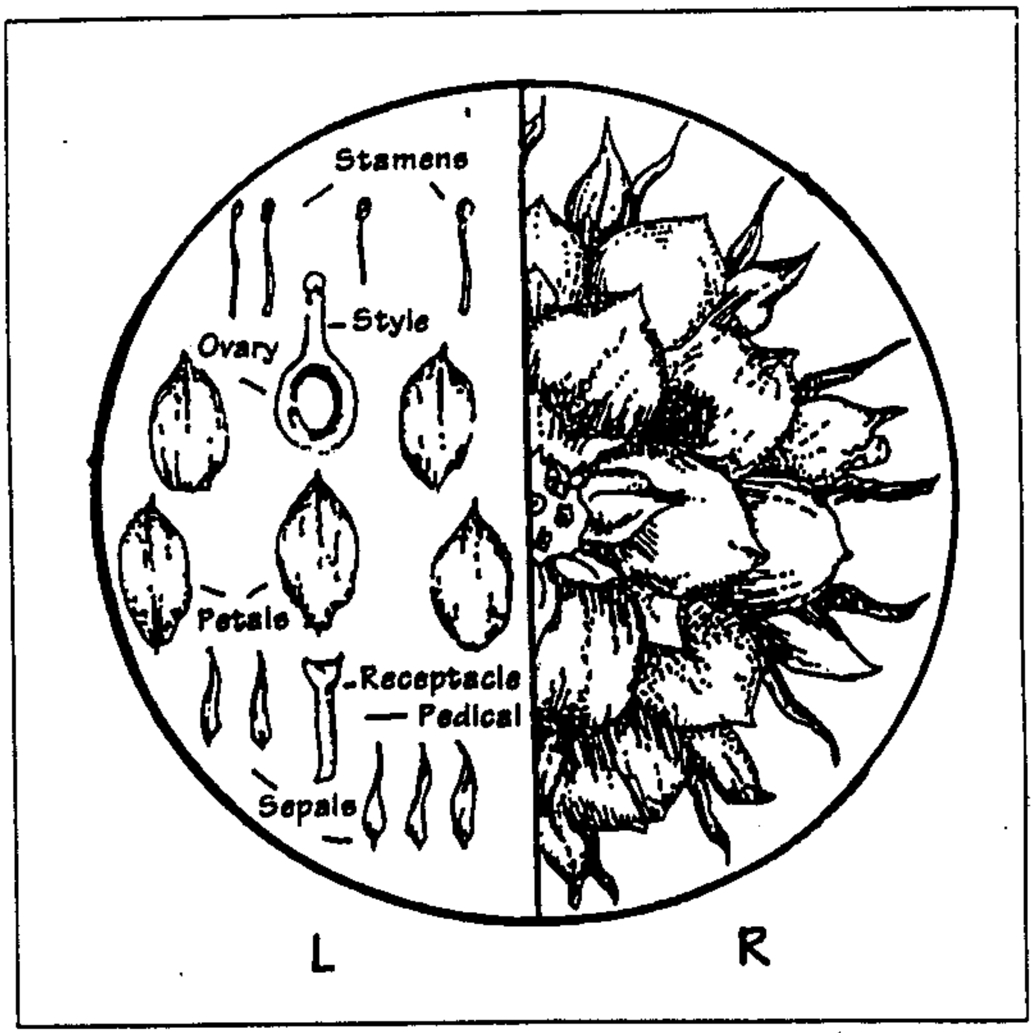
Current brain research has found that (1) The two halves of the brain process information differently; (2) Both hemispheres are equally important in terms of whole-brain functioning; and (3) Individuals rely more on one information processing mode than the other, especially when they approach new learning. (Bogen, 1975).

Individuals' unique methods of operation in the mental sphere have been referred to as their cognitive style (Willing, 1989; Trautman, 1979). Cognitive style has been differentiated by the following terms: "Global vs. Analytic" ; "Holist versus Serialistz" (Pask,1988); "Right versus Left-brained"; "Field-dependent versus Field-independent" (Witkin, Moore, Goodenough, & Cox, 1977.)

The different functions of the two hemispheres have been confirmed by comparing the electrical activity from the left and right sides of the brain. When the brain is in a fairly relaxed state, it tends to show alpha rhythms—that is, waves of about eight to ten cycles per second. Robert Ornstein (1984) compared the relative levels of alpha from the left and right sides of the brain for different mental activities. He found that when he gave his subject a mathematical problem to solve, the alpha increased in the right hemisphere, suggesting that the right side was relaxing, and decreased in the left, showing that awareness was focused more in this side. Conversely, when the subject was asked to match colored patterns, the alpha intensity increased in the left and decreased in the right, suggesting that the subject was making greater use of the right hemisphere (Russell, 1979).

In many people the left hemisphere is concerned with language - speech output, verbal activities, analytical apprehension, serial processing, and linear functions (Springer & Deutsch, 1989). Experiments have shown the right hemisphere to be better in the perception of depth, in the specialization of music and also in the recognition of faces and other familiar patterns (Kimura, 1992; Bever & Chiarello; Ellis & Shepherd; Springer & Deutsch, 1989).

Figure 4. How each hemisphere interprets "flower" (Richards, 1993, p. 20).



The corpus callosum, the main connection between the two brain hemispheres, connects and carries information both ways across the two sides of the brain (Hart, 1983).

> "Any time we consider the brain, we must bear in mind that it has no truly separate parts-every part is elaborately interconnected with

all other parts, and the brain always operates as an intricate system, a whole. Our training may miss training or developing half of the brain, but it probably does so by missing out on the talents of both hemispheres." (Springer & Deutsch, 1989, p.192).

A review of recent studies of mental rotation, response competition, hemispheric activation, regional cerebral blood flow, dreaming, and electrical brain stimulation suggests a trend away from models of global hemispheric specialization, toward componential or computational models that include both sides of the brain as an integrated structure. The precise identification of the area or areas of the brain involved in any postulated component of imagery processing is difficult at this stage, but it is definite that there is involvement of the left hemisphere in imagery processes (Loverock, 1995).

Another difference between left and right hemispheric processing is that the left hemisphere processes in a serial mode while the right processes in parallel. But this only occurs for verbal material. When the items are shapes, both hemispheres appear to work in a parallel mode, since its verbal abilities are no longer of any use in distinguishing abstract shapes (Russell, 1979). It is only a preference, and when obliged to, either hemisphere can function in either mode.

The value of specialization of function is that it effectively increases our mental capacity. Each hemisphere tends to analyze its own input first, only swapping information with the other side once a considerable degree of processing has already taken place. Thus we can process two streams of information at once and then compare and integrate them in order to obtain a broader and more sophisticated impression. Specialization of function also divides the load of each hemisphere (Dimond, 1972).

Language sets up different patterns in your brain. If you learn to write a "picture" language, it is largely learned through part of the right-hand side of your brain. If you grow up in one of the Western "alphabet" cultures, you learn how to take in information through all your senses but to communicate in lineal writing. Communicate in alphabet languages, and you will largely be using a section of the left-hand side of your brain (Dryden & Vos, 1994). Therefore, most people in Western societies tend to use the functions associated with the left side more than those associated with the right (Sylvester, 1994), which is probably the result of culture and training that emphasize the faculties associated with the left (Russell, 1979).

While it does not seem reasonable that learners would be able to switch their hemispheres on and off at will, nor that instruction can be directed to one hemisphere rather than the other, there is certainly evidence that the two hemispheres of the brain process information differently and the right hemisphere is better suited for processing spatial information (Wittrock, 1977).

As far as graphic forms are concerned, it has been speculated that the superiority of instruction in sociology that uses diagrams might be accounted for by the fact that this form calls upon the right-brain processes that otherwise would not have been used by learners. Wittrock (1977) bases his claim on the argument that the right hemisphere can create images that can in turn help the left hemisphere interpret information (Wittrock, 1977).

Results from studies done by Michael Gazzaniga (1992) and Stephen Kosslyn (1980, 1981) demonstrated that image generation is crucially dependent upon the left hemisphere because of that hemisphere's close relation to language processing, but they do not indicate which particular mental operation is involved. Their results support the view that mental operations involved in creating mental imagery are carried out in precise locations, but that different operations may be carried out in widely different areas of the brain. The common belief that creating imagery is a function of the right hemisphere is clearly false. However, the idea that creating imagery is a general function of the brain as a whole is just as false. The operations involved in forming images are localized, even if many different areas become active in the performance of the imagery task (Posner & Rachle, 1994). Ornstein (1997) has changed his original theory on the way the two hemispheres perceive the world, which was in a sequential or simultaneous way, to the thinking that the two hemispheres of the brain organize themselves by the handling of high and low frequencies, be it visual, tone, or kinesthetic. Large dimensions or outlines of vision, fundamental tones, large-muscle movements are handled by the right side of the brain. The left side deals with the details of vision, the auditory overtones, and the precise movements. So our right-brain, left-brain preference may be hard-wired starting in the womb.

Most individuals have a distinct preference for one of these styles of thinking. But by nature, some are more "whole brained" and are equally adept at both modes. These human beings would be termed are whole-brain learners. The brain prefers cooperation rather than conflict, and it will work to develop an efficient system that incorporates the two different processing styles (Richards, 1993).

Lay Ling Yeap's (1989) research measured the psychological domain of the learner in terms of hemisphericity. He compared three levels of learner achievement: low, moderate and high. His research showed significant differences between the low to middle achievers, but between the moderate and high achievers there was a "distinctly different" hemispheric dominance profile (Jensen, 1994; Ornstein, 1997).

Yet numerous studies have shown that when we use both sides of our brain together, the whole brain responds significantly better (Lewis, 1997). In general, training tends to favor left-brain modes of thinking, while down-playing right-brain modes. One way to give everyone the opportunity to learn in a whole brain way is to balance the verbal techniques with visual strategies (Williams, 1983).

Learning Styles

Learning styles can be as the composite of characteristic cognitive, affective, and physiological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment (Keefe, 1979). Included in this comprehensive definition are "cognitive styles," which are intrinsic information-processing patterns that represent a person's typical mode of perceiving, thinking, remembering, and problem-solving (Grinder, 1989).

Learning style is a combination of three factors: How your perceive information most easily—whether you are a visual, auditory, or kinesthetic/tactile learner; How you organize and process information—whether you are predominantly left-brain or right-brain, analytical or global; What conditions are necessary to help you take in and store the information you are learning-emotional, social, physical and environmental (Dryden & Vos, 1994).

When considering how we perceive information there are at least three main learning style preferences: Haptic learners- kinesthetic-tactile learners. Visual learners- who learn best when they can see a picture of what they are studying, with a smaller percentage who are "print-oriented" and can learn by reading. Auditory learners, who learn best through sound: through music and talk (Dryden & Vos, 1994).

Keefe (1989) describes learning style as both a learner characteristic and an instructional strategy. As a learner characteristic, learning style is an indicator of how a learner learns and likes to learn. As an instructional strategy, it informs the cognition, context and content of learning. Each learner has distinct and consistent preferred ways of perception, organization and retention. These learning styles are characteristic cognitive, affective, and physiological behaviors that serve as relatively stable indicators of how learners perceive, interact with and respond to the learning environment.

Every human being has a learning style and every human being has strengths. One's learning style is as individual as a signature; no learning style is better - or worse- than any other style; and all groups - cultural, academic, male, female, - include all types of learning styles (Dryden & Vos, 1994; Dunn & Dunn, 1978)

Researchers have identified twenty-two factors (most of which are biologically determined) that can powerfully affect our ability to take on and process new learning.

Research validates that when learners go about their learning in concert with their personal learning style requirements, all can be successful learners, regardless of subject matter (Reichmann & Grasha, 1974; Keefe, 1989). Knowles states that a central principle of andragogy (the instructing of adults) should be the consideration of the learners' life experience as well as their learning styles (Knowles, 1984).

Diagnosing and interpreting learning styles provide data as to how individuals perceive, interact with, and respond to the learning environment. A knowledge of our own learning style makes us aware of needs of learners, which implies knowledge of our own preferences and a conscious effort to expand our repertoire of instructional strategies and techniques to respond to learner diversity.

Many instruments assess learning style (Dunn, Dunn, & Price, 1982, 1985; Perrin, 1981; Hermann, 1996; Kolb,1985; Gregorc, 1979). Many of these instruments base their development on a similar conception of thinking and experience.

The learning style instruments selected for this study are part of the assessment tools for Bernice McCarthy's 4MAT system. The 4MAT system is an eight-step cycle of instruction that capitalizes on individual learning styles and brain dominance processing preferences. "The theories of David Kolb (1981, 1984,1985), Carl Jung (1923), Jean Piaget (1969), Joseph Bogen (1975), Gabriele Rico (1983), Betty Edwards (1979), and John Bradshaw and Norman Nettleton (1983) have contributed to 4MAT's conception." (McCarthy, 1990, p. 31).

According to Bernice McCarthy's 4MAT system, we all learn in a whole brain style with dominance for left or right brain in each quadrant. This cycle of learning is based on a number of premises. First, is David Kolb's (1976, 1984,1985) premise that describes the two major differences in how people learn: How they perceive and how they process. Different individuals perceive and process experience in different preferred ways and these preferences comprise our unique learning styles. Essential to quality learning is an awareness in the learner of his/her own preferred mode, becoming comfortable with his/her own best ways of learning and being helped to develop a learning repertoire, through experience with alternative modes. McCarthy's system incorporates left brain/right brain research into an instructional system that identifies four different learning styles:

· Type 1: Innovative Learners are primarily interested in personal meaning. They need to have reasons for learning--ideally, reasons that connect new information with personal experience and establish that information's usefulness in daily life.

· Type 2: Analytic Learners are primarily interested in acquiring facts in order to deepen their understanding of concepts and processes.

· Type 3: Common Sense Learners are primarily interested in how things work; they want to "get in and try it."

· Type 4: Dynamic Learners are primarily interested in self-directed discovery. They rely heavily on their own intuition, and seek to instruct both themselves and others (McCarthy, 1980).

Inherent in the 4MAT System are two major premises: (1) people have major learning styles and hemispheric (right mode/left-mode) processing preferences; and (2) designing and using multiple instructional strategies in a systematic framework to instruct to these preferences can improve instructing and learning.

Experiments show that learners learn best when their learning style is matched by the instructor's instructing style (Cafferty, 1980), but the typical class contains a wide array of different learner learning styles.

In experiments by Torrance and Ball (1978), learner learning styles were assessed, and then the learners were put through a course to expose them to alternative learning strategies. Through exposure to right-hemisphere, non-linear learning strategies (imagery, intuition, brainstorming, metaphors, etc.), the learners were able to make more use of their existing capabilities and extend into new areas. The results also showed that the learners were able "to change their preferred styles of learning and thinking through brief but intensive training" (Torrance & Ball, 1978).

Studies suggest that the effectiveness of learners' strategies depends on the context of learning and on the learner's own characteristics (e.g. academic environments, learning style) (Pask, 1988).

Metacognition

For learning to occur, it is necessary to instruct learners on *how to learn*. Because learning is a knowledge domain just as physics and medicine, instruction should be given to enable learners to incorporate this type of knowledge and/or skill into their schemas (Gagne', 1985). Studies show that people have had developmental increases in the amount they know about their own cognitive processes (Brown and DeLoache, 1978; Flavell, 1979). Therefore, metacognitive instruction would be beneficial.

The term metacognition is used to describe the mind's management system (Gagne, 1985; Flavell, 1985). Basically, metacognition means that, when confronted with a dilemma or some obstacle, humans draw on their mental resources to plan a course of action, monitor that strategy while executing it, then reflect on the strategy to evaluate its productiveness in terms of the outcomes it was intended to achieve (Hyerle, 1996).

Brown (1978), Flavell (Flavell & Wellman, 1977), and Markman (1979) were pioneers in this area and described metacognition as the explicit consciousness of ourselves as problem solvers. This ability is a higher level process and involves the possession of lower cognitive levels such as basic processes of working memory, crystallized knowledge in the form of mental schemas and strategies, and weak and strong methods of problem solving.

Metacognition includes two linked capabilities: the ability to focus awareness and the ability to control or direct mental processing to achieve goals. Metacognitive awareness monitors activity in all the layered systems of the mind, but allows attention to be focused on one thing at a time. Timing, sequencing, recognizing checkpoints in a process, aiming for effects, evaluating errors, choosing and adapting strategies, and checking output against goals-such is the work of metacognition. Metacognitive control directs the work of the mind toward purposes, rather just letting things happen (Clarke, 1990).

Studies have indicated that poor learners are unable to monitor the use of metacognitive skills as good learners do. Monitoring involves the continuous process of determining strategy effectiveness via knowledge products. This in turn leads to strategy alteration towards maximized usage and output. At the same time, monitoring within a domain-specific domain is dependent on general metacognitive skills and domain-specific knowledge (Schraw, Dunkle, Bendixen, Roedel & DeBacker, 1995). Also, knowledge about cognition does not necessarily lead to its regulation and usage (Schraw, 1994). Despite the fact that individuals are aware of metacognitive knowledge many do not use this to monitor performance (e.g. reading comprehension). Brown, Bransford, Ferrara and Campione (1983) found that less skilled learners were less likely to use self-assessment techniques such as self-tests and self-questioning as a means of gauging the appropriateness and correction of knowledge concepts and strategy usage. Thus, monitoring of higher level processes within the learning paradigm (e.g. comprehension, memory) is in itself a metacognitive skill (Markman, 1985).

In essence, "the ability to apply this skill differentiated strong and weak learners of all ages" and that it is not a tendency made explicit through development (Bruer, 1993, p. 72). Pressley (1990) has suggested that poor monitoring is evident in even skilled adult (e.g. readers) and results in knowledge acquisition and achievement failures. Thus there appears a need for such metacognitive strategies such as self-monitoring to be taught. Instructing metacognitive strategies have been considered challenging and often requires externalizing thoughts as a means to cognition awareness (Perkins, Simmons & Tishman,1990).

Research has shown that when learners are taught learn-to-learn skills, their ability to process new information can rise substantially (Weinstein & Underwood, 1985; Segal, Chipman & Glaser, 1985). Other studies on metacognition have shown the importance of metacognition skills (Belmont, Butterfield, & Borkowski, 1978; Pressly & Levin, 1983; Paris, Newman & McVey, 1982).

Learning Strategies

Memory devices have been around since 500 or 600 BC. The Greeks and Romans used well-developed imagery, mnemonics and the memory house, derived from Aristotle's model of memory, very effectively. The pedagogical uses of most of these types of strategies has declined.

Many learners lack and are unaware of the techniques available to them through the use of learning strategies and basic study skills. In most situations, instruction of study skills in any systematic way is nonexistent, and most instructors appear to expect learners to develop study skills by osmosis or maturation.

Studying the thought processes involved in stimulating learning, memory, and comprehension based on the new cognitive research, has caused a recent resurgence in the interest of instructing, learning and using strategies. According to Pressley (1995) the concept of cognitive strategies, and the research being conducted that shows that learning can be facilitated by the use of many strategies, represent the most important instructional advance of the past 15 years. Learning strategies have been defined as "mental operations or procedures that a learner may use to acquire, retain, and retrieve different kinds of knowledge and performance" (Rigney Lutz, 1976, p. 165; Danserau, 1985, p. 13).

The term learning strategies is used in a very broad sense to identify a number of different competencies that researchers and practitioners have postulated as necessary, or helpful, for effective learning and retention of information for later use. These competencies include cognitive information-processing strategies, such as techniques for organizing and elaborating on incoming information to make it more meaningful; active study strategies, such as systems for note-taking and test preparation; and support strategies, such as techniques for organizing study time, coping with performance anxiety, and directing attention to the learning task at hand. In addition, there is a range of metacognitive strategies that learners can use to detect discrepancies between what they know and what they do not know and to monitor and direct their acquisition of the new information (Weinstein, 1985, 1988).

There are different classes of learning strategies designed to facilitate different types of learning (Jonassen, 1984) and meta-learning. Learning or memory strategies include paired-associate learning, serial learning, and free-recall learning. Specific strategies under these areas are imagery, stimulus selection and coding, keyword mnemonics, the loci method (Anderson, 1989), the pegword method (Paivio, 1971), and initial letter strategies. These techniques engage learners in higher-order thinking such as exemplifying, categorizing, integrating, elaborating, and analyzing. Mapping techniques such as pattern notes and concept maps require learners to graphically analyze subject matter in order to illustrate its structures (Jonassen, et al., 1993).

The benefit of formal training in strategy instruction has been shown to have significant positive impacts on the learner (Segal, et al., 1985; Weinstein & Underwood, 1985; Pressley, et al., 1995; Kulik, Kulik & Schwalb, 1983). This emphasis was also evident in a study by Chi and her colleagues (1988), who explored the learning strategies used by academically successful and less-successful college learners as they encountered examples in their physics texts. Chi and her colleagues found that successful learners engaged in a process of self-explanation; they tried to figure out why each particular aspect of the solution was applicable and asked themselves about other cases in which the general solution might also be applicable. As a result, they acquired an understanding that was more general than a memorization of the specific steps necessary for the particular problem in the text. Academically less-successful learners showed much less of a tendency to attempt to explain to themselves why and when particular solutions worked.

Visual Strategies

Vision is of vital importance to learning. When we think, we see or visualize. Vision and thinking are one process; they cannot be separated, either logically or physiologically.

The earliest records of human drawings was during the Ice Age. Between 60,000 to 10,000 BC, cave dwellers in France, Spain, Africa, and Scandinavia painted drawings of animals and scenes from their own experience. Such pictorial imagery eventually led to the development of writing and mathematics. Language evolved from images to pictographs to symbolic codes becoming increasingly abstract.

The most powerful influences on your learners' behaviors are concrete, vivid images. Current research shows that things that we can see or picture in our minds are generally easier to learn and remember than things we cannot see or picture. Information processing research suggests that this is because our working memories can hold only seven or so chunks of information before some information is forgotten. Images, which form a continuous representation of information, therefore take up less space than things we cannot imagine. Consequently, many items can be "chunked" together as one image, leaving much more space in working memory for additional information or thought (Gagne, Yekovich & Yekovich, 1993). In a study on memory, Ralph Haber showed that humans have an almost photographic visual memory. Subjects were shown 2560 photos, then subjects were show 2560 pairs of photos and asked in each case which photo was in the original group of 2560. The success rate averaged between 85% and 95%. (Haber, 1989).

Fossil records indicate that long before the human mechanisms for speech had evolved, the organs of vision were highly developed, serving as important tools of knowledge for early human beings.

Neural tissue developed in order to make use of incoming visual information, but the eye is not the recorder of information (Sless, 1981). The eye is not biologically separate from the brain. It is actually part of the same organ; or more accurately, the brain is part of the eye. In the development of the embryo, the eyes are first to appear, the brain being a subsequent outgrowth. In structural terms, the eyes have not grown out of the brain, the brain has receded from the eyes (Sless,1981). Seventy percent of our body's sensory receptors are located in our eyes. To absorb light rays the retina has 120 million rods and 7 million cones, with each rod or cone focusing on a small, specific segment of the visual field.

Neuroscientists say that vision is important and effective because 1) the brain has an attentional bias for high contrast and novelty; 2) 90% of the brain's sensory input is from visual sources; and 3) the brain has an immediate and primitive response to symbols, icons and strong, simple images (Jensen,1995).

The eye, unlike a camera, is not a mechanism for capturing images so much as it is a complex processing unit to detect change, form, and features, and which selectively prepares data that the brain must then interpret (Barry, 1997).

The crossover in the visual system is slightly more complex than in the rest of the body. The eyes themselves are not directly crossed, but the left side of the retina of each eye connects to the left side of the brain, and the right side of the retina of each eye connects to the right side of the brain. Thus, since the retinal image is inverted, the left side of the visual field connects to the right side of the brain and the right side of the visual field connects to the left side (Russell, 1979).

In recent decades scientists have made extraordinary progress in understanding the processes that transform words into images. The study of imagery forms a part of a more general inquiry into the relationship of mind and brain that is now producing real insight into workings of this least understood of human organs. A number of researchers have used imagery theory as the basis for constructing and testing hypotheses concerning learning from graphic forms. Rigney and Lutz (1976) used computer graphics in a lesson on the battery and found that these helped learners learn the material. They accounted for their findings in terms of the images that they suspected the graphics encouraged the learners to form. In a subsequent study, Alesandrini (1981) reported that learners who had to draw a diagram of the battery and who related specific details to more inclusive concepts performed better than learners who did not. In this study, imagery appeared to be related to visual, holistic thinking. These studies exemplify a body of research that leads to the following conclusion: Graphic forms encourage learners to create mental images that, in turn, make it easier for them to learn certain types of material.

One of the main theorists in visualization, Paivio (1971, 1986) proposes the dual-code model, a verbal system specialized for processing and storing linguistic information and a separate nonverbal system for spatial information and mental imagery. The two systems can function independently, but they are also interconnected so that, for example, a person looking at a picture might engage in covert verbalization. When a concept is registered in both memory systems, it is said to be dual-coded. Paivio argues that dual-coding is more likely to occur with pictures than with words, and since two memory traces are better than one, dual-coding explains the pictorial superiority effect. Once concrete images are established within the learner's memory, they will act as hooks on which other ideas are connected. This is what Gambrell and Bales (1986) refer to as associative learning and it forms the basis for a learning theory known as concept mapping.

In addition to Paivio, a number of researchers have proposed that certain types of information are stored in memory as image-like structures (Anderson 1978; Kosslyn, 1980, 1981; Shepard, 1978; Shepard & Cooper, 1982) which retain some, though not all, of the properties of the pictures, the graphic forms, or the direct visual experiences that give rise to them. It should be added that there has been considerable debate as to whether this is in fact the case, or whether all information in memory is stored as propositions in language-like structures as Pylyshyn (1973, 1981) has suggested.

Research has shown that many learners are visually oriented and that such individuals benefit more from visually oriented learning strategies (Dwyer, 1972; Lesgold, Mccormick, and Goinkoff, 1975; Carnine and Kinder, 1985). Mapping seems to be an advantage to learners who are visually oriented -they become better learners; and visual images of maps are likely to stick in the memory longer and more accurately than words alone (Smith, 1991).

Visual/spatial intelligence is one of Howard Gardner's (1993) theory of multiple intelligences made up of eight intelligences: musical, spatial (visual), interpersonal, intrapersonal, naturalist, logical, linguistic, and bodily kinesthetic intelligence. Visual/spatial intelligence requires the incorporation of visual/spatial learning strategies and tools for the best learning to occur. Visual-spatial intelligence includes an aggregate of related skills including visual discrimination, recognition, projection, mental imagery, spatial reasoning, image manipulation, and the duplication of inner or external imagery, any or all of which may be expressed by a single person.

Although visualization is central to spatial intelligence, it is not directly related to sight, and in fact, can be highly developed in those who are blind (Lewis, 1997). This intelligence is referred to as both visual and spatial since people perceive and process information through both modalities.

Spatial learning strategies are aimed at coding and transforming text information into spatial representations that preserve and make explicit the structural information that can be abstracted from a text. Today, most training stresses the importance of abstract symbols in reading, writing, and arithmetic, often overlooking other aspects of visual-spatial intelligence.

Mapping Strategies

The theory behind the use of mapping strategies involves all of the latest neuroscience, learning theory, learning style assessments, hemisphericity assessments and visual implications.

Research conducted over a number of years in cognitive science and human factor engineering shows that we need to provide learners with skills or techniques for acquiring knowledge. An extensive study of instruction found that presenters still used strategies that consisted mainly of their own talk and monitored seatwork (Goodlad, 1983; Gardner, 1991). Zemke (1998) states that self-directed learning strategies may be the only way to meet the knowledge requirements of this vastly changing and competitive marketplace and because of this, the development of mapping strategies, like Mind Mapping will be essential to workers long-term ability to keep learning.

There are many terms for mapping strategies-visual representations of ideas. Terms such as webbing (Bromley, 1996), Mind Mapping (Buzan, 1994), pattern noting (Buzan, 1974), clustering (Rico, 1983), semantic maps, cognitive maps, graphic organizers, mindscaping (Marguiles, 1991), knowledge maps or K-mapping (McCagg &

Dansereau, 1991), organizational matrix (Ausubel, 1960), concept maps (Novak & Gowin, 1984), comprehension strategies (Hill, 1994), learning maps (Rose & Nicholl, 1997), and thinking maps (Hyerle, 1996) are seen throughout the literature and are often used interchangeably.

In this portion of the review of literature, I will use the term *mapping strategies* or *maps* as a generic term for any of these learning strategies..

The most succinct definition of the array of these mapping strategies is " . . . words on paper, arranged to represent an individual's understanding of the relationship between words. Whereas conventions of sentence structure make most writing linear in form, graphic organizers take their form from the presumed structure of relationships among ideas" (Clarke, 1990, p. 30). Bromley states, ". . . no matter what the special name, a graphic organizer is a visual representation of knowledge" (Bromley, 1996, p. 6). Hyerle describes his "thinking" visual tools as forms of metacognition-graphically displayed thinking processes (Hyerle, 1996).

Each mapping strategy --visual outlines, spatial organizers, concept maps, mindmaps, clusters, or mindscapes--is clearly useful for different purposes and preferences. Not only are they useful for organizing information, but also for generating ideas. They are used to create patterns, build connections, and establish associations between the learner's own experience and new information, between known facts and new concepts, between parts of a concept or problem and its whole. Some of the processes are more linear in nature and lend themselves to analytical tasks; whereas others are more global, and are useful for creative purposes. None of these mapping strategies are difficult to instruct or to learn, and they all offer both instructors and learners an array of tools for the variety of tasks involved in the learning process (Campbell, Campbell, & Dickinson, 1996).

The process involved in creating maps is for the learner to begin with a center or nucleus. The general idea of the lecture, book, movie, the topic for creative writing, or the central issue in a problem-solving exercise, is placed in the center of the page. Main ideas are connected to the central topic by drawing lines from the center. Supporting ideas become branches off main ideas. Working outward from the center in all directions, the learner produces a growing, organized structure composed of key words, phrases, and images.

Mapping strategies are based on these premises:

1. Meaningful learning involves the assimilation of new concepts and propositions into existing cognitive structures. In order for learning to occur it must be meaningful. Brain based learning has as one of its objectives to develop a sense of deeper meaning- as opposed to surface meaning. Deeper meaning can only occur when an emotional investment is made by the learner. Deep meaning also requires multiple associations on multiple levels throughout the material (Jensen, 1996). The theory of knowledge (epistemology) underlying mapping strategies holds that the new meaning humans construct about events or objects is based upon their prior knowledge (All & Havens, 1997). Maps have been reported to be a potent instructional tool for promoting what Ausubel has described as meaningful learning. Meaningful learning refers to anchoring new ideas or concepts with previously acquired knowledge in a nonarbitrary way (Novak,

1993). It is now recognized that the maps are more meaningful if the links between the concepts are labeled with a reason for that link (Novak, 1990; Stewart, 1979). In a study of the effect of meaningfulness on learning, groups were tested on recall of facts after reading a selection. Subjects that used mindful strategies making the material relevant to themselves versus subjects that learned the material in the traditional manner, performed significantly better, recalling more of the information. (Lieberman & Langer, 1995; p.78, Langer, 1997).

2. Knowledge is organized hierarchically in cognitive structure, and most new learning involves subsumption of concepts and propositions into existing hierarchies. Because learning occurs in an organized way (Ausubel, 1968; Novak & Gowin, 1984), structural knowledge is essential to recall and comprehension. We naturally and necessarily organize our mental representations of phenomena in order to be able to access them. The more semantically meaningful the relationships between the ideas are, the better they are recalled. When important information is isolated, we can see how concepts are connected, and this makes it more easily understood (Novak & Gowin, 1984).

3. Knowledge acquired by rote learning will not be assimilated. Memorization of facts and specific skills are the lowest level of learning (Caine & Caine, 1996).

Most of the research on maps is in the area of advance organizer and concept maps. Advance organizers, developed by David Ausubel (1960, 1963), helps to orient learners to material they are about to learn and to help them recall related information that could be used to assist in incorporating new information. There is some evidence that use of advance organizers increases learner learning, although the magnitude of the effect is controversial (Corkill, 1992; Glover et al., 1990). Some researchers present the learners with the concepts to be used in the map while others require the learners to generate their own concepts (e.g., Edwards & Fraseer, 1983; Okebukola, 1990). Advance organizers seem to be most useful for instructing content that has a well-organized structure that may not be immediately apparent to learners. Advance organizers help learners activate prior knowledge, and provide an anchor for later learning (Austin & Shore, 1994).

Concept maps, developed by Joseph Novak in 1972, are flexible diagrams showing relationships between concepts (Novak, 1990). The use of this instructional strategy encourages the identification of key concepts and their relationships, thus facilitating the encoding of information into long-term memory and successful recall of concepts at a later date (Van Patten, Chao, & Reigeluth, 1986; Ault, 1985).

Research on the effects of concept mapping as a study technique is mixed. Studies using concept mapping as a tool for learning have been primarily related to science training. In these studies, researchers investigated the effectiveness of concept mapping on the learners' organization of content, achievement, and attitudes toward concept mapping as a learning strategy. Many authors have reported successful training applications of concept mapping (Ault, 1985; Arnaudin et al, 1984; Novak, Gowin, & Johansen, 1983; Novak, 1991; Mikulecky, Clark & Adams, 1988; Heinze-Fry and Novak, 1990; Jegede, Alaiyemola, and Okebukola, 1990; Okebukola, 1990; Willerman & MacHarg 1991; Smith & Dwyer, 1995; Pinto & Zeitz, 1997; Armbruster, Anderson and Meyer, 1991; Clarke, 1991; Horton, McConney, Gallo, Woods, Senn, 1993).

Research into the effectiveness of the use of mapping strategies has shown that creating maps to illustrate the organization of ideas and information aids comprehension, learning, and recall (Armbruster, Anderson, & Meyer, 1991; Anderson & Arbruster, 1980,1984; Flood & Lapp, 1988; Heimlich & Pittelman, 1986; Dunston, 1992; Moore & Readance, 1984; Chi, Feltovich, & Glaser, 1988; Gaines, 1996; Okebuklo, 1990).

Studies show that the effects of mapping strategies are greatest when learners have in-depth instruction in their use and are actively engaged in the construction of the graphics themselves. However, the technique is not equally effective among all learners. Low-achieving and midrange learners appear to benefit most from mapping content, whereas high-achieving learners may see it as a diversion from techniques that already work for them (Holly & Dansereau, 1984).

A disadvantage of the use of concept mapping is that it can be time consuming, first in learning the technique and then in putting it to use. With limited prior knowledge, learners may find concept mapping of little value (McKeachie, 1984). When mapping is taught as a study technique, refinement of the process to ensure accuracy and inclusiveness can take several weeks (Dansereau & Holley, 1984; Arnaudin et al., 1984).

A study by Jay (1994) indicated that the use of concept mapping in a college-level cell biology course was positive attitudinally, but no significant difference in achievement was ascertained. Learners indicated that an instructor-generated "concept list" was necessary for success with concept mapping. Using "free form" mapping may fail to clarify the nature of relationships included, leaving vagueness in both concepts and their relationships (Van Patten, Chao, & Reigeluth, 1986).

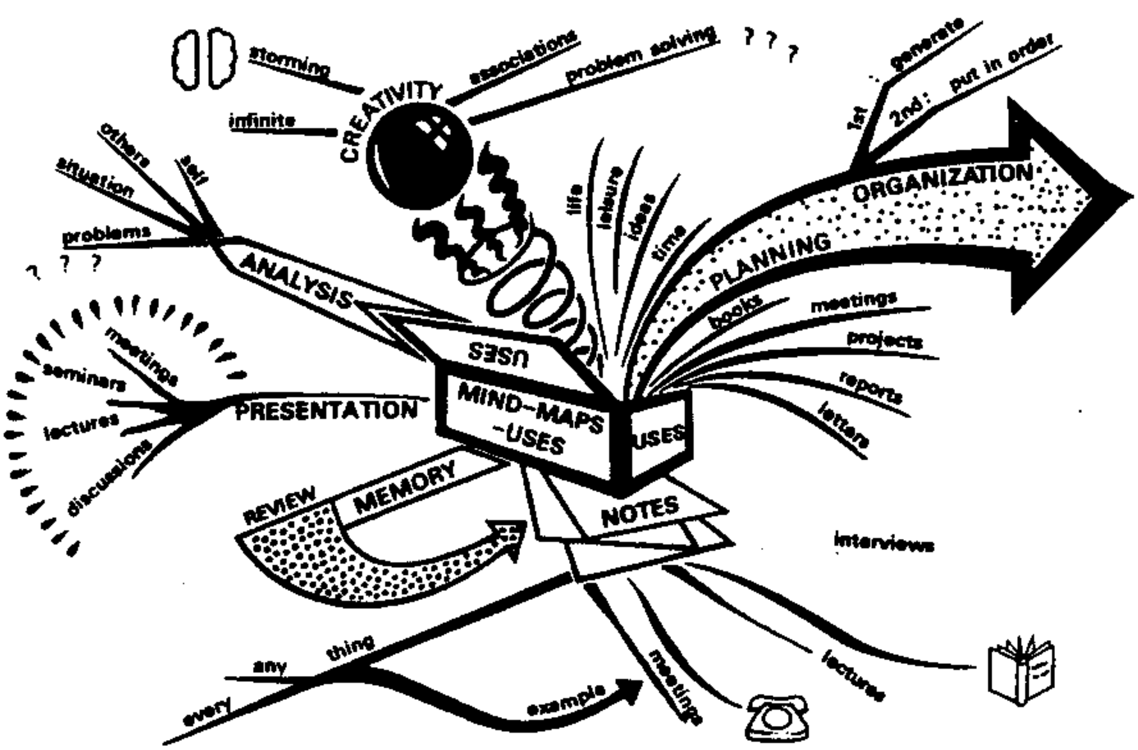
Mind Mapping

Tony Buzan (1984) originated the Mind Mapping technique as a spatial, non-linear approach to note-taking since it taps the mind's natural ability to work in an integrated, interlinked, complex manner. The theories and concepts behind learning strategies and other types of mapping hold true for Mind Mapping except that mindmaps feature treelike branches of information that display key concepts as well as relationships. Differing from more linear concept maps and other mapping strategies, however, mindmaps are more global in their approach.

Mind Mapping is a brain-based learning strategy in that it meets all the requirements of the brain for long-term learning. Maps are a dynamic way to capture significant points of information. They use a global format, allowing information to be displayed in the same way that our brain functions-in many directions simultaneously. Ornstein (1984) has shown that the process of thinking is a complex combination of words, pictures, scenarios, colors, and even sound and music. Thus the process of presenting and capturing lesson content in maps closely approximates the natural operation of thinking. (Rose, 1997).

The human brain is not designed for linear, one-path thought (Hart, 1983). The human brain does not store information in neat lines or columns. The brain stores information on its tree-like dendrites. Mind Mapping has its origins in the results of research into the human brain. Like brain cells which have a central body with a lot of branches which radiate from the center or nucleus of the cell, the mindmap starts with a central image and branches are added. The branches carry the information transmitted by the cell. As with a brain cell, the branches are bundles of chemicals which carry messages. Messages are passed from brain cell to brain cell, forming pathways that create a kind of memory map. These pathways become more efficient the more they are used. The brain stores information by patterns and association. Mind Mapping and taking notes with pictures, color, symbols and patterns and associations, follows the same steps as the brain does in learning and in this manner we make use of the innate abilities of the human brain.

Figure 5. Mindmap on Mind Mapping (Russell, 1979, p. 181).



To create a mindmap for note-taking, start with a central concept, add sub-topics on the connecting lines. Colors, images, and key words should be placed in the middle of a page. Codes can be used as mnemonic devices. Color-coding can be used in the appropriate topic areas. The words in a mindmap should be printed. Mindmaps have pictorial elements added. These words and visual patterns provide you with highly charged cues to "jog" your memory.

Mindmaps are useful for several purposes, however, for the purpose of this study I will limit the research to the effectiveness of Mind Mapping as a note-taking device. Although the human race has made visual notes throughout history, i.e.--the cave paintings of primitive man, the hieroglyphics of ancient Egypt, and early Chinese ideograms (Gregory, 1970), in recent history learners have taken linear notes, by writing down words line by line. Most people find that note-taking insures better recall of information. Positive effects of note taking as a study strategy are most likely when used with complex, conceptual material in which the critical task is to identify the main ideas (Anderson and Armbruster, 1984). Simply writing down information as notes is not as effective as note-taking that requires some mental processing before writing (Kiewra et al., 1991; Kiewra, 1991). In a study on note-taking systems, Michael Howe (1977) found that "Key word notes personally made" (vs. Fill-in blanks and another's notes) scored highest in understanding and recall compared to other non-patterned note-taking systems (Jensen, 1994,1996). Howe found that when the ratio of key words to non-key words is higher, the better the recall. Because key words have greater meaningful content they tend to "lock up" more information in memory and are "keys" to recalling ideas (Russell, 1979).

In another study, Buzan studied the three common techniques for taking notes during a lecture: writing a complete transcript, writing a summary, and writing key words. The results of his study showed that the learner who writes his own key words showed the greatest amount of learning and retention. (Buzan, 1993).

Mind Mapping offers many advantages over conventional formats of notetaking. Mind Mapping capitalizes on several factors that enhance recall. Essential key words are noted, associations, relationships, and patterns are highlighted, hemispheric interplay exists, conscious involvement is required, subjective visual organization is imposed, and input is through dual-coding.. These techniques employ free-association of ideas, creating a "structure" quite unlike the traditional outline method, but equally effective.

Key Words. Key words are one of the most helpful and critical parts of a mindmap. Some estimates claim that only five to ten per cent of language consists of key words. Learners who rely on conventional, long-hand, or outline-formatted notes may be at a disadvantage. Time and energy are wasted in such note-taking, information is lost, reviews are too lengthy and the key words are disconnected visually from important relationships.

Patterning. The complexity and elegance of the way the brain learns is quite amazing. The brain is a self-organizer (Caine & Caine, 1996) and has an enormous capability of categorizing in connected ways (Carnine, 1990). One of the most unique and useful traits of our brain is its innate ability to make patterns. To bring meaning to life experiences, the brain, acting as a pattern sensor, looks for patterns in daily experience that agree with its own internal patterns. New learning is facilitated when the brain can relate newly introduced material to something it already knows (Caine & Caine 1991; Edelman, 1992). Having made patterns, the brain uses them as guidelines to drive behavior. These patterns then tend to be acted out in daily experience, generally without our recognizing the connection between them and our actual behavior and experience (Caine & Caine, 1991). As a patterning device, the brain almost certainly has no equal. It is capable of sorting and storing virtually every major piece of data it takes in.

Associations. The brain is very efficient. It stores information by making great use of associations (Dryden & Vos, 1994). Every person's brain has an association cortex. It can link up like with like, from different memory banks (Jensen, 1995, p.141). By working directly and consciously with the brain's pattern making function, we can access expanded brain function and take advantage of two important aspects of memory which are association and emphasis. When we learn something new, the new information is stored by associating it with something we have already stored, making it easier to remember something new. We also easily remember new things that are emphasized as being unique or very important.

Hemisphericity interplay. Mind Mapping makes provision for hemispheric interplay. A mindmap uses both right and left brain functions. The process begins as a left brain activity involving task orientation. Then, the process shifts to the right brain where image-making, ideation, and insight can take place. Returning to the left brain, images and ideas are verbalized and the creative results evaluated (Eberle, 1982). Buzan (1994) feels that by labeling people as either left- or right-side dominant we are missing the importance of hemisphericity discussions, therefore it is counter-productive. Utilizing skills inherent to both sides of the brain, become very valuable techniques. Mindmaps are compatible with "schema" theories of cognitive processing in which information about a concept is filed into an existing framework of categories (Rumelhart, 1980) So, when prior knowledge is retrieved, this schema provides a framework on which to attach new knowledge.

Visual. When something can be visualized, it is easier to remember, and mindmaps are highly visual. Visualizing the mindmap will help to release the flow of information being learned (Richards, 1993). By organizing the details of a subject into categories, a visual pattern develops that unifies the separate parts into a whole.

Dual input. Mapping strategies provide input in two modes (visual and verbal), rather than just one (Paivio, 1971). The use of both visual and verbal language to create maps results in active learning. The learner is engaged through listening, speaking, reading, writing, and thinking, and this aids meaningful learning. A map containing key ideas and information is easier to remember than extended text, whether the text is visual or verbal (Vygotsky, 1962).

Research on Mind Mapping

Research supports Mind Mapping as a learning aid. It has been discovered that creating a suitable mindmap can greatly enhance learning and memory. Learners compile chunks of information that are retrieved through schema memory structure. Much of the research examining the use of mapping strategies is in the area of reading. These studies show that they aid in comprehension (Dunston, 1992; Moore & Readance, 1984)

Research on outlining, networking and mapping is limited and inconsistent, but generally finds that these methods are helpful as study aids and help learners understand and recall information better (Anderson and Armbruster, 1984; Van Patten et al., 1986) Much of the research has been done with younger children (Chi, Feltovich, & Glaser, 1988), but positive results were also found with adolescents and adults.

The literature review resulted in only one dissertation specifically on Mind Mapping. This study was conducted for adults in a corporate setting on the effectiveness of Mind Mapping vs. traditional note-taking. In addition, brain hemisphericity was also assessed. The Human Information Processing Survey (HIPS) was administered to the experimental group in the study. The HIPS survey sampled the specialized functions of the right and left brain hemispheres. A right, left, or integrated brain hemisphere style profile was measured. Data from the HIPS was correlated with an attitudinal survey to examine a possible relationship between brain dominance and attitude towards Mind Mapping. The study showed that those with a right brain preference had higher test performance and also reported a positive preference for Mind Mapping on the attitudinal survey (Mehegan, 1996).

Rooda conducted a study to determine if the introduction of the instructing strategy, Mind Mapping, into an introductory nursing research course would increase overall learner performance. The results supported the use of Mind Mapping activities as a way to improve academic success (Rooda, 1994).

McCagg and Dansereau's (1991) studied mapping as a supplemental learning strategy in a college classroom. In this study, a multiple choice test was used to assess achievement. Results of their study indicated that learner implementation of mapping activities led to improved performance on multiple choice tests.

Malloy (1987) conducted a study on the effects of introducing college learners to techniques that would assist them in integrating diverse ideas at a deep cognitive processing level. The study evaluated writing in the college classroom with an experimental group that was taught integration techniques of Mind Mapping, visual imagery, and analogy against a control group that was given practice in organizing papers and paragraphs. The criterion task to test their integrative abilities required subjects to integrate three unrelated, abstract ideas. The results indicated that the group given integration techniques of Mind Mapping, visual imagery and analogy scored higher than the control group. The experimental group also showed that the techniques affected their organization as well as their surface structure of the written product (Malloy, 1987).

In a study by Keng (1996) comparing the effectiveness of outlining, concept mapping, and note-taking as learning strategies on non-science students' understanding of heat and temperature, results showed that students who used either an outlining or mapping learning strategy scored significantly better than students who used only a personalized note-taking strategy. In addition, students scored almost equally on the multiple-choice tests, but when pressed for explanations on the constructed response, essay-type examinations, students that used only note-taking strategies "were unable to provide the in-depth responses necessary to earn high marks" (Keng, 1996, p. 90)

About half the people who learn this process (Mind Mapping) find it extremely useful; the other half find it uncomfortable to use. The latter seem to object to the lack of structure and find it difficult to be as spontaneous as the process requires. But for those who are comfortable with it, it can be a very useful and versatile tool (Higgins, 1995).

Traditionally, training and the training culture have emphasized instruction of specific skills that people need to do their jobs more effectively, but not on the ability to learn. When taught and used properly, Mind Mapping can reach the "hard-to-reach" learner, improve visualization skills, boost memory, recall and retention, improve collaborative skills/team work, and allow for both right and left brain learners to "win" (Jensen, 1995).

"The key is to use both hemispheres, three modalities (visual, auditory, and kinesthetic) and all four learning styles (concrete, abstract, cerebral, and limbic)." (Jensen, 1995. p2).

CHAPTER 3

PROCEDURES AND METHODS

This chapter describes the methodology used in this study to examine the effectiveness of Mind Mapping as a note-taking device in a training course as measured by pre-test, post-test results. The learning style and hemisphericity of the sample was also studied in respect to success in Mind Mapping to identify if there is any correlation between success in Mind Mapping and learning style or brain hemisphericity. The population, design, controls and treatments, sample, instrumentation, materials, data collection procedures, analytical and statistical treatment, and study time frames are discussed.

Data Treatment Analysis

The hypotheses for this study are:

1. Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training.

2. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across learning style as measured by the Learning Type Measure instrument.

3. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across hemisphericity as measured by the Hemispheric Mode Indicator instrument.

4. There will be no significant interaction between the learning style and hemisphericity variables.

Design of the Study

In this study the effectiveness of Mind Mapping as a notetaking technique was compared with the effectiveness of traditional notetaking. The treatment was the brain-based learning strategy, Mind Mapping. The effect of Mind Mapping was measured by the pre-test and post-test of the control and experimental groups. The design of the study was an experimental pre-test, post-test control group design (Campbell & Stanley, 1963, p. 55).

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Population/Sample

The population for this study consisted of personnel employed by a major high-tech firm, which employs 105,000 people worldwide. This study involved the participants in a Mind Mapping training class sponsored by a large high tech corporation. Participants in the training class came from all areas of the company, therefore, a wide range of educational level, expertise, interest, and job areas were included in this study. Due to the corporate environment and possible subject sensitivity due to participation in an experiment in the workplace, participation in this study was voluntary. Assignment to either the experimental or control groups was random, as specified by criteria for a pre-test, post-test control group experimental design. To ensure confidentiality and minimize experimenter bias, all subjects were given numerical codes on tests and instruments used in this study. The informed consent form, as set out by the University of North Texas Institutional Review Board for the Protection of Human Subjects in Research, was signed by each participating subject insuring confidentially. All subjects elected to participate in this study.

The sample of participants for this study were selected at random as they voluntarily sign up for this class through the corporate training services registration process, which is a corporate on-line system available to all corporation employees. This course is offered 2-4 times per month. Once registered, the subjects were randomly assigned, via training administration software, to a specific course session.

The power of a test has a direct correlation to the size of the sample (Kirk, 1995). Therefore, the sample size for this experiment was determined to be N=120 subjects using the formula on page 63 of Kirk (1995). The four determinants of the power of the test: level of significance, size of the sample, size of the population standard deviation, and the magnitude of difference between their means aided in the determination of sample size. This large sample was necessary in order to achieve the best results of the statistical analysis required for the study which required use of a 2 x 4 ANOVA. The large sample size helped to ensure that there were no empty cells which would have been detrimental to the statistical analysis of the study.

Pilot Study I

A pilot study was conducted with a sample of 13 participants in a Mind Mapping course in a corporate environment. As a result of the pilot study, the procedures for administering the instruments were altered. In addition, the reading passage used in the pilot study could have biased the results of the study in that some study participants could have prior knowledge of the content that they were being tested over. A new reading passage and true/false test were selected, designed, and tested for validity and reliability.

Pilot Study II

A second pilot study was done to determine the reliability of the revised achievement assessment tool. This new achievement assessment tool, consisting of a reading passage and a 30 items true/false quiz, was selected with the intent to avoid participants having prior knowledge of the subject matter. The content of the reading passage was of a technical information nature. The reading passage had several limitations in its design in that it needed to be technical in nature, cutting edge material that would not be common knowledge to the subjects but short enough to be read, mapped or noted, and comprehended within a ten-minute period of time.

A 30 item true/false test was constructed to test comprehension of the reading material consisting of thirty items. The 30 item true/false test was administered to 115 subjects that were not part of the Mind Mapping study. The scores from the 115 subjects were statistically evaluated to test for reliability of the true/false instrument. The true/false test was tested for internal consistency and reliability, as measured by the Cronbach alpha statistic. The results of the reliability testing of the achievement test instrument showed a Cronback alpha of 0.844, using the MicroCAT (tm) Testing System, Copyright (c) 1982, 1984, 1986, 1988, 1992 by Assessment Systems Corporation, Rasch Model Item Calibration Program -- RASCAL (tm) Version 3.50 The mean score of the test was $\underline{m} = 8.1$, with a standard deviation, SD = 109.5.

An item analysis of test questions was conducted with this pilot test data. The difficulty index, measuring the number of people who answered a given item correctly, was .0950. Although there were several test items that were in the "too difficult" and "too easy" range, elimination of those items did not significantly affect the reliability alpha, therefore, all thirty items were left in the test. The rationale behind this is that the longer the test, the more reliable it is.

To establish the content and construct validity, the achievement instrument was evaluated by a team of four subject matter experts as to their opinions on the items. These experts reviewed the test and found it to have content and construct validity.

Data Gathering

Instruments used in this study to gather data were the achievement assessment (a reading passage and true/false); the Learning Type Measure(LTM), and the Hemispheric Mode Indicator (HMI).

The pre-test, post-test achievement assessment tool (a reading passage and true/false test) was developed and checked for validity and reliability as mentioned in the previous section.

The Learning Type Measure (LTM) instrument, developed by Bernice McCarthy (1980) to facilitate application of the 4MAT System for learning, teaching, and leadership, is based on the Kolb Learning Style Inventory (1985). The LTM measure describes the four learning types as depicted by McCarthy. The LTM consists of 15 items and the content and construct validity have been tested and confirmed (McCarthy & St. Germain, 1997). Content validity has been established in that the stems in the 15 items of Part A represent the descriptions of the four types of learners found in several books and articles by McCarthy and her colleagues. Construct validity is established in the fact that only 10 subjects out of 390 had tie scores on the quadrants. This delineates the fact that the test does distinguish learning style quadrant. Further construct validity of the LTM shows that 70% of the respondents had differences between their maximum sum and their next highest sum of 5 or more. A percentage of 50% of the respondents had differences of 7 or more. The differences ranged from 0 (for the ten who had two identical sums) to 25 (a very peaked profile).

Construct validity was established by analyzing the "correct" respondents rating a particular stem strongly, i.e., 3 or 4.

The reliability of the LTM instrument was tested for internal consistency, as measured by the Cronbach alpha statistic. The alpha values for the four sets of items forming the four learning type sums in Part A and the do vs. watch items in Part B are:

Learning Type One	0.853
Learning Type Two	0.835
Learning Type Three	0.767
Learning Type Four	0.885

An alpha value between 0.80 and 0.90 is typical on an achievement tests. Attitude or affective inventories have alphas between 0.70 and 0.90. The alpha values shown here indicate the internal consistency of the items.

A second form of reliability testing was done by an analysis of the LTM, which yielded a .71 test-retest coefficient which indicates a high level of stability.

Concurrent validity on the LTM was established by comparing the LTM scores with the Learning Style Inventory (LSI), and the Myers Briggs Type Indicator (MBTI). In a replication study on the validity of the LTM as a measure of individual differences in learning, high levels of correlation were established between the LTM-61.1% agreement between the two measures (107/175). The chi-square test, Cramer's V and the Contingency Coefficient all show a significant relationship between the LSI and the LTM as well.

The LSI and MBTI were compared and show a significant relationship between the two instruments (St. Germain, Leiberman, & Mathiesen, 1987). In another study, results indicated that the LTM is reliable as a measure of personal preference in learning (St. Germain, Leiberman, & Cohen, 1988).

The Hemispheric Mode Indicator (HMI), developed by Bernice McCarthy (1987), is an instrument to measure the preferences in the individual's approach to learning with a bias for right, left, or whole brain-mode processing techniques. The HMI is used in conjunction with the LTM to establish a learners' preference for approaching and representing learning (McCarthy, 1987). The HMI consists of 32 items that are rated on a Likert-type scale. Each item consists of a continuum between two adjectives. On the continuum, there are four choices, the subject either chooses "a lot (2)" or "somewhat (1)" from the other side of the continuum. The HMI rates the participant as to their inclination toward right, left or whole brain preference. The high negative scores in the HMI are associated with a left hemispheric mode, and high positive scores are associated with a right hemispheric mode. The Cronback alpha for the HMI is 0.90. The test-retest reliability (Pearson moment correlation coefficient is 0.904 (Lieberman, 1986). The HMI's items were correlated with the items of Torrance's measure of hemispheric dominance (Your Style of Learning and Thinking, SOLAT-C). The Spearman rank correlation coefficient is 0.819. The Pearson Product-moment correlation is 0.659 (Lieberman, 1986).

The relationship between learning style and hemispheric dominance is shown to have a statistically significant relationship between HMI and learning style (Chi-square=373.1, p, .001).

In a study of the nexus of brain hemisphericity, personality types, temperaments, learning styles, learning strategies, gender, majors, and cultures, the HMI was used to determine brain hemisphericity preference (Saleh, 1998).

Procedures for Conducting the Experiment

In this study the effectiveness of Mind Mapping as a note-taking device was compared with the effectiveness of traditional note-taking. The hemisphericity of each participant and the learning style of each participant was also studied as to their effect on the success of Mind Mapping. The effect of Mind Mapping was measured by a pre-test given to a control group prior to the Mind Mapping training and a post-test given to the experimental group immediately following training.

Participants within each Mind Mapping training class were randomly assigned to a Group A or a Group B.

Prior to any instruction on Mind Mapping, Group A was given the achievement assessment portion of this experiment (a reading passage on a technical training topic unfamiliar to the subjects and a 30 item true/false test over the content and comprehension of the reading material). A time period of ten minutes was given to the participants to read the passage, make notes, make highlights or use whatever strategy that they would normally use to study a reading passage. At the end of the ten minutes, a true/false quiz over the information in the reading passage was administered to the participants in Group A. The participants were given five minutes to complete the true/false quiz.

Group B was administered the Learning Type Measure instrument and the Hemispheric Mode Indicator instrument. Both Group A and Group B then received two days of training on Mind Mapping from a single certified Mind Mapping instructor. At the end of the training, Group B was administered the post-test (the same achievement assessment given the control group consisting of a reading passage and 30 item true/false quiz). Group B was under the same time constraints as Group A, but Group B was asked to mindmap the material in the reading passage as their study strategy before taking the quiz. These instruments measured the difference in achievement between Group A and Group B on the same achievement assessment instrument to determine whether traditional note-taking or the brain-based learning strategy of Mind Mapping was most effective. In all instances, the achievement assessment tool was timed - ten minutes to read and study the passage and five minutes to complete the true/false quiz. The LTM and HMI assessed the effect of hemisphericity and learning style on achievement scores.

Method of Data Analysis

The statistical procedure used in this study was a one-tailed t-test to determine if there was a significant difference between mean achievement scores of the two groups. Calculations for the t-test were done using the computer program (SPSS). A level of significance of .05 was specified. In addition, the one-way analysis of variance (ANOVA) General Linear Model SPSS version 8.0 was performed on the data to test for group differences between the Mind Mapping and no Mind Mapping group.

A 2 x 4 ANOVA was the statistical procedure used to analyze the scores from the LTM and the HMI. These scores were tested to determine the main effects of hemisphericity and learning style and to check for interaction between hemisphericity and learning style.

In this study, it was highly probable that there would be unequal cell frequencies. Therefore, statistical analysis to deal with this problem were used.

CHAPTER 4

RESULTS

Introduction

The purpose of this study was to examine the effect of the brain-based learning strategy, Mind Mapping, as a notetaking device in adults in a training situation with consideration to learning styles and brain hemisphericity, as determined by the achievement assessment tool, the Learning Type Measure and the Hemispheric Mode Indicator.

Hypotheses

The hypotheses for this study were:

1. Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training.
2. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across learning style as measured by the Learning Type Measure instrument.
3. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across hemisphericity as measured by the Hemispheric Mode Indicator instrument.

4. There will be no significant interaction between the learning style and hemisphericity variables.

Data for this study were collected at a large high tech corporation with voluntary enrollment of subjects in a Mind Mapping class offered at the corporate training center. This study was conducted with 112 subjects receiving two days of training on Mind Mapping from the same instructor who is a certified Mind Mapping instructor. The subjects were divided randomly into a control group and an experimental group. A timed achievement assessment test was given to the control group before being trained in Mind Mapping to test comprehension on a reading passage with subjects taking notes in the traditional manner. The same timed achievement assessment test was given to the experimental group after two days of training in Mind Mapping. Subjects in the second group were told to mindmap the information in the reading passage rather than take traditional linear notes before taking the achievement assessment test. This experiment tried to determine if there was any significant difference in the Mind Mapping group versus the traditional notetaking group judged by the scores on the achievement assessment tool. In addition, the Mind Mapping group was assessed as to learning style by the Learning Type Measure and brain hemisphericity by the Hemispheric Mode Indicator to determine if learning style or hemisphericity had an influence on success with Mind Mapping.

In this chapter results of data analysis are presented according to the purposes described in Chapter 1 and the procedures outlined in Chapter III. Results of all analysis procedures related to the hypotheses are presented.

Data Analysis

Hypotheses 1. Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training.

Hypothesis 1. Is rejected as the Mind Mapping group did not score significantly higher on the achievement score measure that the participants that did not receive the Mind Mapping training at the $p > .05$ level.

At an alpha level of .05, a t-test was performed to determine if there was a significant difference between the achievement assessment tool scores of the Mind Mapping group versus the non-Mind Mapping group. Table 1 presents the results of the t-test for independent samples (alpha = .05) comparing the post-test results for both groups, which show that there was no significant difference. The group statistics are seen in Table 1.

Table 1. Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
SCORES	Mind Mapping	56	20.9643	3.6430	.4868
	No Mind Mapping	56	21.1964	2.9813	.3984

Independent Samples Test
t-test for Equality of Means- -.369
$p > .05$

In addition to the t-test for group differences between the group that received Mind Mapping training versus the group that did not receive Mind Mapping training, the one-way analysis of variance (ANOVA) General Linear Model (GLM) SPSS version 8.0 was performed. The GLM statistical procedures were used as they provide more information regarding the data. Group 1 (Mind Mapping group) had 56 subjects and the Group 2 (No Mind Mapping group) also had 56 subjects. As a result of the Cook's D statistical test, one case was dropped from this analysis, as shown in Table 2.

Table 2. Between-Subjects Factors

Between-Subjects Factors			
		Value Label	N
Group	1	Mind Mapping	55
	2	No Mind Mapping	56

Table 3. Presents the results of the GLM ANOVA showing the mean for the Mind Mapping group as 21.2000 with a standard deviation of 3.2169 and the mean for the group with no Mind Mapping training as 21.1964 and a standard deviation of 2.9813.

Table 3. Descriptive Statistics SCORES

Dependent Variable: SCORES			
Group	Mean	Std. Deviation	N
Mind Mapping	21.2	3.2169	55
No Mind Mapping	21.1964	2.9813	56
Total	21.1982	3.0861	111

Figure 6. Plot of Scores for Mind Mapping group

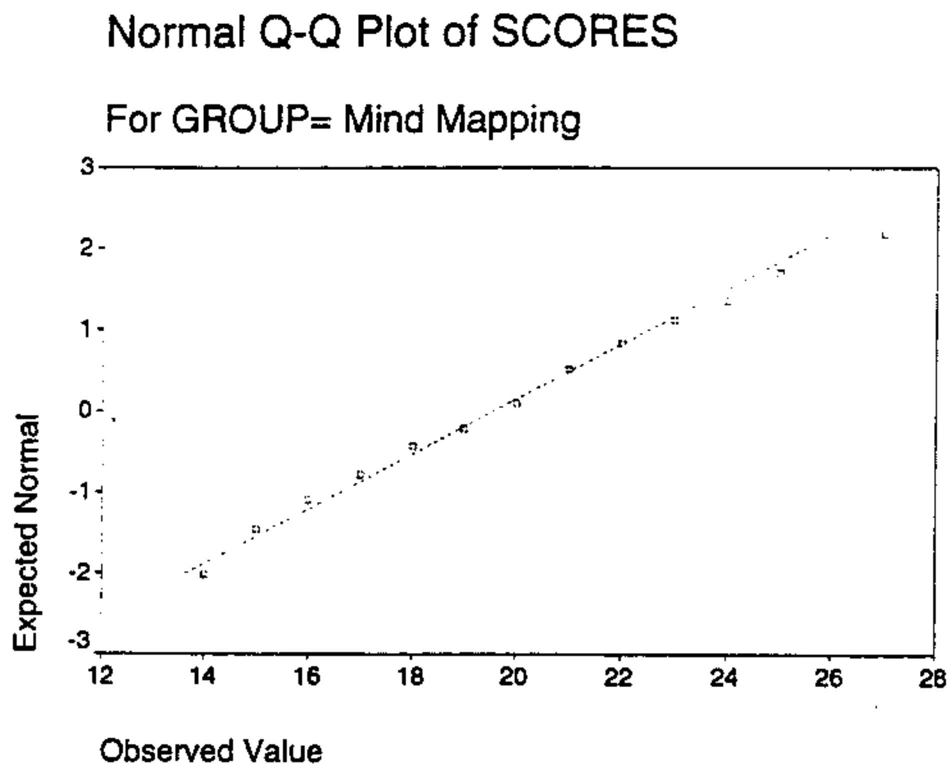
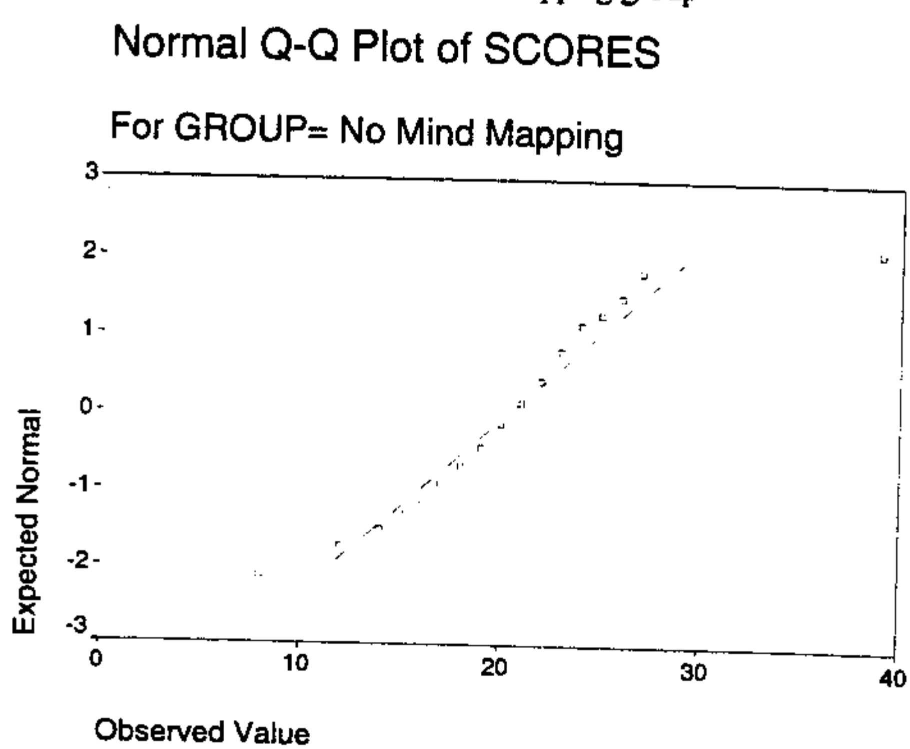


Figure 7. Plot of Scores for No Mind Mapping group



The test for homogeneity of variance was .458 which shows that the assumption has been met in Table 4.

Table 4. Levene's Test of Equality of Error Variances

Levene's Test of Equality of Error Variances(a)			
Dependent Variable: SCORES			
F	df1	df2	Sig.
0.554	1	109	0.458

The tests of between-subjects effects resulted in a significance of .995 which showed that there was no statistically significant difference between the Mind Mapping and no Mind Mapping group means at the probability of .05 (p>.05), as shown in Table 5.

Table 5. Tests of Between-Subjects Effects

Tests of Between-Subjects Effects							
Dependent Variable: SCORES							
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Power
Corrected Model	3.539E-04(b)	1	3.54E-04	0	0.995	0	.050
Intercept	49875.39	1	49875.39	5189.207	0	0.979	1.000
GROUP	3.54E-04	1	3.54E-04	0	0.995	0	.050
Error	1047.639	109	9.611				
Total	50927	111					
Corrected Total	1047.64	110					
a Computed using alpha = .05							
b R Squared = .000 (Adjusted R Squared = -.009)							

Only the group that received Mind Mapping training was analyzed as to their hemisphericity and learning style. The statistical analysis was done to determine if a specific learning style quadrant and or type of hemisphericity would have more success using Mind Mapping. The statistic used to do the analysis of hemisphericity and learning style was a two-way analysis of variance (ANOVA) using General Linear Model (GLM) by SPSS version 8.0. Cook's D statistic was also run on this data and two subjects were dropped from the study. These statistical measures were used to test Hypotheses 2, 3, & 4, which are stated below and the conclusions are given:

Hypothesis 2. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across learning style as measured by the Learning Type Measure instrument.

Quadrant 1 and Quadrant 3 are statistically significantly different within the Mind Mapping group, thus the hypothesis is rejected.

Hypothesis 3. Within the group trained in Mind Mapping there will be no significant difference in performance among participants across hemisphericity as measured by the Hemispheric Mode Indicator instrument.

Left and Right Brain (Hemisphericity) are not statistically significantly different, thus the hypothesis is retained at the $p>.05$ level.

Hypotheses 4. There will be no significant interaction between the learning style and hemisphericity variables.

There is no interaction between Learning Style Quadrant and Hemisphericity, thus the hypothesis is retained.

The statistical analysis of the learning style and hemisphericity of the Mind Mapping group showed the following:

The distribution of the scores, as shown in Table 6, among learning style quadrants and hemisphericity shows that Quadrant 3 had the largest number (28) of subjects. The hemisphericity of the group was almost equally divided with left-brain having 26 subjects and right-brain having 28 subjects.

Table 6. Between-Subjects Factors

Between-Subjects Factors			
		Value Label	N
Learning Style		Quadrant 1	10
		Quadrant 2	8
		Quadrant 3	28
		Quadrant 4	8
Hemisphericity		Left Brain	26
		Right Brain	28

The distribution of subjects among learning style quadrants is as graphed below in Figure 8, with the largest percentage, 51%, falling into Quadrant 3.

Figure 8. Learning Style Quadrants

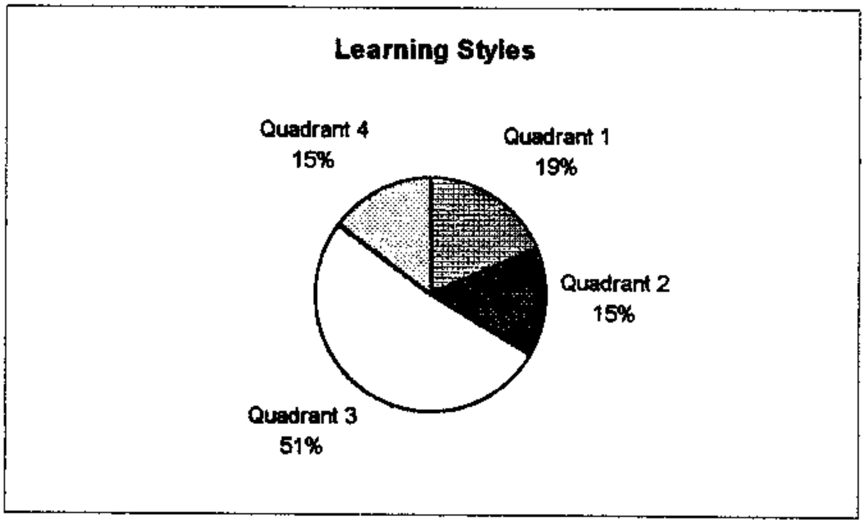
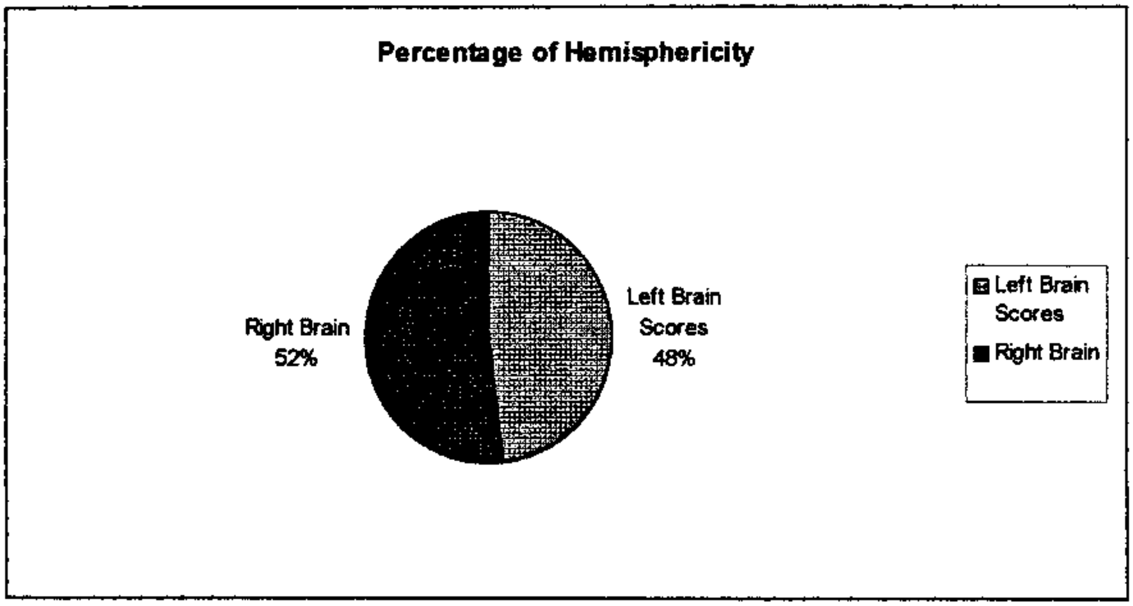


Figure 9. Shows the distribution of hemisphericity is almost equally divided with left-brain having 48% and right-brained having 52%.

Figure 9. Percentage of Hemisphericity

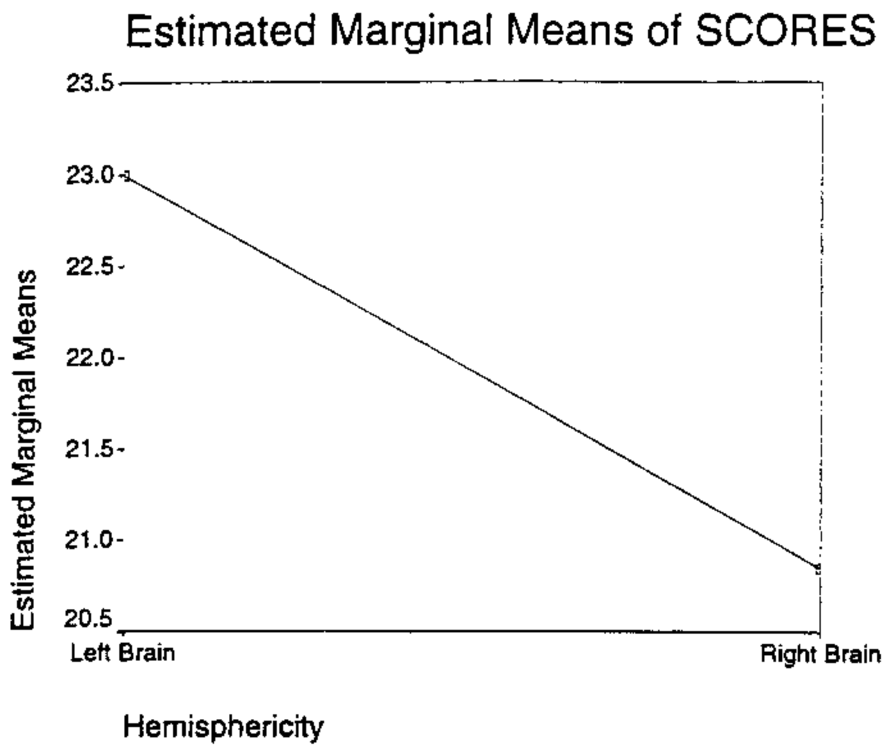


The mean scores and the standard deviations of the four learning style quadrants and the hemisphericity scores of the subjects in the Mind Mapping group are shown in Table 7.

Table 7. Learning Style - Hemisphericity Scores

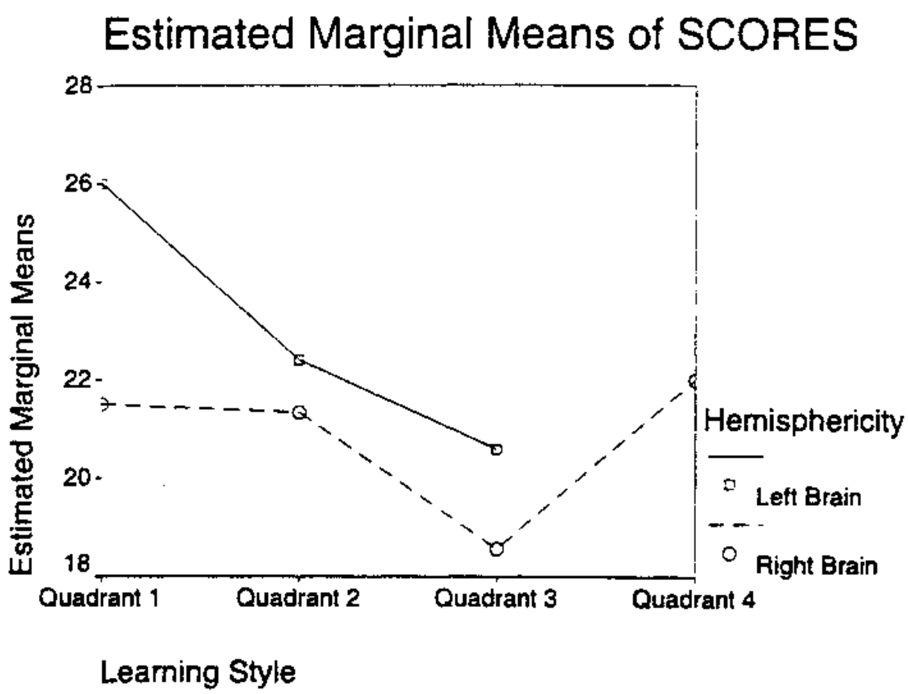
Dependent Variable: SCORES				
Learning Style	Hemisphericity	Mean	Std. Deviation	N
Quadrant 1	Left Brain	26	2.8284	2
	Right Brain	21.5	3.3381	8
	Total	22.4	3.6271	10
Quadrant 2	Left Brain	22.4	2.881	5
	Right Brain	21.3333	1.5275	3
	Total	22	2.3905	8
Quadrant 3	Left Brain	20.5789	3.5483	19
	Right Brain	18.5556	4.4752	9
	Total	19.9286	3.9056	28
Quadrant 4	Right Brain	22	3.4226	8
	Total	22	3.4226	8
Total	Left Brain	21.3462	3.6215	26
	Right Brain	20.6786	3.7816	28
	Total	21	3.6858	54

Figure 10. Means of Hemisphericity Scores



The distribution of the scores in the cells of the ANOVA were such that the Quadrant 4 only had one subject as an entry. The elimination of this subject was due to the Cook's D statistic which eliminated that subject as an outlier. As a result, it was necessary to use Type IV Sums of Squares to test this data. Type IV is a method designed for the situation in which there are missing cells. Type IV sum-of-squares is commonly used for any unbalanced model with empty cells.

Figure 11. Scores of Learning Style and Hemisphericity



Levene's Test of Equality of Error Variance tests for homogeneity of variance. This test shows that the assumptions are met for homogeneity of variance in Table 8.

Table 8. Levene's Test of Equality of Error Variances

Levene's Test of Equality of Error Variances(a)			
Dependent Variable: SCORES			
F	df1	df2	Sig.
0.672	6	47	0.673

The test for between-subjects effects found that there was no interaction at .648 using p<.05.

Table 9. Tests of Between-Subjects Effects

Dependent Variable: SCORES							
Source	Type IV Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Corrected Model	127.280(b)	6	21.213	1.682	0.146	0.177	.582
Intercept	1.60E+04	1	1.60E+04	1272.164	0	0.964	1.000
QUADRANT	61.218(c)	3	20.406	1.618	0.198	0.094	.703
HEMISPHE	43.575(c)	1	43.575	3.455	0.069	0.068	.445
QUADRANT * HEMISPHE	11.039	2	5.52	0.438	0.648	0.018	.117
Error	592.72	47	12.611				
Total	24534	54					
Corrected Total	720	53					
a Computed using alpha = .05							
b R Squared = .177 (Adjusted R Squared = .072)							
c The Type IV testable hypothesis is not unique.							

A post hoc analysis was done on the main effects.

Learning Style

The means for the scores in the learning styles quadrants are indicated in Table 10.

Table 10. Scores for Learning Style Quadrants

Estimates					
Dependent Variable: SCORES					
	Mean	Std. Error	95% Confidence Interval		
Learning Style			Lower Bound	Upper Bound	
Quadrant 1	23.75	1.404	20.926	26.57	
Quadrant 2	21.867	1.297	1.93E+01	24.48	
Quadrant 3	19.567	0.719	18.122	21.01	
Quadrant 4	22.000(a)	1.256	19.474	24.53	
a Based on modified population marginal mean.					

An omnibus F test usually lowers power, so in this case the statistical analysis used was post hoc pairwise comparisons (see Table 11).

Table 11. Pairwise Comparisons

Dependent Variable: SCORES						
		Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
(I) Learning Style	(J) Learning Style				Lower Bound	Upper Bound
Quadrant 1	Quadrant 2	1.883	1.911	0.329	-1.961	5.728
	Quadrant 3	4.183(*)	1.577	0.011	1.01	7.355
	Quadrant 4	1.750(b)	1.883	0.358	-2.039	5.539
Quadrant 2	Quadrant 1	-1.883	1.911	0.329	-5.728	1.961
	Quadrant 3	2.299	1.482	0.128	-0.683	5.282
	Quadrant 4	-.133(b)	1.805	0.941	-3.764	3.498
Quadrant 3	Quadrant 1	-4.183(*)	1.577	0.011	-7.355	-1.01
	Quadrant 2	-2.299	1.482	0.128	-5.282	0.683
	Quadrant 4	-2.433(b)	1.447	0.099	-5.343	0.477
Quadrant 4	Quadrant 1	-1.750(c)	1.883	0.358	-5.539	2.039
	Quadrant 2	.133(c)	1.805	0.941	-3.498	3.764
	Quadrant 3	2.433(c)	1.447	0.099	-0.477	5.343
Based on estimated marginal means						
* The mean difference is significant at the .05 level.						
a Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						
b An estimate of the modified population marginal mean (J).						
c An estimate of the modified population marginal mean (I).						

From this analysis we can see that Quadrant 1 and Quadrant 3 are statistically significant at the .05 level. It is also important to look at Eta (effect size). Although small, Eta is close to .1 as seen in Table 12.

Table 12. Univariate tests of Learning Style

	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)	
Contrast	111.998	3	37.333	2.96	0.042	0.159	8.881	0.665	
Error	592.72	47	12.611						
The F tests the effect of Learning Style.									
a Computed using alpha = .05									

Hemisphericity

The hemisphericity of the subjects in the Mind Mapping group were analyzed showing the mean of the Left Brain as 22.993 and the mean of the Right Brain as 20.847, as seen in Table 13.

Table 13. Hemisphericity Scores

Estimates					
Dependent Variable: SCORES					
	Mean	Std. Error	95% Confidence Interval		
Hemisphericity					
Left Brain	22.993(a)	1.027	20.927	25.059	
Right Brain	20.847(a)	0.74	19.359	22.336	
a Based on modified population marginal mean.					

The pairwise comparisons of hemisphericity are not significant at $p>.05$, as presented in Table 14.

Table 14. Pairwise Comparisons of Hemisphericity Scores

Dependent Variable: SCORES						
		Mean Difference (I-J)	Std. Error	Sig.(a)	95% Confidence Interval for Difference(a)	
(I) Hemisphericity	(J) Hemisphericity				Lower Bound	Upper Bound
Left Brain	Right Brain	2.146(b,c)	1.266	0.097	-0.4	4.692
Right Brain	Left Brain	-2.146(b,c)	1.266	0.097	-4.692	0.4
Based on estimated marginal means						
a Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						
b An estimate of the modified population marginal mean (I).						
c An estimate of the modified population marginal mean (J).						

Table 15 . F test of the effect of Hemisphericity

Univariate Tests								
Dependent Variable: SCORES								
	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power(a)
Contrast	36.246	1	36.246	2.874	0.097	0.058	2.874	0.383
Error	592.72	47	12.611					
The F tests the effect of Hemisphericity.								
a Computed using alpha = .05								

Summary

In this chapter, the study data were analyzed and results presented. In summary, the results include: 1.) Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training. Hypothesis 1 is rejected as there is no statistically significant difference in the means of the groups being tested. 2.) Within the group trained in Mind

Mapping there will be no significant difference in performance among participants across learning style as measured by the Learning Type Measure instrument. Hypothesis 2 is rejected as Learning Style Quadrant 1 and Quadrant 3 showed significant difference in performance among participants. 3.) Within the group trained in Mind Mapping there will be no significant difference in performance among participants across hemisphericity as measured by the Hemispheric Mode Indicator instrument. Hypothesis 3 is retained as no significant difference in performance among participants across hemisphericity was detected. 4.) There will be no significant interaction between the learning style and hemisphericity variables. Hypothesis 4 was retained as there was no interaction between the learning style and hemisphericity variables.

These results are discussed further in Chapter 5, along with their relationship to current literature. In Chapter 5, conclusions are drawn regarding the implications of the results for each hypothesis and recommendations for further research are made.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the research study is summarized. Conclusions regarding the results of the data analyses for the various hypotheses are presented and discussed. Recommendations for further research in the area of Mind Mapping, as a notetaking strategy, are made.

Summary

The purpose of this study was to determine the effectiveness of Mind Mapping, a brain-based learning strategy, as a note-taking device with adults in a corporate training environment. The effect of learning style and brain hemisphericity preference on success in the use of Mind Mapping was also assessed as a tool to better understand how to aid people in becoming effective, efficient learners. This study has increased the body of knowledge concerning the effectiveness of Mind Mapping as a notetaking strategy with consideration to learning styles and brain hemisphericity of adults in a corporate training situation.

This study has shown that brain-based strategies provide greater achievement by using both hemispheres of the brain and that using certain brain-based strategies, such as

Mind Mapping, training can be redesigned to enable learners to become more successful learners. There is a lack of current research in the areas of Mind Mapping and its effectiveness as a note-taking device and the effect of learning style and hemisphericity on success in Mind Mapping made this dissertation study a critical area for study.

Subjects using Mind Mapping versus traditional notetaking strategies were compared to determine the effectiveness of Mind Mapping in consideration with learning style and brain hemisphericity on adults in a training situation. The brain-based learning strategy, Mind Mapping, is based on the translation of brain research which shows that the mind does not process information in solely list-like, linear representation. The use of associations, graphics, color, and key words make the Mind Mapping strategy "brain-friendly", thus extremely effective in aiding the learning process.

This study was conducted in a corporate training environment with 112 subjects receiving two days of training on Mind Mapping from the same instructor who is a certified Mind Mapping instructor. The subjects were divided randomly into a control group and an experimental group. An achievement assessment test was given to the control group before being trained in Mind Mapping to test comprehension on a reading passage with subjects taking notes in the traditional manner. The same achievement assessment test was given to the experimental group after two days of training in Mind Mapping. Subjects were told to mindmap the information in the reading passage rather than take notes. This experiment examined the data to determine if there was any significant difference in the Mind Mapping vs. traditional notetaking group judged by the scores on the achievement assessment tool. In addition, the Mind Mapping group was assessed as to learning style by the Learning Type Measure and brain hemisphericity by the Hemispheric Mode Indicator to determine if learning style or hemisphericity had an influence on success with Mind Mapping.

Conclusions

The study hypothesis was rejected:

1. Participants that receive Mind Mapping training will score significantly higher on the achievement score measure than the participants that did not receive the Mind Mapping training.

Participants that had been trained in Mind Mapping did not score higher than the group that used traditional note-taking techniques. Previous findings show that the brain-based learning strategy, mapping, is helpful as a study aid and helps learners understand and recall information better (Anderson and Armbruster, 1984; Armbruster, 1991; Chi, Feltovich, & Glaser, 1988; Dansereau, 1985; Dunston, 1992; Moore & Readance, 1984; Pressley, Woloshyn & Associates, 1995; Van Patten et al., 1986).

This study shows that Mind Mapping, as a learning strategy, was equally effective as a note-taking device for participants in the study-the mean scores of the Mind Mapping group were 21.2 and the non Mind Mapping group were 21.1964. This is especially significant in that the strategy of Mind Mapping was a new skill and no practice or study time was allowed. The achievement assessment tool was administered immediately after the training. The amount of time required to assimilate a new skill was not part of this study. However, the results of this study, which showed that after a two-day training class on Mind Mapping the study subjects were able to score equally well as those that used traditional note-taking, is extremely significant. Traditional note-taking, a skill that most of the participants have practiced a lifetime, usually consists of grammatically correct phrases and sentences and is often cumbersome and inefficient when compared with key word noting (mapping). The introduction of Mind Mapping and the requirement to use it after only two days of limited practice would definitely affect the success of the Mind Mapping group. The benefit of formal training in strategy instruction has been shown to have significant positive impacts on the learner (Segal, et al., 1985; Weinstein & Underwood, 1985; Pressley, et al., 1995; Kulik, Kulik & Schwalb, 1983). Kiewra and Fletcher (1984) found that the modification of notetaking behavior may require some degree of intensive learning. When mapping is taught as a study technique, refinement of the process to ensure accuracy and inclusiveness can take several weeks (Dansereau & Holley, 1984; Arnaudin et al., 1984). Still, the basics of mapping can be mastered in less than an hour by individuals who complete a few mapping exercises and get feedback on them from teachers or peers (Clarke, 1990). The fact that the group scored equally as well as the traditional note-taking group is a true indication of the impact and effectiveness of the skill of Mind Mapping. With more time, practice, and skill with Mind Mapping a greater disparity among the scores would probably be evidenced.

In addition to learning a new learning strategy as part of this study, the amount of time given the subjects to practice before taking an immediate post-test was nil. In a study done by McCagg and Dansereau (1991), findings showed that implementation of mapping strategies requires that the students be adequately familiar with the mapping technique to reduce possible anxiety; provided with appropriate examples of mapping usage; and should be allowed to practice mapping prior to implementing the technique as a supplemental learning strategy.

This study looked at the learning style of the learner as well as the hemisphericity of the learner in an effort to evaluate one's learning style's impact on the use of the brain-based strategy of Mind Mapping. This type of study was suggested by Trautman (1979) in which he suggested that further research should be done to establish better, more succinct criteria by which to determine the cognitive style and learning style characteristics of curriculum, resources, and instructional strategies.

The study statistics showed that Quadrant 1 and Quadrant 3 were significant as to the scores of the achievement assessment tool. This result may be the result of the quantity of the number of subjects in each cell rather than the scores relating to those cells. Brain hemisphericity was not significant as a predictor of success with Mind Mapping. According to McCarthy (1987), we all learn in a whole brain style with dominance for left or right brain in each quadrant. Studies suggest that the effectiveness of learners' strategies depends on the context of learning and on the learner's own characteristics (e.g. academic environment, learning style) (Pask, 1988). Learning style research has shown that when student learning styles were assessed, and then the students were put through a course to expose them to other methods other than their preferred mode of learning, the students were able to change their preferred styles of learning and thinking through brief, but intensive, training. Through exposure to right-hemisphere, non-linear learning strategies the learners were able to make more use of their existing capabilities and extend into new areas (Torrance & Ball, 1978).

Mehegan's study (1996) showed that those with a right brain preference had higher test performance and also reported a positive preference for Mind Mapping on the attitudinal survey. Although an attitudinal survey was not part of this study, results of the study show that brain hemisphericity was equally distributed among the subjects and it was not a significant influence on the success of achievement on mapping.

Research on the effects of mapping as a learning strategy is mixed. Used as a learning strategy, mapping has been shown to increase knowledge acquisition (Ault, 1985; Arnaudin et al., 1984). According to McKeachie (1984) mapping can also be time consuming, first in learning the technique and then in putting it to use. With limited prior knowledge, students may find mapping of little value. Rooda's results (1994) supported the use of Mind Mapping activities as a way to improve academic success. McCagg and Dansereau's (1991) study showed that learner implementation of mapping activities led to improved performance on multiple choice tests. In a study by Malloy (1987), results showed that the group given integration techniques of Mind Mapping, visual imagery and analogy scored higher than the control group. The experimental group also showed that the techniques affected their organization as well as their surface structure of the written product. Keng's study (1996) compared the effectiveness of outlining, concept mapping, and note-taking as learning strategies on non-science students' understanding of heat and temperature. Keng's results showed that students who used either an outlining or mapping learning strategy scored significantly better than students who used only a personalized note-taking strategy. About half the people who learn this process (Mind Mapping) find it extremely useful; the other half find it uncomfortable to use. The latter seem to object to the lack of structure and find it difficult to be as spontaneous as the process requires. But for those who are comfortable with it, it can be a very useful and versatile tool (Higgins, 1995).

The reading passage selected for this study was of a technical nature and purposely chosen so as to avoid participants' prior knowledge of the reading material. As a result, the information was difficult to read, assimilate, and most participants had no prior knowledge from which to attach this new information. The complexity or difficulty of the reading passage has a potential impact on notetaking. Cook and Meyer (1983) and Locke (1977) found that complex, information-dense lectures can result in ineffective notetaking and lower recall scores under this response condition.

Recommendations

Other areas, in addition to strategy research, related to maps that need to be researched are cognitive development, schema theory, cognitive styles, learning styles, cultural differences, and secondary language acquisition.

Mehegan (1996), recommended that research regarding the relationship between Mind Mapping and brain hemisphere dominance be done using a more comprehensive and reliable instrument. As a result, this study used the Hemispheric Mode Indicator which has been proved to be valid and reliable. Further studies in this area would be beneficial in substantiating the research of this study.

Evaluation of mapping strategies is problematic in that they are difficult to evaluate. Learning strategies research needs improvement in the experimental methods used to study spatial learning strategies. It is difficult to assess a student's entry-level ability to use mapping strategies.

Problems for Further Study

Further research in the area of Mind Mapping, brain-based learning and brain-based learning strategies, learning styles and brain hemisphericity will aid in the development of more effective means of teaching people how to learn.

As a suggestion for future studies, research into the effect of a time delay after reading the passage and being tested would be very interesting. In a telephone conversation in regard to this study's design, Dr. D. Dansereau suggested that as a future study a two hour delay of testing after reading and noting or Mind Mapping the passage would allow a better evaluation of the effect of Mind Mapping versus traditional notetaking, as Mind Mapping should afford better long term memory incorporation.

Dillon and Schmeck (1983) have identified a number of individual differences and individual difference variables that affect cognitive processes, particularly learning strategies. Few studies have investigated these factors, but investigation of the factors and how they relate to other experimental variables can improve our understanding of the mechanisms underlying the use of mapping strategies and the instructional techniques needed to teach them exclusively on group data.

According to Smith (1991), mapping seems to be an advantage to learners who are visually oriented. This study did not look at the different modalities of learning-visual, auditory, or kinesthetic; but this would be an excellent and interesting study in terms of success with Mind Mapping.

Additional areas that were not considered as part of this study, but would be excellent areas for further research are:

1. The effect of Mind Mapping within other training or educational environments.
2. Success with Mind Mapping among subjects with high, medium, and low intelligence scores.
3. Success with Mind Mapping when considering educational level of participants in the Mind Mapping class.
4. The effect of the training over time.
5. The correlation of gender and hemisphericity and success with Mind Mapping. Gender was not evaluated as part of this study. Novak (1991) and Jegede, et al (1990) have reported that males using mapping have greater achievement gains than similar females and males maps are more integrated and complex.
6. Consideration of age and success in the use of Mind Mapping.
7. The influence of the use of color versus black and white in the process of Mind Mapping.
8. The effect of music on the success with Mind Mapping and/or notetaking.
9. The effect of a longer period of time for instruction and practice of the Mind Mapping skill.
10. The effect of time delay in testing and comprehension of information comparing Mind Mapping and traditional notetaking.

Summary

In summary, this final chapter has synthesized the results of this research, provided conclusions based on the findings, and indicated recommendations for further research. This study provides the basis for future investigations in the area of Mind Mapping's potential as a brain-based learning strategy for trainers and educators. Mapping can afford great benefits to trainers and educators in development of classroom environments that can be more supportive and inviting. The use of mapping can make learning more effective, more efficient and more satisfying; as well as simplifying and organizing complex content and connecting new ideas to old ones.

Trainers and educators use of mapping as a strategy will allow them to:

- Focus attention on key elements
- Help integrate prior knowledge with new knowledge
- Enhance conceptual development
- Enrich reading, writing, and thinking
- Aid writing by supporting planning and revising
- Promote focused discussion
- Assist instructional planning
- Serve as an assessment and evaluation tool

The growing emphasis on learning (Argyris, 1991, 1993; Senge, 1990, 1992), in corporations and the educational arena, will necessitate the incorporation of this research into methods of training and into the design and development of learning organizations. In the future, training will become devoted to teaching learners *how to learn* by using specialized thinking strategies and learning techniques, such as Mind Mapping (Gross, 1992). The findings of this study show that brain-based strategies provide greater achievement by using both hemispheres. For training departments, learning strategies, such as Mind Mapping, can be a more successful method of instructing people how to comprehend, store and utilize information.

APPENDIX A

ACHIEVEMENT ASSESSMENT TOOL

Digital Light Processing

Flat-panel video projectors are among the hottest audio-visual products on the market. The majority of these projectors use liquid-crystal display (LCD) imaging technology. The LCD panels absorb a lot of the projection lamp's light energy in their polarizing filters and individual pixels. This characteristic of liquid-crystal displays led to research in the early 1980s by scientists at Texas Instruments, the goal of which being to develop an alternative flat-panel display technology with improved light efficiency.

In 1987, TI's efforts paid off with the invention of Digital Light Processing, a system that used reflective light-not transmissive- to form images. DLP achieved higher levels of efficiency than those found in the LCD panels and had the bonus of being a digitally modulated imaging system. Eventually, this would make it possible to send video and computer images to a projector as digital data, not analog signals as are currently used. Such a digital projection system could be largely immune to noise and signal attenuation, as well as other artifacts often found in analog systems.

In an LCD projector, the individual pixels contain tiny crystals, which block more or less light, in response to changing voltage applied to their control transistors. The variation in light from one pixel to another creates a grayscale image, which is more apparent as the number of pixels increases. If the pixels can change state fast enough, it is possible to project video through these panels.

Unlike liquid crystal display panel projectors, whose transmissive operation resembles that of a slide projector, DLP forms images by reflecting light from a mirrored surface back through a projector's lens and on to the screen. The amount of light reflected from one mirror to the next also creates a grayscale image, which becomes more apparent as the number of mirrors increases. Again, if the mirrors can move quickly enough, video can be projected.

The gadget that makes this process possible is known as a Digital Micromirror Device (DMD). DMD's are actually small arrays of tiny mirrors, measuring only 16 micrometer square (16mm2) and resting on a static RAM chip. Each mirror can tilt a maximum of 10 degrees, responding to a "1" or "0' command from the RAM chip. A mirror fully tilted in the "1" position reflects the maximum amount of light, while the "0" position results in no reflection. Grayscale images are created only when each mirror cycles rapidly between the "1" and "0" states, using a process similar to digital pulse-width modulation.

This transition from "1" to "0" is extremely fast, taking less than 15 milliseconds. If an individual mirror spends more time in a "1" state than "0" within a given time interval, the reflected light from the mirror will appear darker. DMDs can easily move fast enough to reproduce video images, as well as high-resolution computer graphics and data. They are also pretty efficient, reflecting 60% of the light that strikes their surfaces.

Video Systems, May, 1998,

Digital Light Processing

Name________________________________
Group_______________________________
Date________________________________

Please read each question carefully, then write T (true) or F (false) on the line next to the question.

1. _____ Liquid Crystal Display panels do not absorb a great deal of the projection lamp's light energy in their polarizing filters and individual pixels.
2. _____ Liquid Crystal Display (LCD) panels use reflective light to form images.
3. _____ Analog systems are subject to noise, signal attenuation and other artifacts.
4. _____ In an LCD projector, tiny transistors block more or less light.
5. _____ Only the Digital Light Processing system can creat a grayscale image.
6. _____ LCD panels transmissive operation forms images by reflecting light from individual pixels that contain tiny crystals.
7. _____Analog signals make it possible to send video and computer images to a projector.
8. _____ Flat panel video projectors will soon come to the audio-visual market.
9. _____ The mirrors in the Digital Micromirror Device are commanded by a RAM chip.
10. _____ If a Digital Micromirror Device mirror is fully tilted in the "1" position it results in no reflection.
11. _____The transition on a Digital Micromirror Device from "1" to "0" takes less than 10 milliseconds.

12. _____ Digital Micromirror Devices can reflect 30% of the light that strikes their surfaces.

13. _____Improved light efficiency was the impetus to develop Digital Light Processing.

14. _____ Digital Light Processing systems use transmissive light to form images.

15. _____ Each mirror in et Digital Micromirror Device can tilt a minimum of 10 degrees.

16. _____ The grayscale image is more apparent as the number of mirrors increases.

17. _____ Only Digital Light Processing systems can project video.

18. _____ In 1978, TI invented Digital Light Processing technology.

19. _____ The Digital Micromirror Device (DMD) is made up of small mirrors that measure only 16 millimeters square.

20. _____ Most projectors now use the Digital Light Processing technology.

21. _____If an individual mirror spends more time in a "1" state than "0"a given time interval, the reflected light from the mirror will appear darker.

22. _____ Liquid Crystal Display panel projectors have operation that resembles that of a slide projector.

23. _____ Digital Light Projectors have the bonus of being a digitally modulated imaging system.

24. _____ Video and computer images can only be sent to a computer as digital data.

25. _____ Most flat-panel video projectors use liquid crystal displays.

26. _____ In an LCD projector, the changing voltage applied to their control transistors determines how much light is blocked by the individual pixels.

27. _____ The Digital Micromirror Device makes the LCD panel a viable flat-panel video projector.

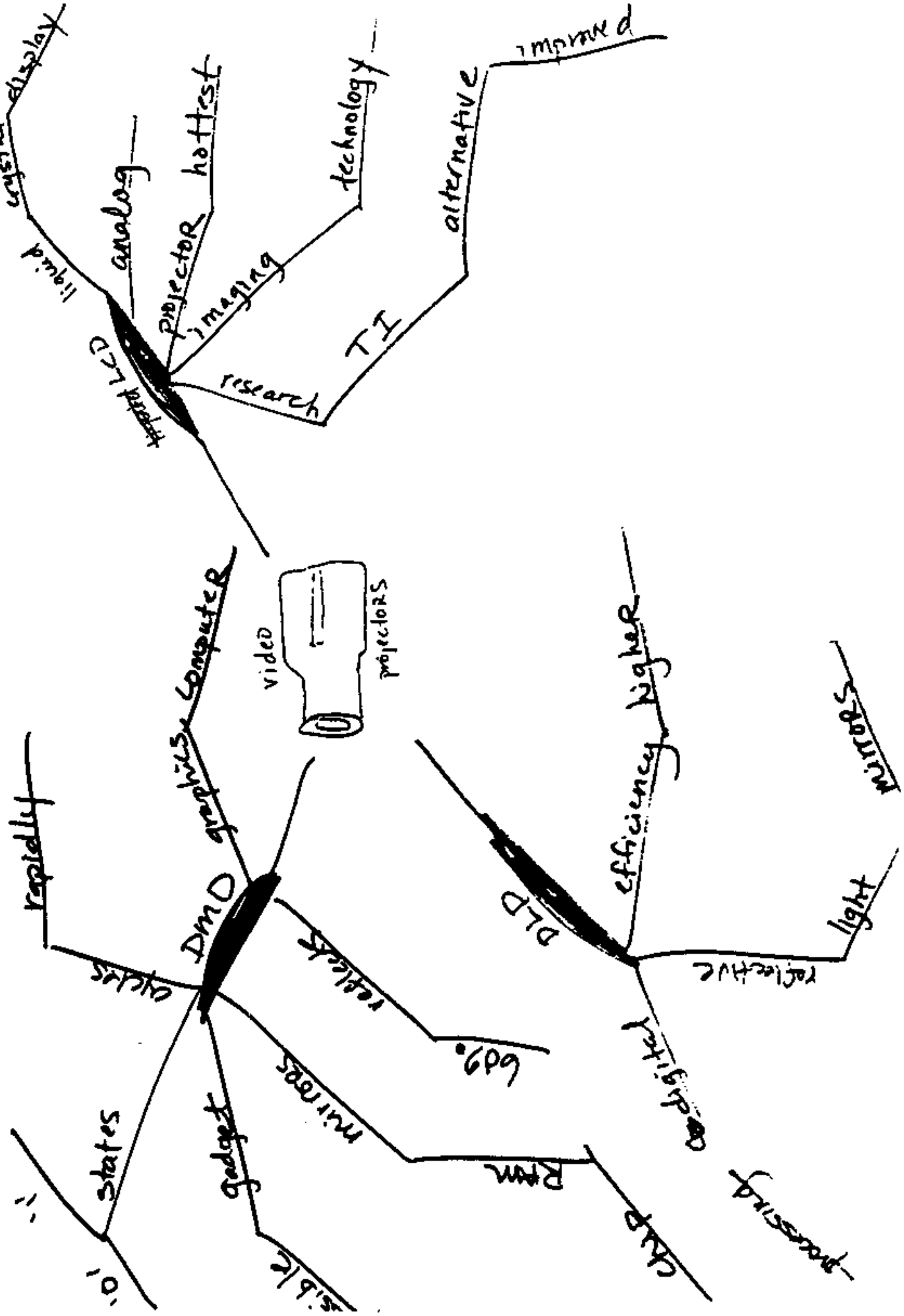
28. _____ Digital Light Process forms images by reflecting light from a mirrored surface back through a projector's lens and on to the screen.

29. _____ Currently, with the LCD projector, analog signals are used to send video and computer images.

30. _____ In an LCD projector, the individual pixels contain tiny crystals.

APPENDIX A

EXAMPLES OF MIND MAPS OVER READING MATERIAL


video
projectors
LCD
liquid
crystal
display
analog
projector
hottest
imaging
technology
research
TI
alternative
improved
computer
graphics
DMD
rapidly
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mirrors
RAM
reflects
chip
DLP
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higher
mirrors
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digital
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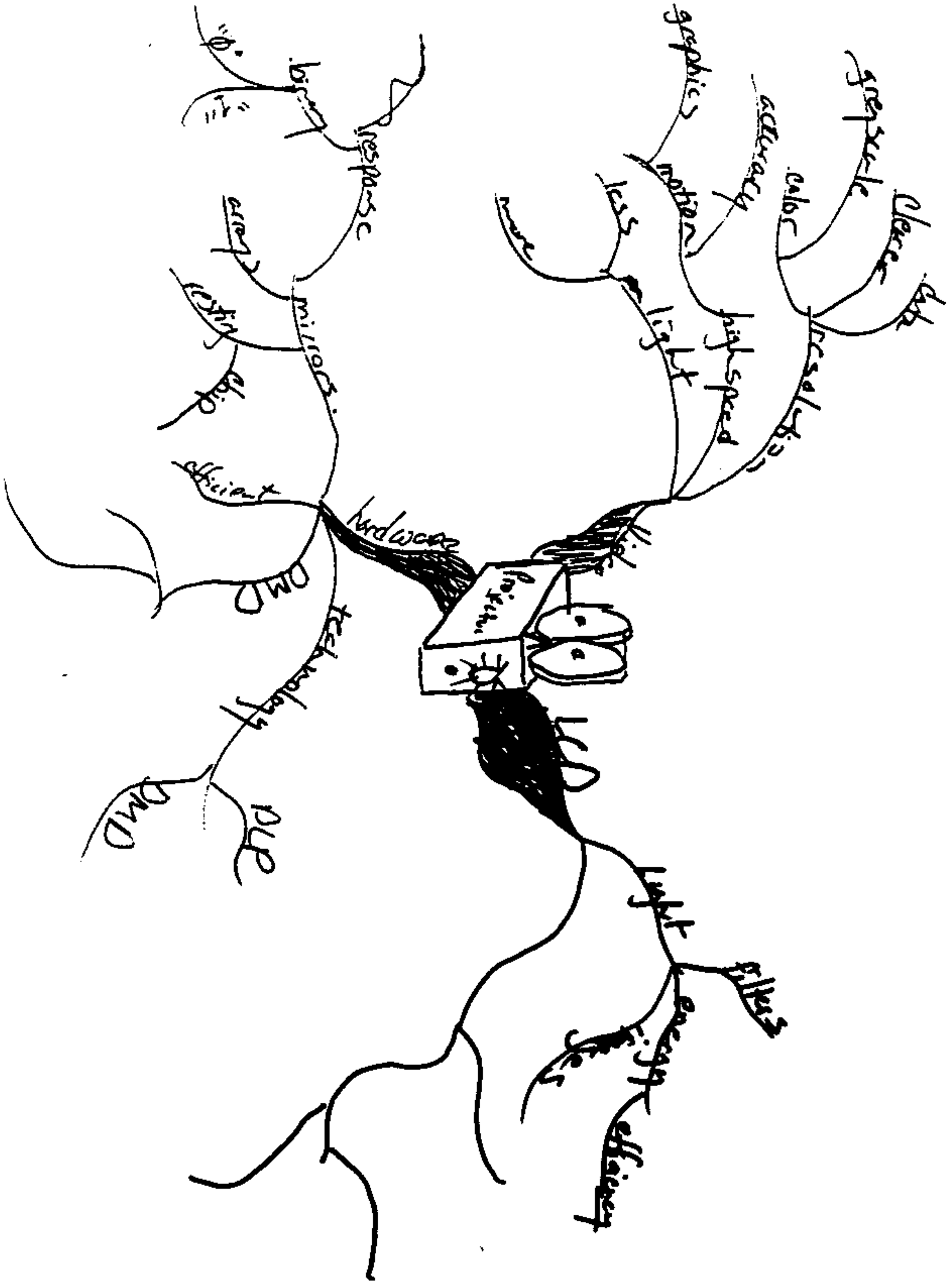
projection
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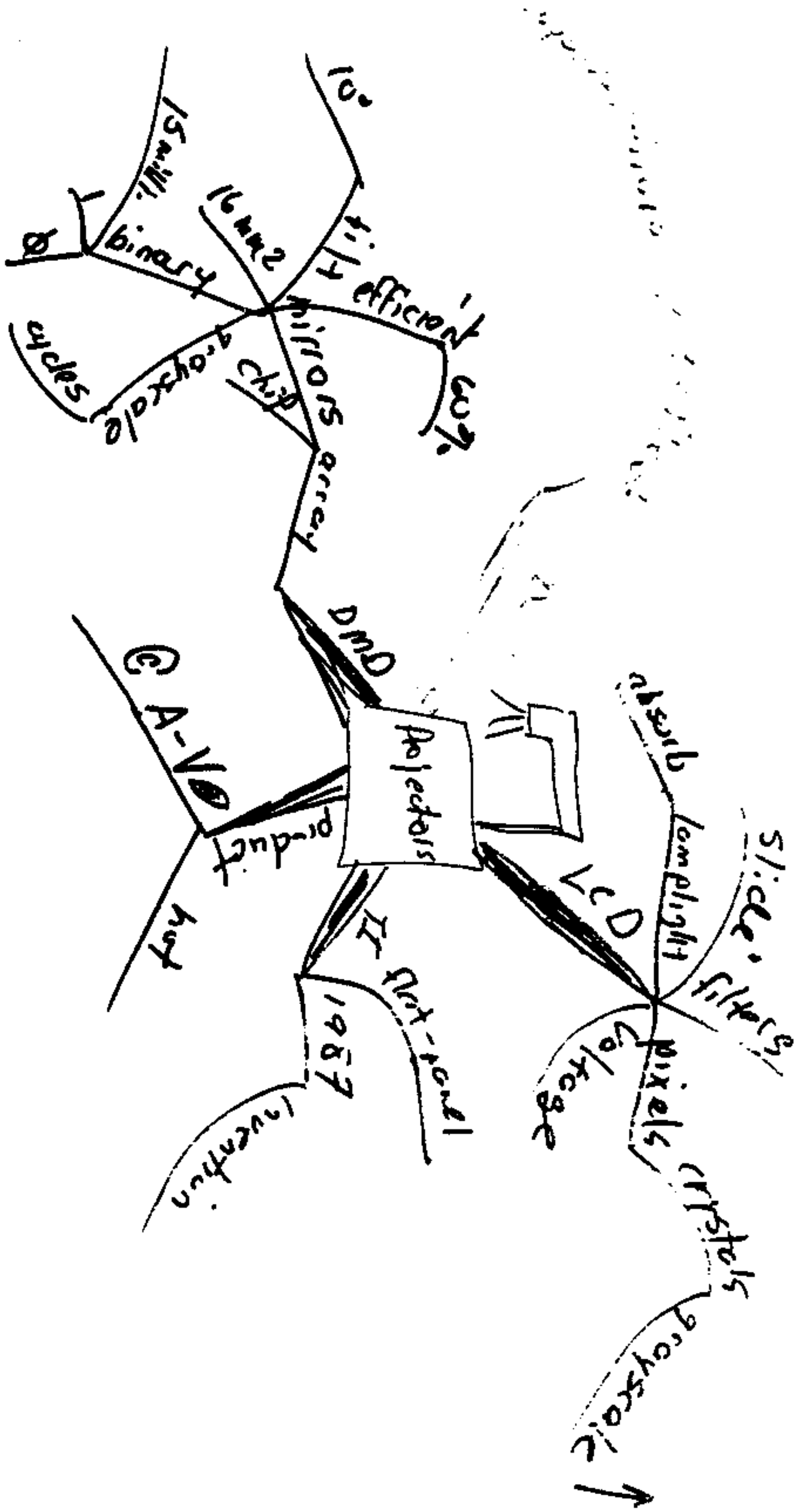
Projectors
DMD
array
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grayscale
cycles
binary
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0
16 mm2
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© A-V
product
hot
TI
first-panel
1987
invention
LCD
absorb
lamplight
slide
filters
voltage
pixels
crystals
grayscale

APPENDIX A

EXAMPLES OF TRADITIONAL NOTE-TAKING OVER READING MATERIAL

Digital Light Processing

Flat-panel video projectors are among the hottest audio-visual products on the market. The majority of these projectors use liquid-crystal display (LCD) imaging technology. The LCD panels absorb a lot of the projection lamp's light energy in their polarizing filters and individual pixels. This characteristic of liquid-crystal displays led to research in the early 1980s by scientists at Texas Instruments, the goal of which being to develop an alternative flat-panel display technology with improved light efficiency.

In 1987, TI's efforts paid off with the invention of Digital Light Processing, a system that used reflective light-not transmissive- to form images. DLP achieved higher levels of efficiency than those found in the LCD panels and had the bonus of being a digitally modulated imaging system. Eventually, this would make it possible to send video and computer images to a projector as digital data, not analog signals as are currently used. Such a digital projection system could be largely immune to noise and signal attenuation, as well as other artifacts often found in analog systems.

In an LCD projector, the individual pixels contain tiny crystals, which block more or less light, in response to changing voltage applied to their control transistors. The variation in light from one pixel to another creates a grayscale image, which is more apparent as the number of pixels increases. If the pixels can change state fast enough, it is possible to project video through these panels.

Unlike liquid crystal display panel projectors, whose transmissive operation resembles that of a slide projector, DLP forms images by reflecting light from a mirrored surface back through a projector's lens and on to the screen. The amount of light reflected from one mirror to the next also creates a grayscale image, which becomes more apparent as the number of mirrors increases. Again, if the mirrors can move quickly enough, video can be projected.

The gadget that makes this process possible is known as a Digital Micromirror Device (DMD). DMD's are actually small arrays of tiny mirrors, measuring only 16 micrometer square (16mm2) and resting on a static RAM chip. Each mirror can tilt a maximum of 10 degrees, responding to a "1" or "0' command from the RAM chip. A mirror fully tilted in the "1" position reflects the maximum amount of light, while the "0" position results in no reflection. Grayscale images are created only when each mirror cycles rapidly between the "1" and "0" states, using a process similar to digital pulse-width modulation.

This transition from "1" to "0" is extremely fast, taking less than 15 milliseconds. If an individual mirror spends more time in a "1" state than "0" within a given time interval, the reflected light from the mirror will appear darker. DMDs can easily move fast enough to reproduce video images, as well as high-resolution computer graphics and data. They are also pretty efficient, reflecting 60% of the light that strikes their surfaces.

Video Systems, May, 1998,

Digital Light Processing

Crystal

Flat Panel video hot LCD

Flat-panel video projectors are among the hottest audio-visual products on the market. The majority of these projectors use liquid-crystal display (LCD) imaging technology. The LCD panels absorb a lot of the projection lamp's light energy in their polarizing filters and individual pixels. This characteristic of liquid-crystal displays led to research in the early 1980s by scientists at Texas Instruments, the goal of which being to develop an alternative flat-panel display technology with improved light efficiency.

imaging

1987 DLP image.

In 1987, TI's efforts paid off with the invention of Digital Light Processing, a system that used reflective light-not transmissive- to form images. DLP achieved higher levels of efficiency than those found in the LCD panels and had the bonus of being a digitally modulated imaging system. Eventually, this would make it possible to send video and computer images to a projector as digital data, not analog signals as are currently used. Such a digital projection system could be largely immune to noise and signal attenuation, as well as other artifacts often found in analog systems.

In an LCD projector, the individual pixels contain tiny crystals which block more or less light, in response to changing voltage applied to their control transistors. The variation in light from one pixel to another creates a grayscale image, which is more apparent as the number of pixels increases. If the pixels can change state fast enough, it is possible to project video through these panels.

Light DLP

Unlike liquid crystal display panel projectors, whose transmissive operation resembles that of a slide projector, DLP forms images by reflecting light from a mirrored surface back through a projector's lens and on to the screen. The amount of light reflected from one mirror to the next also creates a grayscale image, which becomes more apparent as the number of mirrors increases. Again, if the mirrors can move quickly enough, video can be projected.

DMD = mirror

The gadget that makes this process possible is known as a Digital Micromirror Device (DMD). DMD's are actually small arrays of tiny mirrors, measuring only 16 micrometer square (16mm2) and resting on a static RAM chip. Each mirror can tilt a maximum of 10 degrees, responding to a "1" or "0' command from the RAM chip. A mirror fully tilted in the "1" position reflects the maximum amount of light, while the "0" position results in no reflection. Grayscale images are created only when each mirror cycles rapidly between the "1" and "0" states, using a process similar to digital pulse-width modulation.

mirror

1 = max

This transition from "1" to "0" is extremely fast, taking less than 15 milliseconds. If an individual mirror spends more time in a "1" state than "0" within a given time interval, the reflected light from the mirror will appear darker. DMDs can easily move fast enough to reproduce video images, as well as high-resolution computer graphics and data. They are also pretty efficient, reflecting 60% of the light that strikes their surfaces.

Video Systems, May, 1998,

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