AN EPISTEMOLOGICAL FRAMEWORK

FOR CURRICULUM AND INSTRUCTION

By

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Introduction

This Dissertation is written in an unconventional manner. One of the principal advisers on my dissertation committee specified that the dissertation evidence the dynamic human process of intellectual growth and development that actually occurs during a process of real inquiry. In concert with the philosophy of Dewey (Noddings, 2007), all facts, concepts, theories and procedures that initially guide our inquiry can be preliminarily considered as knowledge. As we progress through our inquiry, only a portion of these survive in their original form. Many are modified, reconfigured or outright rejected. When the inquiry achieves its aim, those facts, concepts and theories that survive as formulated, via a process that is inevitably recursive and compensatory, we may regard as having justified assertability - Dewey's definition of knowledge with the character of truth (Noddings, 2007). This is Dewey's pragmatic response to the metaphysical query: what is truth?

The process Dewey describes is not a neat linear progression from unassailable foundational axioms to logically-necessary consequences. It is a messy and realistically human process that includes: false starts, revisions, compensations, reconsiderations and the recursions required to make the final result a cohesive and coherent body of knowledge that achieves an aim. In short, it is a chronology of intellectual growth and development. If reported accurately, it is also exemplary of Dewey's idea that the ultimate aim of learning is growth.

Traditional dissertations have the character of a mathematical proof or a biography written by a successful businessman. Only those items that demonstrate a consistent and successful progression from beginning to end are included. Knowing what the conclusion is, the introduction and succeeding chapters are written in a fashion that anticipates and supports this conclusion. Hidden from the view of the reader is the fact that the successful strategy the businessman reports may have been preceded by nine false starts or that the mathematician, like Laplace, often made thousands of attempts to derive a mathematical proof before success was achieved.

If the goal of a dissertation is simply to report final results and the justifications that support those results, a traditional construction will suffice. If the reader, like my adviser, wishes to see a progression of growth and development as well as a realistic depiction of the process of inquiry, then a less conventional construction is required.

This Dissertation attempts to comply with the spirit of the aforementioned adviser without taking on the character of a learning log. It is an attempt to effect a construction that meets the diverse requirements of all the members of the advisory committee.

The aim of the Dissertation is to develop an epistemological predicate for the design of curriculum and instruction. It endeavors to do so through a critical examination of intellectual innovation in the 20th century. The goal is to extract the epistemological basis and implications that undergird these innovations in the selected fields of:

1) Philosophy,
2) Psychology,
3) Mathematics,
4) Physics,
5) Neuroscience,
6) Linguistics and
7) Education.

A composite or synthesized epistemology is then derived and implications for curriculum and instruction discussed.

Each section is structured similarly. The results of an innovation or principal figure in a discipline are summarized. Epistemological implications are then discussed. In some cases, where it was deemed necessary or helpful, an immediate connection was made to epistemological implications derived from innovation in other disciplines or domains. Where epistemological implications immediately suggested an educational application, they were also discussed within the specific section or chapter. Philosophy is discussed throughout the Dissertation and discussed extensively in the conclusions section. The epistemology of Gregory Bateson is also discussed throughout the Dissertation and blended in as deemed appropriate and pertinent.

As previously alluded, in order to preserve the spirit of inquiry, the reader will experience the content and thought process as it evolved. One can consider the process as analogous to that of getting to know a person. The treatment is both top-down and bottom-up. It moves from one discipline to the next with various connections made and implications asserted. As the reader moves through the Dissertation, a generalization and understanding of the whole should emerge.

The conclusion is conventional in nature. An emergent, composite epistemology is asserted. The implications of this epistemology for curriculum and instruction are extensive. To illustrate an example application, a model derived from the epistemology for learning concepts and theories is provided in the conclusions section. Research affirming the conclusions of the Dissertation is also cited. The remainder of this introduction elaborates, in summary fashion, some personal aspects of my journey of growth.

I would like to begin by expressing my sincerest gratitude to the members of my Dissertation Committee for allowing me to pursue what many would regard as an overly broad topic. Human knowledge and information expands at an exponential rate. As it is physically impossible for any one individual to know all that is potentially knowable, and certainly impossible to know at the expert level the entire breadth of currently available knowledge, it is both natural and logical that human knowledge is categorized and subdivided into disciplines or specialized lines of inquiry. The body of human knowledge is now deep and rich enough that sub-disciplines of sub-disciplines of sub-disciplines of disciplines have evolved. It is entirely possible, for example, for an Individual to spend his entire life researching, understanding and documenting the processes that occur within one single type of human cell.

While this subdivision of knowledge is necessary and has led to great advances in understanding within disciplines, it is a sword with two edges. It has enabled investigators to cut deeply into the specifics of selective portions of their disciplines. It has also, however, exacerbated the problem of integrating the results of these investigations into comprehensive theories and internally-consistent bodies of knowledge within the disciplines. We often find, within sub-disciplines, researchers and scholars pursuing questions and issues with entirely different paradigms, philosophies and methodologies. In addition, it is typical that sub-disciplines evolve a specific vernacular and terminology unique to their fields of inquiry. This results in what Ludwig von Bertalanffy (1968) calls the creation of "private universes" (p. 30). Bertalanffy (1968) also alludes to an additional consequence: the research results and ideas of scholars often remain within the covers of books, having little impact outside of the specific sub-discipline within which they were generated.

In the discipline of Psychology, the sub-discipline of Cognitive Psychology is subdivided into different fields of inquiry. They are roughly as follows: Similarity, Concept Formation, Inductive Reasoning, Deductive Reasoning, Analogy, Causal Learning, Mental Models and Representations, Visio-spatial Reasoning, Decision Making, Judgment, Problem Solving, Creativity, Language and Memory. Great progress and significant contributions toward the understanding of human cognition have emerged from each of these lines of inquiry. There is yet to emerge, however, anything resembling a unified theory of human cognition, nor has there been an attempt to combine results from these different lines of inquiry into an internally consistent body of knowledge and theory. Such an undertaking would obviously be an enormous task. Even within a single field of inquiry, Mental Models and Representations, for example, we find different schools of thought from scholars and researchers employing various paradigms, philosophies and methodologies. There is no consensus as to how or even if the human mind creates representations of the external world from sensations, or how such representations are subsequently manipulated by the mind to carry out cognitive activities such as problem-solving or decision-making. Stephen Sloman (1996) documents the ongoing debate in Cognitive Psychology between two competing schools of thought concerning the human reasoning process. One group of adherents visualizes an associative system which utilizes similarity and temporal structure while the other espouses a rule-based system operating on mental representations. In the cited paper, Sloman (1996) attempts to reconcile these conflicting positions by making the empirical case that both systems of reasoning coexist and are alternatively or cooperatively invoked, contingent upon the mental task that the mind is attempting to perform. We will plumb the depths of this debate later in the dissertation.

The sub-discipline of Developmental Psychology exhibits similar issues relating to depth of information, conflicting theory and lack of a coherent body of knowledge which connects and relates research results within the field. When conflicting research findings and theory are reported and taught outside of the specialized area in which they are developed, the lack of consensus among theorists is represented as either equivalent alternative perspectives on the same issue or as differentiated theory which emphasizes different aspects of a single issue. For example, shown below is a summary table of major perspectives on child development taken from a textbook currently used in teaching Child

Development courses.

TABLE 2-3 Major Perspectives on Child Development

Perspective	Key Ideas About Human Behavior and Development	Major Proponents	Example
Psychodynamic	Behavior throughout life is motivated by inner, unconscious forces, stemming from childhood, over which we have little control.	Sigmund Freud, Erik Erikson	This view might suggest that an adolescent who is overweight has a fixation in the oral stage of development.
Behavioral	Development can be understood through studying observable behavior and environmental stimuli.	John B. Watson, B. F. Skinner, Albert Bandura	In this perspective, an adolescent who is overweight might be seen as not being rewarded for good nutritional and exercise habits.
Cognitive	Emphasis is on how changes or growth in the ways people know, understand, and think about the world affect behavior.	Jean Piaget	This view might suggest that an adolescent who is overweight hasn't learned effective ways to stay at a healthy weight and doesn't value good nutrition.
Contextual	Behavior is determined by the relationship between individuals and their physical, cognitive, personality, social, and physical worlds.	Lev Vygotsky, Uric Bronfenbrenner	In this perspective an adolescent may become overweight because of a family environment in which food and meals are unusually important and intertwined with family rituals.
Evolutionary	Behavior is the result of genetic inheritance from our ancestors; traits and behavior that are adaptive for promoting the survival of our species have been inherited through natural selection.	Konrad Lorenz; influenced by early work of Charles Darwin	This view might suggest that an adolescent might have a genetic tendency toward obesity because extra fat helped his or her ancestors to survive in times of famine.

Note. From *Child Development* (p.33), by R. Feldman, Upper Saddle River, NJ: Prentice Hall, Copyright 2007 by Prentice Hall.

Feldman (2007), after presenting the table, immediately addresses the question: which one of these perspectives is right? He states that this is not an entirely appropriate question. Each perspective emphasizes somewhat different aspects of development. For instance, the psychodynamic approach emphasizes unconscious determinants, the behavioral emphasizes behavioral responses to stimuli, the cognitive emphasizes how people mentally process stimuli and the contextual emphasizes the impact of environmental influences, while the evolutionary emphasizes the impact of inherited biological factors. He asks the reader to view these differing theories as a set of roadmaps that depict different features of the landscape. “No one map is complete, but by considering them together; we can come to a fuller understanding of the area” (Feldman, 2007, p.35).

While this explanation is both intelligent and practical, given the goal of writing a comprehensive textbook on the subject of child development, it is problematic from the standpoint of scholarship. For one, Freud, Skinner, Piaget and Vygotsky considered their theories to be comprehensive and not confined to a specific aspect of development or to certain factors influencing development. Each of these perspectives is predicated on different paradigms, philosophies and methodologies, which have a bearing on the applications one derives from each perspective.

As I began work on my doctoral studies, I was much like any explorer about to embark on a great adventure: filled with excitement, enthusiasm and a fair bit of hubris. Like Lewis and Clarke, or Sir Edmund Hillary before his ascent of Everest, I felt that I had adequately appraised the challenge and developed an appropriate plan for success. I was filled with excitement and with confidence that I could meet any challenge that presented itself. Also like the aforementioned explorers, I was about to find out that I had, in fact, underestimated the challenge and had placed myself in a situation that would require considerable personal growth and development to get through. I would be a changed individual at the end of this experience.

My first semester of "academic boot camp" was designed by my principal adviser, Dr. Dan Powell, a man whom I had known, trusted and admired for over 20 years. He had selected as my drill sergeants, or those entrusted to turn this raw recruit into a fledgling scholar and academician, Dr. Sharon Reynolds and Dr. Judy Groulx. His course selections were based on whatever these two professors happened to be teaching that semester. As I came to find out, his goals for me that semester included epistemological development as well as specific course content coverage.

When I began my studies, I was a 55-year-old retired president of a Fortune 500 company who had spent the previous 34 years as an engineer, geologist and executive. In addition, I had spent 20 years in educational policy roles at the local, state and national levels. Education had been my avocation and love during those 20 years. It was therefore natural that I would choose to pursue a second career in this area.

My background experience and training was, shall we say, less than fully congruent with the mindset required for success as a scholar and academician in the Social Sciences. For an executive in a highly competitive business enterprise, the emphasis is on execution and action. One is typically required to make decisions and execute actions in limited periods of time and with limited or incomplete information. Such decisions are therefore probabilistic judgments. There is precious little time for introspection, careful reflection or comprehensive consideration of multiple perspectives. The time interval between imperatives for action is extremely short.

The mindset of the engineer is also incongruent with that of the modern scholar in the Social Sciences. As an engineer, one is in pursuit of "**the"** answer or the optimal solution. The relationships and equations used are called laws, not theories, as in: Newton's Laws or Kirchhoff's Laws. They deterministically supply "the" answer if the system conforms to the assumptions inherent in the equations derived from application of the relevant laws. For example, if one designs an electrical circuit and determines the voltages and currents using Kirchhoff's Laws, the physical implementation of the circuit will perform precisely as described by the equations employed in the design of the circuit. If it does not, then an arithmetical error was made in the calculations or the circuit was wired improperly. The problem is human error, not the efficacy of the relevant law applied. Given the role that an engineer plays in society, such a mindset is entirely appropriate. When designing bridges or buildings, it is imperative that their structural stability be known to a high degree of certainty. The safety of the public depends on this. Likewise, when designing a passenger jet, it is critical that the jet perform in a completely predictable manner. Contrast this, however, with the process undertaken by a current day scholar in the Social Sciences employing postmodern qualitative research practices. The strategy used by this scholar would be to arrive at multiple perspectives of the problem using varying philosophies and methodologies in order to create a structure or morphology of understanding. As we will see as this dissertation progresses, nonlinear systems, such as human interactional systems, cannot be fully understood using traditional linear, deterministic analytical methods.

Prior to beginning my studies, I had read extensively in the area of Cognitive Psychology and had the privilege of serving on national committees with several eminent Cognitive Psychologists. I had convinced myself that this field held "the" answers to the problems of education. I also felt that this field could put education on a firm "scientific" foundation.

I was in two of Dr. Groulx’s classes during my first semester: Educational Assessment and Advanced Educational Psychology. After reviewing the textbook and the prospectus for the Advanced Educational Psychology class, I arrogantly asked Dr. Groulx, in class, why we were going to waste time covering the work of Freud and Skinner. Modern research had, after all, invalidated their theories and rendered them of purely historic interest. Didn't Noam Chomsky drive an intellectual stake into the heart of Skinner decades ago? Instead of administering the intellectual punch in the mouth that this question deserved, she calmly responded that perhaps I should withhold my judgment until we had covered the material. There was at least some possibility that I might find something of value in their work. This was, of course, indeed the case.

During my first semester, I also took Dr. Reynolds’s Educational Research class. I credit Dr. Reynolds for much of my epistemological growth both during this first semester and over the next three years. Among Dr. Reynolds varied and extensive talents, she is an expert on qualitative research and complexity theory. One of the many lessons learned from Dr. Reynolds during this first semester and thereafter, was the principle of least commitment, in relation to the gathering of observational research data. During the observation and data-gathering phase of qualitative research, it is critical that the investigator withhold judgment, interpretation and inference. There is a natural tendency to immediately evaluate and interpret data in the context of pre-existing schemas, scripts and paradigms.

In so doing, we filter and preprocess observations through our existing belief structure. Perceptions themselves are colored by this belief structure and observations tend to be forced into the context of our pre-existing theories and hypotheses. This has the effect of making the process an exercise in deductive logic. The exercise becomes, in effect, one of determining whether the observations are logically consistent with pre-existing premises. This is essentially the paradigm used in quantitative research or scientific inquiry, wherein theory is in the foreground, and the object of research is in the background.

In contrast, the qualitative research paradigm for human subjects' research puts the lived stories and experiences of the participants in the foreground and theory in the background. Qualitative research is largely an inductive process. The investigator does not impose a theoretical structure on observations or make assumptions about the relationships among the data before conducting the investigation. The focus is on discovery and understanding as suggested by the data. Data are analyzed, subsequent to collection, for patterns, relationships and themes that may emerge from inductive analysis. Methods are often altered during the study based on preliminary results (Glesne, 2006; Gay, Mills, & Airasian, 2006). In a sense, this research exhibits an existential character, since experience precedes essence.

Since theory building is ex post facto data collection, "thick and rich" descriptions of observations are necessary. This goes beyond mere reporting of actions. Descriptions should be robust enough to permit subsequent interpretation of "intentions, motives, meanings, contexts, situations and circumstances of action" (Glesne, 2006, p. 27).

I found the discipline of collecting "thick and rich" observations, while simultaneously withholding judgment and inference, particularly difficult. My natural tendency was to conclude quickly and decisively as soon as I had discerned a pattern consistent with my prior understanding. This tendency, by the way, is a highly valued skill for a corporate executive. It took several applications of a velvet hammer to my noggin by Dr. Reynolds, before I was able to adhere to the principle of least commitment when conducting observations.

Dr. Reynolds also introduced me to the wonderful world of Complexity and Post Modernism. A full elaboration of these paradigms will be made in the body of this dissertation. For now, a few summary comments will suffice to make the point. Complexity and postmodernism include the idea that realities are multiple, complex, context-bound and shaped by the interaction of the learner and the object of learning. These paradigms include the idea that the phenomenology of the whole cannot be reduced in analytic fashion to atomistic elements acting according to invariant laws. The whole is greater than the sum of the parts. Also included, is the idea that no single perspective, discipline or methodology provides the path to truth or ultimate reality: one form of knowledge/methodology cannot be reduced to another. In other words, there is no "one" knowledge (Guba, 1985). Knowledge is obtained by looking through the lenses of multiple perspectives, since multiple realities can be constructed of the same phenomena, contingent upon the knower's pre-existing perspective, philosophic orientation and guiding paradigm.

Suffice to say, for someone who spent a considerable fraction of their career as a scientist and engineer firmly ensconced in objectivism and the quest for "the" answers, employing a principally scientific paradigm, the mindset of postmodernism represents a profound paradigm shift. For many, the idea of multiple realities, as articulated in postmodernism, is most difficult to accept. The idea is counterintuitive. Most people regard what they know to be objective reality. The idea that it may in fact be subjective, relevant to a specific context and paradigm driven, often evokes a defensive response. Acceptance of this paradigmatic shift becomes for many, “a bridge too far." A full understanding of the idea of perspective in postmodernism requires considerable elaboration. It is one of my goals for this dissertation to contribute to the construction of a bridge of understanding that can facilitate an easier transition from modern to postmodern thought.

My first semester's academic experience was rounded out by hours of philosophic discussion with one of my principal advisers, Dr. Donal Sacken. Dr. Sacken was my Socrates. One of the best read and most contemplative individuals on the planet, he easily either illuminated a logical contradiction in my philosophical meanderings or brought them to the point of ambiguity. Although he has not directly articulated this viewpoint, I believe he views ambiguity as the beginning of real knowledge. It is in ambiguity that we begin to realize other possibilities or other alternative perspectives. Articulated in the language of nonlinear dynamics, this viewpoint would hold that, at points of instability, the possible formation of structures at a higher logical level is enabled. We will investigate these dynamics extensively, later in this dissertation.

A significant obstacle to my progress during my first semester was the fact that I was totally bereft of computer skills. As a senior executive in a large corporate enterprise, I had indulged my ability to have other people utilize technology on my behalf. I had not even learned to use e-mail. My secretary, for example, downloaded my e-mails into hard copies, upon which I wrote responses that she subsequently sent electronically. If I needed a spreadsheet or an information report, I had access to many people who could prepare one on my behalf. As a student, obviously, such luxuries are nonexistent. The lack of computer skills added considerable time and inefficiency to my efforts. I recall many nights being up until three o'clock in the morning with a Microsoft Word manual in one hand, a Microsoft Windows manual in the other, in absolute panic that my computer would not respond in a manner that would allow me to meet the time deadline for my paper. The staff of the TCU library is undoubtedly still laughing about the guy (me) who came in asking to see the card catalog. I felt like the Washington Irving character, Rip van Winkle, who, after a hundred year slumber, woke up in a world he did not understand.

The four courses I took during my first semester did not consist of listening to lectures, reading the textbook, memorizing the material and reproducing it on multiple-choice tests. They were constructivist in nature and project oriented. They consisted of conducting research, consulting multiple and varied reference sources, producing meaningful papers and undertaking project-oriented activities. Some assessments were traditional, but many were authentic and performance-based. This, combined with the previously discussed challenges, made my first semester a true test of will and one of the most difficult periods in my life. In a moment of epiphany, I knew I had to decide whether I had the will to stay the course and remain on the road toward scholarship or to quit and remain an intellectual dilettante, content with merely bantering around interesting intellectualizations. I chose the former and successfully completed the semester. Metaphorically, I continued the trek toward the Pacific Ocean and did not return to St. Louis. I am indebted to the wonderfully talented educators mentioned previously. If I had done nothing but document their instructional strategies and methods, it still would have been worth the price of admission (tuition). They proved that it is indeed possible to "teach an old dog, new tricks." So it is with a newly-opened mind that I will proceed to give Freud and Skinner their due.

Psychology

Freud

There is perhaps no more controversial figure in the history of Western thought than Sigmund Freud. The mention of his name and theories do not merely invoke intellectual badinage, they evoke a torrent of highly emotional and visceral debate. This owes to the nature of his theories and the nature of the man himself. Numerous biographers have wreaked havoc on our conception of Sigmund Freud, the man (Breger, 2000; Eysenck, 1990; Gay, 1988). They have documented and cited evidence for his ongoing affair with his sister-in-law, his use of cocaine and its possible influence on his thought process and his bouts with psychosomatic disorders and phobias. Most damaging are the critiques leveled at his research. He is said to have fabricated fictitious patients and case histories in order to bolster his theories. There are claims that some of Freud's purported patients were, in fact, inventions based on Freud's psychoanalysis of himself. Freud is accused of making exaggerated claims about the success of his psychoanalytical treatments and the consistent nature of his findings among patients. For example, at one time, Freud reported that most of his patients had suffered some form of early childhood sexual abuse. A close examination of his records during this period reveals that these patients did not actually report sexual abuse; Freud had inferred sexual abuse based on symbolic interpretation of somatic symptoms and/or dreams. Freud is also accused of formulating theories with scant justification or experimental evidence. For example, Freud's theory of the Oedipal complex and stage of development is said to have been derived from Freud's self-analysis of his acknowledged sexual feelings for his mother and resentment toward his father, which he then generalized and hypothesized to exist as a stage of development for all humans.

If we accept the above allegations, they depict a man who did not let facts and evidence get in the way of his theories. He becomes a veritable poster child for the necessary imposition of the strict standards and protocols for scholarship, research and experimental inquiry in place today. It is also not surprising that many of the specifics of Freud's theories (universality of the Oedipal complex, penis envy, infantile sexuality, psychosexual stages of development) have received little if any definitive research support (Feldman, 2007; Adler, 2006). While it is easy to critique Freud the man, Freud the insightful genius is not so easily dismissed. Many of his ideas have, in fact, withstood the test of time and are receiving renewed interest and attention because of research findings in Neuroscience and Cognitive Psychology. The existence and importance of unconscious mental processing, the mechanism of repression, the existence of a mental mechanism resembling Freud's "Id", the dialectic between conscious and unconscious mental processes (Freud's Ego vs. Id), and the impact of psychoanalysis are all receiving validation from experimental research in Neuroscience.

Sigmund Freud is popularly credited with having discovered the unconscious: the idea that a substantial part of our mental processing lies outside of our conscious awareness. Freud hypothesized that much of what we believe about the world and much of what we do has little connection with conscious thought. For Freud, behavior and personality originate from unconscious inner forces and are the product of the dialectic between these unconscious forces representing the passions and desires (the Id) and conscious forces representing the realities and demands of the world (the Ego).

It is instructive to examine Freud's intellectual roots. Freud was a student and disciple of Ernst Brücke. Brücke, along with Emil Du Bois-Reymond and Hermann Helmholtz formed an intellectual triumvirate that exerted great influence on the course of Western thought in the second half of the 19th century and the early 20th century. In addition to exerting an influence on Freud, they were the intellectual progenitors of what became known as the Vienna Circle of logical positivists. Positivism is the ideal of the Enlightenment paradigm carried to its logical extreme. In its philosophic incarnation, logical positivists contended that unless a statement or question concerning an object of consideration could be stated in a manner that permitted determination of the truth or falsity of the statement or question using logic and reason, the statement or question had no meaning. For example, the question, "Does God exist?" has no meaning because it is impossible to determine if this statement is true or false; arguments, ultimately not resolvable by logic and reason, can be posited for each side of the issue; hence, the question is irresolvable and without meaning (Morton, 1997). As we can see, logical positivism is the penultimate statement of the modern paradigm; the only things worthy of consideration are those things determinable through the application of logic and reason to the observations and experiences of the external world (universe).

B. F. Skinner (1974) exemplified the scientific incarnation of this worldview. Skinner's position was that the inner workings of the mind were inaccessible, unobservable and unmeasurable. As such they could not be the object of scientific inquiry. What was observable and measurable was human behavior. The science of psychology, then, in his view, should be restricted to the study of behavior, where hypotheses could be posed that could be scientifically proven to be true or false.

The adherents of logical positivism hoped to implement the mindset, methodologies and findings of the physical sciences into the investigation of all human thought and action (Gay, 1988). The positivist paradigm flourished in the 19th century and yielded great achievements in the fields of physics, chemistry, astronomy and medicine. The desire to extend this mindset to other domains of human inquiry was therefore natural. It was also inspired, in no small measure, by the work of Charles Darwin. Darwin had placed man firmly in the realm of the animal kingdom. His theories provided an explanation for the emergence and development of man in completely scientific and secular terms. Gay (1988) cites the work of Darwin as having had a large influence on Freud. We can certainly see overtones of Darwin in Freud's characterization of the Ego evolving as an adaptation of the Id to the circumstances of an external environment.

In the manner of a Hegelian dialectic, the application of a positivist paradigm to the natural sciences became the antithesis to the thesis of vitalism prevalent among natural scientists of the time (Gay P. , 1988). Vitalism is the idea that the functions of a living organism are the result of a vital principal distinct from physical and chemical forces; the laws of physics and chemistry alone cannot explain the life process; there is also a vital force or energy existent in living beings that accounts for the unique attributes of organisms, such as self-regulation, life maintenance and self-determining behavior. The debate or dialectic between positivism and vitalism continues to the present day. While the biological sciences and conventional medicine have long distanced themselves from vitalistic notions, alternative medical practices, such as chiropractic therapy and traditional Eastern healing practices, still incorporate vitalistic conceptions.

The Modern paradigm or the paradigm of the Age of Enlightenment is built around the idea that knowledge and truth are obtained through the application of mental reasoning processes to observations of the phenomena of the world. It rejects the pre-modern idea that knowledge and wisdom are only attainable through mysticism or Divine revelation.

In Freud's work we see a curiously eclectic blend of vitalism, logical positivism and, at times, descriptions that invoke a sense of mysticism. Freud describes the Id as containing everything that is inherited, including an imprint of the egos of past generations (Freud, 1960). The mind of a newborn child consists entirely of an Id, which is an undifferentiated mass containing all of our instinctual drives and impulses and which demands immediate gratification. The Id is responsible for all of our motivations and desires: eating, drinking, sex and so forth. It also is the source of aggressive and destructive behaviors. The Id has no inherent logic or morality and is completely ego-centric. It is driven by the pleasure-pain principle or the idea that a human will undertake and repeat those behaviors that produce a pleasurable outcome and avoid those that produce pain. Note here that this principle is also a premise contained within Skinner's concept of operant conditioning. Freud divides drives and instincts into two categories: 1) an instinct for life and creation (Eros) which drives pleasurable behaviors such as eating and sex, and 2) a death instinct (Thantos) or an unconscious death wish, which creates a desire to give up the struggles associated with survival and the creation of happiness. The Thantos, or death wish, was a later addition to Freud's theory. We can reasonably presume that it was added in order to account for the destructive and self-destructive tendencies that he noted in many of his patients. The following is Freud's (1960) statement of its origin:

On the basis of theoretical considerations, supported by biology, we put forward the hypothesis of a death instinct, the task of which is to lead organic life back into the inanimate state; on the other hand we supposed that Eros, by bringing about a more and more far-reaching combination of the particles into which living substances disburse, aims at complicating life and at the same time, of course, at preserving it (p. 38).

Exhibiting the influence of Helmholtz and Brücke, Freud's theory is one in which energy is conserved. The energy which powers the Eros is called the libido. The libido is Freud's "élan vital", life force or psychic energy source. When something becomes the object of the passions of the Id, an individual invests mental or emotional energy in it. This process of attaching or investing the energy of the libido to the object of desire is called, by Freud, a cathexis or object-cathexis. Since in the real world and particularly a world in which social relationships exist, an individual cannot completely and immediately satisfy his passions and desires, a mediating and controlling mechanism which responds to the demands of the real world is necessary. This mechanism Freud terms the Ego. Freud (1960) describes the ego as follows:

> Moreover, the ego seeks to bring the influence of the external world to bear upon the Id and its tendencies and endeavors to substitute the reality principle for the pleasure principle which reigns unrestrictedly in the Id. For the ego, perception plays the part which in the Id falls to instinct. The ego represents what may be called reason and common sense, in contrast to the Id, which contains the passions (p. 19).

The ego utilizes a number of mechanisms with which to mediate, mitigate or repress the passions of the Id. Freud implicitly characterizes this process of blocking the libidinal energies as a release or re-channeling of the energy into alternative outlets, or re-cathecting. Examples of the redirecting mechanisms of the ego are: sublimation, reaction-formation, regression, denial, intellectualization, projection, displacement and repression. Sublimation is the transformation of impulses which can produce outcomes unacceptable to the ego into something less harmful: for example, when a man kicks the dog when he is angry at his wife. Reaction- formation is the undertaking of a behavior opposite to one's actual desire: for example, when someone who has an addiction to pornography joins an anti-pornography organization as a mechanism for controlling his behavior. Intellectualization is where anxiety-inducing emotions associated with behavior are stripped of their emotional impact by contending that the behavior was due to more rational and socially acceptable causes: for example, when someone who enjoys hurting people ascribes his behavior to toughening people up so that they can better contend with society's cruelty. Repression occurs when painful experiences are buried deep in the subconscious and made inaccessible to waking memory: for example, when someone represents memories of events experienced during a war. The description and elaboration of these mechanisms is one of Freud's most enduring legacies. Their acknowledgment and exploration in psychotherapy and psychiatric research continue to the present day.

When the ego undertakes a rechanneling of libidinal energy as described above, the Id experiences a loss or abandonment of the object of desire. In Freud's theory (1960, 1997), the ego replaces this loss by taking on the identity of the lost object - a more rational or socially acceptable incarnation of the lost object. Freud (1960, 1997) terms this process identification. As Freud (1960, p. 24) explains, "when the ego assumes the features of the object, it is forcing itself, so to speak, upon the Id as a love-object and is trying to make good the Id’s loss by saying:

Look, you can love me too - I am so like the object." This quote by Freud (1960) very clearly explains what he means. It does, however, conjure up images in one's mind of homunculus running around the brain explaining things to one another. It is unclear exactly how such a conversation would occur, and in this sense, Freud (1960) provides a somewhat mystical explanation. An example of this mechanism might be a male undergraduate student whose desire it is to be loved by all the attractive coeds on campus, and who experiences little success in actualizing this desire. This individual might sublimate this desire into a more intensive pursuit of academics. His ego might tell him that this will cause him to be loved also: by his professors, by his parents, by certain fellow students, and last but not least, by his ego.

For Freud, these substitutions or identifications have a great deal to do with determining the form taken by the ego, and they make the seminal contribution toward building what we refer to as the character of a person. In general, the ego either acquiesces to an object-cathexis, uses one of the rechanneling mechanisms or uses the strongest of the rechanneling mechanisms - repression. Through the mechanism of identification, the object of desire is set up within the ego. Freud (1960, p. 24) thus surmises that, "it makes it possible to suppose that the character of the ego is a precipitate of abandoned object-cathexes and that it contains the history of those object-choices." Freud (1960) also makes the observation that this transformation or identification process is narcissistic and changes sexual-object libido into a narcissistic libido with a different aim. He also points out that if object- identifications become too numerous, too powerful and incompatible, the result could be pathological. He speculates that perhaps multiple personality disorder is the result of different identifications that are cut off from one another being seized alternatively by consciousness. Individuals too heavily reliant on defense mechanisms may develop distorted views of self, others and objective reality that result in personality disorders (Lefrancois, 2001).

Identification is also Freud's explanation for the evolution of the ego ideal or what he terms the super -ego. Freud derives the super- ego from circumstances occurring during his Oedipal stage of psychosocial development. During this stage, he postulates that boys develop a sexual interest in their mothers and an ambivalent or even hostile feeling toward their fathers. Since this is a passion which cannot be actualized, due to a fear of castration (Freud speculates), the ego creates identification with father. This identification permits the retention of an affectionate relationship with mother and the creation of a self-preserving relationship with father. A similar process is postulated for girls and termed the Electra complex. The identification with parent results in the child taking on the ethical, spiritual and societal ideals and values of the parent. This specific ego modification, or as Freud (1960) terms it, precipitate, takes on a special role. It confronts the other contents of the ego as an ego ideal or super-ego. It becomes a reaction-formation against the choices of the ego. The "you may do this, but not do that" external role of parent becomes internalized as the role of the super- ego. The super-ego becomes the conscience of the individual. Freud (1960) states that the stronger the repression of the Oedipal complex, under the combined influence of authority (parental, religious, school), the stricter the domination will be of the super-ego over the ego later in life. The super-ego stands in judgment of the ego and the efficacy of its responses to both the external demands of the world and the success of its mitigation or mediation of the Id. The tension between the demands of the super-ego and the actual performance of the ego is experienced as feelings of guilt. Modern interpretations acknowledge the formation of a mechanism that functionally operates in accordance with Freud's description of the super-ego. They infer, however, that internalization of values from parental and societal influences need not involve the resolution of an Oedipal complex.

In Freud's (1960) description of the interactional dynamics of the Id, Ego and Super-ego we get a sense of the Ego functioning in a way so as to create an **equilibrium** or **harmony** between the passions of the Id, the ideals of the Super-ego and the demands of the external world. This theme of dynamic equilibrium created by systemic relationship through compensations or adaptations is one we will encounter frequently as we explore the intellectual innovations of the 20th and 21st centuries.

It is of interest to also explore Freud's ideas concerning the basic nature of the thought process. With time, Freud altered his views concerning the nature of repression and the unconscious (Freud, 1960, 1997). He split the unconscious (Ucs) into two categories: the latent or preconscious (Pcs) and the repressed. The latent or preconscious is capable of becoming conscious at any time. It is only temporarily unconscious. An example of the content of this portion of the unconscious would be, for example, our inventory of recallable memories. They may not currently be part of our consciousness, but could be brought into consciousness at any time. The repressed portion of the unconscious, however, cannot become conscious because a force opposes this. These repressed ideas, according to Freud (1960), can produce all the effects that ordinary conscious ideas can produce, in spite of the fact that they do not become conscious. It is the goal of psychoanalysis to remove the opposing force and make the repressed ideas conscious. The force which institutes the repression is experienced as resistance during the process of psychoanalysis. It is from the theory of repression that Freud (1997) originally developed his concept of the unconscious.

With the inclusion of the preconscious, he acknowledges that the unconscious does not coincide with the repressed. Freud (1960) characterizes the ego as the coherent organization of mental processes to which consciousness is attached. It is an agency which supervises its own processes and controls the actions and interactions of the individual with the external world. As discussed previously, the ego is also responsible in its defensive or adaptational role, for the repressions. The repressions originally came about from the ego's effort to exclude certain trends in the mind from consciousness and any other form of effectiveness or activity. Freud (1960) then hypothesizes that the resistance is in fact an unconscious part of the ego itself, and that neuroses are not a conflict between the conscious and unconscious, but a conflict between the coherent part of the ego and a repressed part of the ego from which the coherent ego is split off.

The thought process, according to Freud (1960), is a movement of mental energy that ultimately expresses itself in some **action** or activity. In the case of preconscious ideas, Freud theorizes that they have the capacity to become conscious because they are connected to **word representations**. To him these word representations are residues of memories or, as he terms them, mnemonic residues. They were at one time perceptions, and Freud (1960) states:

> … only something which has once been a conscious perception can become conscious, and that anything arising from within (apart from feelings) that seeks to become conscious must try to transform itself into external perceptions: this becomes possible by means of memory traces [e.g. words].

Freud (1960) notes also that it is possible for thought processes to become conscious through connection with visual residues [visual cues], and that, for many people, this seems to be the favored method. He takes the position, however, that what becomes conscious as a result of visual queuing is only the concrete subject matter of thought, and that **relationships** between the **elements** of the subject matter cannot be given visual expression. **Relationships** and consequently **understanding** are derived through verbal recall. Freud (1960) summarizes:

> The part played by word-presentations now becomes perfectly clear. By their interposition internal thought processes are made into perceptions. It is like a demonstration of the theorem that all knowledge has its origin in external perception. When a hypercathexis of the process of

> thinking takes place, thoughts are actually perceived as if they came from without and consequently held to be true (p. 16).

The above is an enormous insight on the part of Freud and, I feel, one that has gone largely unnoticed, or at least underemphasized. This conclusion is precisely the one reached by Russian psychologists Vygotsky (1986) and Luria (1976) concerning the relationship between language and thought. For them, internal speech guides thought, words are the representation (for Freud, the mnemic residue) of concepts, and language is the means by which abstract representation is facilitated and meaning is created. We also find these ideas expressed in the work of Terrence Deacon (1997) and Steven Pinker (2007); work we will review later in the Dissertation.

Freud's (1960) implication that thoughts are mental re-creations is an idea we find echoed in the work of Gregory Bateson (2002) as well as the work of numerous cognitive psychologists. As pointed out by Bateson (2002) and Luria (1976), it is this characteristic that permits us to work with thoughts as though they were actual events themselves and to undertake "what if" analyses, planning and strategy development.

With the above conceptualization of how the preconscious becomes conscious through words, Freud (1960) concludes that it is the job of psychoanalysis, in cases where thoughts or memories are repressed, to supply the preconscious with links that facilitate the connection.

Freud (1960) examines the issue of the nature of feelings associated with pleasure and pain. He points out that they can exert a driving force without the ego noticing the compulsion, in other words, in an unconscious state. It is not until there is a resistance to the compulsion that something becomes conscious as displeasure, for example. It is therefore true, in his estimation, that sensations and feelings only become conscious through re-creation in the perceptual system. If the way forward is blocked or resisted, they do not come into being as perceived sensations. They do, however, exert their influence in the form of excitations, although the individual can be unconscious of the reason for these feelings.

They become, in effect, "unconscious feelings". With unconscious ideas, connecting links must be created before they can be brought into consciousness. Feelings, conversely, require no such link and are either conscious or unconscious. We'll return to these ideas later when we discuss the neurological basis for emotions and feelings, as well as the connection of emotions and feelings to instruction. For now, we can take Freud's point that thought and feelings, while having a connection, are two separate systems with differing dynamics.

Skinner

The story of B. F. Skinner and his approach to psychology begins at the start of the 20th century with the work of Russian physiologist Ivan Pavlov and contemporaneous American psychologist John Watson. Pavlov was experiencing difficulties in his experiments on the digestive system of dogs. When he first began his experiments, dogs salivated in the expected manner, while they were being fed. Next the dogs began to salivate as soon as they saw the food and, later, began salivating as soon as they saw the scientists who would subsequently bring them food. Pavlov inferred from this that the dogs were making a mental association, first between the sight of the food and the process of eating and subsequently, between the sight of the scientist and the process of eating. It was apparent that this association was sufficient to bring about the behavioral response (salivating), which at first occurred only during the process of eating. Pavlov abandoned his original experiments and pursued this idea (LeDoux, 1996; Woolfolk, 2004).

Pavlov began his experiments by sounding a tuning fork and recording the dog's response. As expected, the dog did not salivate. He called the sound of the tuning fork a <u>neutral stimulus,</u> at this stage, because it brought forth no behavioral response. Pavlov then fed the dog, and the dog responded by salivating. The food he termed an <u>unconditioned stimulus</u> (US), because no prior training or experience was needed to establish the connection between food and salivation. The salivation was termed an <u>unconditioned response</u> (UR) because it occurred without training. He then continually paired the food with the sound of the tuning fork. After repeated pairings, the dog associated the sound of the tuning fork with feeding and the sound itself was sufficient to bring about salivation in the dog. The sound Pavlov termed a <u>conditioned stimulus</u> (CS). The response of salivating after the sound was termed a <u>conditioned</u> <u>response</u> (CR). It was clear that, with training, the conditioned stimulus itself could bring about the behavior. The learning process above, we now call classical conditioning

(Woolfolk, 2004). The general idea is that when things occur together in space and time, we tend to associate them. Through this association, different items in the associated stimulus experience can invoke the same reaction. We now understand association as a generalized psychological mechanism that extends beyond classical conditioning. For example, the smell of a particular perfume can restore a memory and engender positive feelings within someone, if they associate the smell with a positive romantic event from the past.

Pavlov also uncovered three other phenomena that occur in connection with classical conditioning (Hill, 2002). Dogs who learned to salivate in response to hearing a particular sound would respond in like manner to sounds with similar tones. This phenomenon he called stimulus generalization. It is the idea that sufficiently similar stimulus can bring about the same response. Pavlov was also able to teach the dogs to discriminate and respond only to a specific tone and not to others that were similar, by making certain that the food was connected or associated with only the specific tone. This process he called discrimination. A third process, formally called extinction, occurs when a conditioned stimulus is continually presented but not followed by the unconditioned stimulus. The conditioned response gradually fades away and is finally extinguished. If for example, the tuning fork tone is continually sounded and food is never delivered to the dog, the association between the tuning fork sound and the food will gradually disappear or become extinguished. It is important to note that conditioning or associative learning occur only when the conditioned and unconditioned stimulus co-occur in time. If there is much difference in time between these two events, they will not become associated, and classical conditioning will not occur.

J. B. Watson, fine fellow that he was, performed analogous experiments with a toddler, code-named little Albert. Little Albert was initially unafraid of a laboratory rat. By hammering a pipe hard enough to frighten the child when the rat was present, Watson was able to classically condition the child to be frightened of the rat alone, absent any loud clanging (Lefrancois, 2001). Watson became so convinced that classical conditioning was the method of learning that he asserted that he could train any child to become competent in any profession through this mechanism. If Watson's training included much in the way of rats, pipe clanging and electroshock, I'm going to speculate that his trained professional would likely become a candidate for treatment by someone trained under Freud's paradigm.

As Skinner (1974) points out, the next 30 years of behavioral psychology, following the lead of Pavlov and Watson, concerned itself primarily with stimulus - response interpretations. Skinner (1974) states that this corresponds to the idea of a machine in which actions, in this case behavior, are the result of a force or pressure. The stimulus is the push or pull that causes the reaction or behavior. Skinner asserted (1974) that both Watson and Pavlov filled in the gaps of their theory by references to physiology [reductionism] and contended that their experiments on behavior were investigations into the physiological activities of the brain. As such, they were forced into hasty and incorrect interpretations of complex behavior (Skinner, 1974). Skinner (1974, p. 7) then states: "… the shortcomings in Watson's account are now, I believe, chiefly of historic interest" [ouch!].

Skinner (1953) developed a revised form of behaviorism based on Thorndike's (1913) Law of Effect. This law states that any act that produces a satisfying effect in a given situation will tend to be repeated in the future, given that same situation . Skinner's premise was that the principles of classical conditioning accounted for only a small fraction of learned behaviors. Many human behaviors are what he termed operants or deliberate actions that are undertaken in order to produce desired consequences. Skinner saw behavior as sandwiched between two sets of environmental influences: ones that precede the behavior and ones that follow it. Since behavior is ongoing, consequences of one behavior become the antecedents for the subsequent behavior. According to his view, the consequences of a behavior will determine whether this behavior will be repeated. The nature of a consequence can either strengthen or weaken the behavior. Skinner called a reinforcer any consequence that strengthens the behavior it follows. Reinforced behaviors increase in frequency and duration with time (Skinner, 1953). He identified two types of reinforcement. Positive reinforcement occurs when the behavior produces a new stimulus. For example, if a child receives milk and cookies after completing his homework, the positive reinforcement of the milk and cookies constitutes the new stimulus. Negative reinforcement is thought of as taking away an adverse stimulus. For example, allowing a child to escape chores after making a good grade on a test. The flip side of positive reinforcement is punishment. Punishment acts to decrease or suppress behavior. Punished behaviors, according to Skinner (1953), will decrease in frequency and duration with time. There are also two types of punishment. Again, the first type involves the appearance of a (punitive) stimulus and is called presentation punishment. An example of this would be the administration of a spanking. The second type is called removal punishment and involves the taking away of a (positive) stimulus (Skinner, 1953). An example of this type of punishment would be taking away privileges from a child who has exhibited an undesirable behavior. Please note the **statistical** nature of this process. A behavior is more likely to occur, or more **probable**, if it has been repeatedly reinforced. Likewise, a behavior is less likely or less probable if it has been repeatedly punished. In colloquial terms, Skinner's theory is commonly known as the "carrot and stick" strategy: If someone behaves appropriately he is rewarded with the carrot; if he behaves inappropriately, he is hit with the stick. Skinner never speculated as to the mental or psychological processes that gave rise to the mechanisms that he described. He regarded it useless to talk about constructs such as meaning or emotions (Hill, 2002).

It is extremely informative to examine the philosophy behind Skinner's work. Skinner's paradigm was strongly influenced by the ideas of Charles Darwin (Skinner, 1974). For Skinner (1974), behavior is always a response to the circumstances of an environment. Skinner eschews the existence of driving forces such as Freudian instincts or Bergson's "elan vital". For Skinner (1974), instincts and reflexes are current manifestations of natural selection and the phylogenetic and ontogenetic history of the individual. He points out that natural selection represents causality different from Newton's push -pull mechanism. The manifestations known as reflexes and instincts can be explained by the contribution that novel features of random origin (as per Darwin) made to survival. Skinner (1974) states:

> Survival may be said to be contingent upon certain kinds of behavior. For example, if members of a species did not mate, care for their young, or defend themselves against predators, the species would not survive (p.36).

Natural selection, not being a force, represents a different kind of causality. It is behavior in response to environment that allows for survival. Behavior is the consequence of chance mutation in the phylogenetic history of the species. If adaptive to the requirements that an environment imposes, the mutated variants of the species survive and the mutation becomes part of the genetic legacy of the species. It is in this way that the mutation eliciting the behavior becomes instinctual or reflexive. Said more simply, what Skinner (1974) is implying is that all of our instincts and reflexes are the result of past behaviors (resulting from mutations) that happened to be adaptive to the conditions of the environment. As they were adaptive, they enabled us to survive (were naturally selected). Said flippantly, we are the descendents of those rats who more successfully navigated the "Skinner boxes" of the past.

In his zeal to develop a single explanatory mechanism for all human phenomena, Skinner (1974) departs from the conventional view of classical conditioning. In the conventional view, a person elicits a conditioned response, like rapid heartbeat, because he associates something in the environment with the requirement for an increased heart rate. Skinner (1974) contends that it is the environment and not the person that makes the association: The connection is made in the external world. The increased heart rate, for example, is brought about by the requirements of running, not as a result of a conditioned reflex. The reflex is simply a way of identifying the fact that running causes the heart to beat more rapidly or as Skinner (1974, p. 38) states: "It is merely a convenience to identify the change as the acquisition of a conditioned reflex." What Skinner (1974) is positing here, is that an internal change independent of environmental influence is impossible. His basic model is completely externally driven and denies the existence of independently acting internal mechanisms. I think "denial" in the Freudian sense of the term is an appropriate characterization of this position.

Operant conditioning, for Skinner, is the way in which a person comes to deal effectively with his environment. Behavior which favors survival (food acquisition, sex, escape from harm), through the process of operating conditioning, is strengthened or reinforced by its consequences. This strengthening makes it more likely that the behavior will be repeated given similar circumstances in future environments. As stated previously, to stimulus and response, Skinner (1953) added consequence. There are three terms in his equation: the circumstance in which the behavior occurs, the behavior and the consequence. A stimulus present when a consequence is reinforced exerts influence over subsequent responses. For Skinner (1974), it does not create a conditioned reflex; it simply makes it more probable that the behavior will occur again. Skinner (1974) takes the position that all learning and development occur through the process of operant conditioning. His philosophic position or fundamental paradigm can be summarized as follows:

1) Human behavior is the reflection of the interaction of the genetic inheritance of an individual and the contingencies of his current environment.
2) Human genetic inheritance is the collection of behaviors of past generations that favored survival and were hence naturally selected and are manifest currently as instincts and reflexes.
3) Learning or modification of behavior occurs as a result of the consequences of actions: consequences resulting from the contingencies of the environment.
4) It is in the environment or through the action of the environment that associations occur, and by implication, that meaning exists or is created.

5) It is a matter of convenience that we attribute associations to the individual, in spite of the fact that association and meaning occur external to the individual.
6) Explanations of human behavior do not require a consideration of dynamics which occur within an individual, they are completely explained by the interaction of the genetic inheritance of the individual and the contingencies of his environment.

This paradigm does several things for Skinner. First of all, it eliminates the requirement or need for a mind that thinks and feels independent of the environment, and, therefore eliminates the need for any explanation of such a mind. Importantly, it reduces all human phenomena to external dynamics which can be observed, measured and analyzed "scientifically" in laboratory settings. With this paradigm he can take the position that it is possible to completely understand human behavior, and in fact all human phenomena, through measurements and observations of carefully controlled and constructed experiments conducted in his laboratory.

It is illuminating to look at Skinner's rebuttal (Skinner, 1974) to the criticism that behaviorism fails to consider: 1) how a situation looks to an individual, 2) how a person interprets a situation and 3) what meaning a situation has for a person. Skinner responds that to consider the above, we must examine the individual's behavior in the situation, and "we can only do this in terms of his genetic and environmental history" (Skinner, 1974, p. 77). Skinner (1974) cites an unnamed authority as having suggested that:

> For perception to go beyond the evidence of the senses, the brain must have stored information, allowing it to use available sensory data to choose between possibilities derived from past situations. Behavior is not controlled directly by stimuli, but by the brain's hypotheses of what probability lies in outside space and in the immediate future.

Skinner (1974) ridicules this explanation and regards it as mentalism or the concoction of unscientific speculation concerning unobservable, unmeasurable attributes of the mind. He derisively points out that the author replaces brain for mind in order to avoid dualism and reveal himself as a mentalist. Skinner (1974) responds:

> The brain is said to use data, make hypotheses, make choices, and so on, as the mind was once said to have done. But we observe simply that a person responds to a current setting (the evidence of his senses) because of his exposure to contingencies of which the setting has been a part. We have no reason to say that he has stored information which he now retrieves in order to interpret the evidence of his senses (p. 78).

The complete body of research on perception over the past 30 years supports the position of the unnamed authority and not Skinner (Reisberg, 2006). It serves no useful purpose to compare and contrast Skinner's position with the last 30 years of research and scholarship. It is sufficient to say that the perspective of human behavior using the context of a human being as a genetically formed organism passively interacting with an environment through the process of operant conditioning falls dramatically short of providing a sufficient framework for understanding the wealth of phenomena and research evidence available today.

A lesson we can learn by studying Skinner is the importance and crucial impact of goal and context on the type and extent of meaning that can be created from experience. Many human activities can be thought of as undertaking a series of **actions** intended to achieve a **goal** that an individual is **motivated** to achieve. Let us say, for example, that we have been hired to drain a swamp: Our motivated goal is to drain a swamp. Our actions are likely to be guided by a **concept** of swamps and a **theory** of swamp draining. This theory can be either received theory (formulated by someone else and communicated to us previously) or one **we constructed** ourselves from prior **experience.** This theory forms the **context** in which swamp-draining activities will occur. **Relationships** between swamp **characteristics** and **attributes** contained within the theory (concept) will guide the swamp draining actions undertaken and provide the **framework** for understanding and **creating meaning** from the specific **events** that occur during the swamp-draining process. If the events that occur during the draining process, events consequent to actions guided by our swamp draining theory, are congruent with those predicted by the theory, we will simply **assimilate** these events as confirmation of our theory. If, however, events occur and relationships emerge in the swamp-draining process that are not anticipated, predicted or explained by our theory, our theory must be altered to **accommodate** for these unprecedented events, if we are to understand or provide an explanation for what occurred. If our accommodations can be effected using the same metrics (characteristics/attributes) and relationships (**logical connections**) contained within our original theory, we can be said, as per Kuhn (1996), to have constructed a theory within a theory.

For example, let us say that our original swamp-draining theory was developed from our experience draining swamps in New England. We are currently, however, draining a swamp in Louisiana. The original theory may not have included the possibility of alligators and poisonous snakes being in the swamp. Our swamp-draining actions in Louisiana must be guided by a theoretical revision which accommodates the existence of these additional variables. The general hydrodynamics involved in draining the swamp, however, remain unchanged, and we simply have a Louisiana corollary to our general theory of swamp drainage. Our theoretical framework remains the same, as do the metrics and relationships contained within our original theory. Our Louisiana corollary is simply a theory within our overarching theory or framework (context).

Let us now say that our Louisiana swamp fills back up with water as soon as we drain it. This is in contrast to our New England experience, which was the basis for the original theory. In New England, perhaps, the swamps have impermeable clay that contains water in low lying areas that are principally sourced by water flowing to them during rainy periods. In New England, once drained, a swamp remains drained. In contrast, in Louisiana, swamp bottoms are sandy and swamps are formed by the continual influx of water from sources that are constantly replenished. This might describe swamps, for example, in the Mississippi River Delta of Louisiana. The circumstances or events we encountered in Louisiana call for a completely different theory constituted of different variables connected through a completely different relationship. In fact, accommodation of the events just described requires that we move up a **logical level** (higher level of abstraction) and consider our activity as the creation of a landmass in a formerly aqueous environment. In this way, swamp draining becomes a **subordinate concept** within the **super-ordinate** concept of creating landmasses in formerly aqueous environments. Note that accommodating our experience resulted in the **emergence** of a higher logical level, expanded context, additional metrics and altered relationships. We don't have to throw our former swamp-draining theory away; we simply consider it as an element of a bigger theory pertaining to the creation of new landmasses. Kuhn (1996) would characterize the above as a paradigm shift.

Many of the biggest mistakes or lost opportunities in the history of business were the result of the failure to undertake the paradigm shift described above. For example, during the first half of the 20th century, corporations that produced motion pictures dominated the entertainment industry. These companies viewed themselves as being in the motion picture-production business. Had they viewed themselves in the larger context of being in the entertainment business, they could have captured the hundreds of billions of dollars that were subsequently spent on alternative forms of entertainment. The Disney Corporation was one of the first to come to this realization. Disney transformed itself from a nearly bankrupt operator of theme parks into one of America's largest and most successful corporate entities. IBM Corporation provides another example. IBM formerly conceptualized itself as a manufacturer of large main-frame computers. With the advent of microcomputers, this paradigm put IBM on the brink of bankruptcy. Under the leadership of Lou Gerstner, IBM re-conceptualized itself as a provider of information services: a paradigmatic shift that completely changed the nature of the company and restored its vitality.

Let us examine Skinner with respect to context and goal. Perhaps Skinner began his research with a relatively modest goal of improving upon the stimulus-response behavioral psychology of Pavlov and Watson. It is clear from his discussions in *About Behaviorism* (Skinner, 1974), that whatever Skinner's goal originally was, it ultimately became the description and explanation of all human phenomena in the context of operant conditioning. The postulates constituting this context were discussed previously. In summary, the defining postulate is that human behavior is completely specified by the interaction of the genetic inheritance of an individual and the contingencies of his current environment. In this interaction, positive consequences reinforce and make more probable the reinforced behavior, while negative outcomes diminish and make less likely "punished behaviors" or behaviors that have adverse consequences.

There is an implicit goal that is also involved. Skinner wishes to create a context wherein his methodology can provide an explanation for all human behavior; this methodology relies on careful and controlled experiments involving operant conditioning. For this methodology to be comprehensive, he requires the postulate that all meaning is created externally and exists external to the individual. This is why he takes the position that all theories concerning dynamics internal to the individual are speculative mentalisms. While Skinner (1974) distances himself from logical positivism, I believe his position to be exemplary of this philosophy. I believe Skinner takes the position that something not measurable in his laboratory is not only unworthy of consideration, but simply doesn't exist. Logical positivism is the position that something not provable as true or false does not have meaning and hence does not deserve consideration. Also implicit, both in Skinner and logical positivism, is the basic modern paradigm that objective truth exists external to the individual. It is through the application of logic and reason to real external experience that this objective truth is "discovered."

The important point to note is that once we take the position that "we hold these truths to be self evident that" the following [postulate] is true, we fix the context (framework) of our deliberations. The context in turn fixes the metrics by which we characterize the object of our consideration and the nature of relationships that are permissible (logical) within this context. Our swamp example illustrated that this condition is not necessarily intellectually terminal, if we permit an accommodation to occur which allows for the creation or emergence of a new context at a higher logical level. This, however, did not occur with Skinner, who fastidiously held on to his paradigm.

Skinner's paradigm, for example, cannot provide an explanation for how different people experiencing the same stimulus could have different perceptions of the stimulus. For example, a visually ambiguous picture will be perceived differently by different people. Their perception will depend not only on the physical character of the stimulus but also on what is going on in the person's mind at the time the stimulus is presented. In fact, we can't determine what the relevant aspects of the stimulus are until the individual responds. This implies that the character of the stimulus is determined by the inner thoughts of the individual rather than the objective features of the environment (Morton, 1997; Reisberg, 2006). An explanation for this phenomenon, documented in countless experiments (Reisberg, 2006), cannot be formulated in the context of Skinner's (1974) paradigm. Neither the metrics nor the type of relationships necessary to develop an explanation exists within this paradigm.

In summary, there are several epistemological lemmas implicit in the above. First, an individual's goal impacts the nature of the context used in order to create meaning. Second, the context employed controls the metrics (attributes/characteristics) as well as the nature of permissible (logical) relationships that are employed in the meaning-creation process and the kind of process methodology employed. As such, goal and context impact the type of meaning that is created and its depth and breadth. Third, while some preliminary context is required for the meaning-creation process to begin, if we allow for a process of accommodation, a new context, often at a higher logical level, can emerge through a re-equilibration of the conceptual structure of the individual and the contingencies imposed by the environment. A fourth lemma is also implied, that meaning creation occurs within the individual. This lemma requires additional exemplification and will be addressed throughout the Dissertation.

The above has strong implications for learning and the design of learning experiences. The design of curriculum and instructional delivery must carefully consider the specific goals of the learning experience. Caution is required here. It is often the case that context and methodology are incongruent with what has been articulated as goal. In addition, goal specification should be such that a specific and meaningful context is in fact invoked. For example, stating that the goal is to learn algebra is insufficient. While the meaning-creation process and understanding occur within the individual, demonstration that such understanding has occurred is a public act and requires that part of the goal specification include observable and measureable behavior. Whether that is a dramatic presentation or production of text (a paper), an understanding is required of how these goals impact context and how the context, in turn, will impact the metrics, relationships and process methodology of the learning (meaning creation) experience. Instructional activities must also permit and, in fact support the emergence of expanded contexts and understanding. We will flesh these ideas out as the Dissertation proceeds.

As with Freud, Skinner has left an enduring legacy. For several decades behaviorism was the theoretical foundation for considerable work in the fields of psychology, education and institutional management. Skinner and his intellectual descendents extensively evaluated and developed understanding of an extremely important human behavioral characteristic: operant conditioning. While not the "be-all, end-all" theory that Skinner presumed, behaviorism has made important contributions to strategies for classroom management, enhancing the effectiveness of student- teacher relationships and therapeutic treatment of certain mental conditions. A classroom behavioral manifestation called "teaching to the T" provides an illustrative example. This behavioral manifestation is based on two observations. The first is that teachers tend to interact more frequently and more intensively with those students who demonstrate the strongest interest in the lessons they are administering. This is a manifestation of operant conditioning or the positive reinforcement the teacher has received from the responsive students. The second observation is that these students tend to sit in the row closest to the teacher (front row) and in a column directly behind where the teacher normally stands while giving lessons. The engaged and motivated students, the students with whom the teacher more frequently interacts, have therefore arranged themselves geometrically into the letter T. The least engaged and attended-to students are to be found in the far right and left back corners of the room. As a result of these observations, teachers are encouraged to understand these behaviors and increase their level of engagement with students outside of the T. Periodically changing seating arrangements can also be of benefit. This is but one example of a large inventory of practices derived from behaviorism that have been found to be effective in managing classroom behavior or creating behavior in the classroom conducive to the learning process.

Vygotsky

During the 1920s, the primary research interest of Russian developmental psychologist Lev Vygotsky was the mechanism by which the basic, or as he termed them, “natural psychological mechanisms”, such as attention, perception, imagery, and association, were transformed into the higher psychological functions of logical memory, selective attention, problem solving and decision making (Kozulin, 1986). The context in which his investigations were framed, and the initial assumptions which he employed, were in no small measure influenced by and congruent with the socio-cultural environment in which he found himself. Soviet psychology, in general, and Vygotsky in particular, rejected the view that higher psychological functions were intrinsic properties independent of the environment in which an individual found himself. In line with the philosophy of Marx and Lenin, he believed that conscious, directed mental activity was not something given in advance and independent of the developmental history or ontogeny of the individual and the social milieu in which this ontogeny occurred. It was a reflection of the individual’s activities in adapting to and attempting to restructure that environment (Luria, 1976).

In Vygotsky's time, this was a highly radical assumption: that experience could alter and, in fact, structure the mind. Since thought ultimately is a result of biological function, the assumption implicit in this position is that environmental exchange could alter the functioning of the brain. There was no scientific evidence for this in Vygotsky's time. Today, we have an enormous amount of evidence from Neuroscience that this does in fact, occur. A significant number of neuronal connections in the brain are the direct result of the specific experience of the individual and the activities undertaken in responding to, adapting to, and attempting to change the environmental circumstances in which the individual finds himself (Le Doux, 2002). This process occurs not only during the developmental years but also throughout life. Every mental activity we undertake prospectively alters the neuronal configuration and connectivity of the brain (Bear, Connors, & Paradiso, 2007).

Methodologically, Vygotsky insisted on a developmental or ontogenetic method of study (Kozulin, 1986). This context is consistent with the premise, derived from the philosophy of Hegel, Marx and Engels, that the essence of phenomena can best be understood through a study of origin and history (Kozulin, 1986). As Vygotsky (1986) states:

> …. logical analysis is nothing but historical analysis freed from its historical form and from the accidents that obscure the lucidity of discourse. Logical inquiry starts at the very same point where historical development begins, and proceeds in the form of a theoretical reflection upon the unfolding of historical events (p.125-126).

As Vygotsky (1986) points out, a phenotypical analysis (one based on observable physical traits) of a whale could possibly lead to the conclusion that a whale was a fish. Conversely, a genetic analysis, considering the whale's evolutionary history, clearly puts it into the classification of mammal.

Given Vygotsky's context, it is not surprising that he was immediately led to language, the principal mechanism of social and cultural exchange between humans, and its role in concept formation and the direction of thought, as the principal objective of his research. This position is particularly well articulated by Vygotsky's contemporary A. R. Luria (1976):

> From birth on, children live in a world of things social labor has created: products of history. They learn to communicate with others around them and develop **relationships** through the help of adults. Children assimilate language - a ready-made product of socio-historical development - and use it to **analyze, generalize and encode** experience. They name things, denoting them with expressions established earlier in human history, and thus assign things to

> certain **categories** and acquire **knowledge**. Once a child calls something a watch (chasy in Russian), he immediately incorporates it into a **system** of things **related** to time (chas); once he calls a moving object a steamship (parovoz in Russian), he automatically **isolates** its **defining properties** - motion (vozit) by means of steam (par). Language, which mediates human perception, results in extremely complex operations; the **analysis** and **synthesis** of incoming information, the perceptual **ordering** of the world, and the **encoding** of impressions into **systems.** Those words carry not only **meaning** but also the fundamental units of **consciousness** reflecting the external world (p. 9).

Luria (1976) also references the mental portability of abstract representation through language. Through words and verbal meanings we can deal with absent objects and in effect **re-create** the world in our minds. Words maintain the system of **meaning** whether we are experiencing the objects referred to or not. This capacity for re-creation also allows us to **reorder** the **relationships** among things and thereby enables a process of creation. Through the use of syntactic relationships among the words of a sentence, we are able to create complex **relationships** and to transmit thoughts**.** Philosopher Jerry Fodor (1975) characterizes language as a productive system. Sentences in a language are a production or creation. Using a finite set of elements or words and a set of rules for putting the elements or words together, which we call a syntax or grammar, we can produce an infinite number of thoughts and articulate an infinite number of ideas. Through a hierarchy or system of sentences, we can not only reflect on things but also create what Luria (1976) calls objective logical codes. "Such codes enable a person to go beyond direct experience and to draw conclusions that have the same objectivity as the data of direct sensory experience (Luria, 1976, p. 10)". What I interpret Luria to mean by objective logical codes, are the concepts, theories, and rules that result when a **consistent pattern of relationship** is created from the logical/judgmental connection of **abstracted entities** (elements) characterizing the objects of consideration. Once such an objective logical code is constructed through a process which I would characterize as induction or **generalization**, a subsequent **deductive** process or application of the **rule,** concept or theory renders the objective conclusions without the necessity of direct experience, as Luria states above. So, for Vygotsky and Luria, abstract representation through the mediation of language enables both thought and consciousness. In the discussion above, and in fact throughout the Dissertation, I have made bold certain words. This is to call to the reader's attention the fact that these specific words are appearing time and time again in our discussions in various domains of knowledge.

Let us examine Vygotsky’s (1986) characterization of thought. Vygotsky (1986) states that every thought creates a relationship: it connects something with something else. Thought fulfills a function or solves a problem. Implicit in this statement is the idea that consciously directed thought serves the intentionality or motivated goal of the individual. Vygotsky’s (1986) central thesis is that thought does not find its expression in words; it finds its reality and form in words. Words control not only the direction and nature of thought, but also control and direct the development and activity of the higher psychological functions, such as deliberate attention, logical memory, abstraction and the ability to compare, contrast and categorize. The prevailing view during Vygotsky's time and still the view for some today, is that language is simply the externalization of thought or the cloak or mantle that thought puts on as it moves from inside the individual to outside. This implies a measure of separability or independence between the two. For Vygotsky (1986), thought is not merely expressed in words; it comes into existence through them. Language is what makes self-directed thought and consciousness possible.

Thought and words, or thought and language, are connected through word meaning. Meaning is an indispensable component of words. Without meaning, words are only sounds. **The meaning of a word is a generalization or concep**t. Since generalizations and concepts are acts of thought, meaning is a phenomenon or consequence of thinking. It is therefore the case that word and thought are bound in relationship through meaning.

Vygotsky's (1986) research and analysis demonstrated a developmental process and evolution of word meanings. In the beginning, a child's conceptions consist of subjective connections the child has put together based on an impression or unarticulated image that has formed in the child's mind. It is important to note that these images or impressions are composited and undifferentiated. This is understandably the case since a young child has a paucity of experience and little basis with which to differentiate an object of consideration. The child's conceptions do include some objective features, although, in composited form. This permits communication with adults to the extent that child and adult meanings reference the same attributes in an object or circumstance.

Vygotsky (1986) characterizes the next stage in the development of children's concepts as the formation of complexes. In forming complexes, children group items together not only on the basis of subjective impressions, but, in addition, actual physical bonds that are perceived to exist among items. These are generally graphical, physical attributes such as color, form and size. Importantly, children also associate or group items on the basis of similar function or the co-occurrence of items in the events of their experience. Complexes therefore often have the attribute or characteristic of a family relationship. For example, children will associate those items found in a meal situation (the family of things that serve the function of eating): chairs, tablecloth, knife, fork and so forth. Vygotsky (1986) makes the important observation that individual items enter the “complex” form of conceptual grouping as whole entities. While the child is beginning to differentiate or at least identify different attributes or characteristics of objects, the grouping of objects is a grouping of wholes. Individual characteristics and attributes have not yet been abstracted from the objects of consideration. An example, from Vygotsky (1986), of the verbal characterization of the type of conceptualization represented by a complex, would be a child referring to multiple objects as a "bow - wow". He will use the same "word" to refer to dogs, toy dogs, dolls, and a thermometer. The child has not yet differentiated these objects but has made an association between them based on a physical characteristic: their overall oblong shape. The "meaning" of bow -wow for the child, is the collection of all objects in his experience which create the same impression on him with regard to overall physical shape or geometry. Vygotsky (1986) refers to the type of complex just described as an associative complex. The child associates objects on the basis of some single observable physical attribute.

Through word meanings, word usage also reveals the nature of underlying thought. We can see with development, a progressive level of differentiation of the objects and events of a child's experience. Importantly, the nature of relationships between the objects and events of experience also exhibits a developmental progression. As discussed above, the child begins with observable, physical connections, functional relationships and space-time co-incidences (things that occur together go together). The determining factor in creating complexes is graphic (image) perception and graphic recall of relationships among objects. Relationships are concrete factual connections between the concrete objects and events of experience.

While an object is included in a complex because of one of its attributes, it enters as an undifferentiated whole with its full complement of attributes intact. Because of this, all traits are equivalent, and there is no hierarchical structure in a complex. A complex does not rise above its elements (Vygotsky, 1986). Also, since objects enter complexes as undifferentiated wholes, complexes are inherently unstable. Any attribute of an included object can take over and form the basis of a new or revised complex that could supplant the prior complex.

Beginning in adolescence or around age 12 (Vygotsky, 1986), children begin to invoke a completely different set of psychological processes. They now identify, isolate and abstract (remove) distinct characteristics and attributes from the objects and events of experience. Where previously relationships were factual and based on the individual's practical experience, relationships are now based on logical connections between the abstracted characteristics and attributes of objects and events. This permits a categorical representation. Inferences are drawn about objects and events by comparing them and assigning them to a category. The focus of thought is on categorical relationships and logical connections rather than concrete modes of interaction (Luria, 1976).

Both Vygotsky (1986) and Luria (1976) point out that the child's progression does not occur in a vacuum. Adult-supplied words and meanings provide the basis for the formation of complexes as well as the genuine concepts of the adolescent. These words and meanings, which are the product of a society's socio-cultural history, become the basis for abstraction, and they define the nature of the relationships between the abstracted elements (attributes/characteristics) of objects and events. The basis for both is the shared experience of a society conveyed through its linguistic system or system of meanings (Luria, 1976). Adult-supplied words and meanings, or language, facilitate the transition from unmediated sensory reflection to mediated rational thinking (Luria, 1976). Thinking is thus transformed into a scheme of semantic and logical operations. Words become the principal agents for abstraction, generalization and the representation of concepts; word meanings change from emotional impressions and concrete ideas to derivations evolved from a historically developed system of meanings.

The above also implies that the higher psychological functions are developed through the same process (the mediation of language). Abstract rationality and consciousness are born through words. Language determines the structure and nature of logical memory, self directed attention, perception of reality, problem solving, reasoning and judgment (Vygotsky, 1986; Luria, 1976). In giving this seminal role to language, Vygotsky (1986) and Luria (1976) naturally make the case that formal instruction, the principal mechanism by which the semantic structure of a society is transmitted by society to its youth, provides the principal source of conceptual structures and determines the fate of mental development. They also take the position that formal instruction provides the template by which meaning is created from the ordinary, non-academically defined facts, objects and events of life. In other words, as formal instruction proceeds, we organize and make sense of the ordinary events and circumstances of our lives in accordance with the semantic structures we receive from formal instruction.

Let me be clear on this: Vygotsky (1986) and Luria (1976) take the position that development alone will not produce an individual with the capacity for abstract rationality and the range of cognitive abilities that this capacity enables. Abstracted elements connected through logical relationships and physical attributes connected through concrete modes of interaction are two different reflections of reality. These two separate modes invoke different psychological processes. The intellectual capabilities that they enable differ also. For example, concrete thinking is strongly fixed in a situation, while abstract thinking is portable and can be undertaken in the absence of any environmental stimulus. It is the difference between arithmetic and algebra. In algebra, we can create relationships and make statements that are true about sets, categories and classes of numbers. In arithmetic, our statements are true for specific numbers (two plus two equals four). In concrete thinking, it is difficult to create thought from a succession of images. This type of thinking is usually limited to articulating relationships within a single image. It is even more difficult to switch the principle of classification or organization among elements contained in multiple images. These cognitive activities are, however, readily facilitated by abstraction and generalization using the structures of language. Abstraction not only facilitates the portability (off-line nature) of thought, it also enables productivity. Once characteristics are abstracted, they can be reorganized using different logical connectives. This is precisely what happens when we use language. By varying logical connectives, we can express an unlimited number of thoughts with words (abstracted entities). It is difficult, however, to dispense with a visual thought and visually reclassify objects according to a different principle. We can enumerate a large number of differences between the two modes of thinking and will do so later in the Dissertation. At this stage, I simply want to point out that it is Vygotsky's (1986) and Luria's (1976) position that the transition from concrete to abstract thinking, which is a fundamental reorganization of cognitive activity, does not occur in the absence of socio-cultural influence (transmitted through language). They contend that biology alone is insufficient; to biology we must add culture.

Vygotsky (1986) characterizes children's speech as occurring on two planes: the plane of verbalization or phonetic articulation and the plane of meaning or semantic content. He interprets an independent bidirectional movement or evolution between these two planes. The child's first articulation consists of single words. Semantically these words represent complexes or collections of undifferentiated wholes constructed in the manner described above. The child's speech progresses to protolanguage consisting of two or three words, then simple sentences, and finally a coherent series or collection of sentences. This progression in verbalization must be accompanied by a correlative semantic change, wherein the original amorphous wholes become increasingly differentiated into well defined and separated semantic units. Correspondence between verbalization and meaning is a process. Verbal expressions do not emerge fully formed but develop meaning gradually (Vygotsky, 1986).

When a child first begins to use words, verbal forms and meanings are fused and inseparable. A word, to a young child, is an integral part of the object it represents. Due to the fact that the word designates a complex (undifferentiated whole) in the child's thought process, the child does not separate the name of an object from its attributes. As Vygotsky (1986) points out, young children explain the names of objects by denoting their attributes. A cow is a cow because it has horns; if it has horns, it is a cow; the name and the attributes are inseparable. Words have both a nominative aspect and a significative aspect: They refer to something (name something), and they convey meaning. The early words of the child primarily perform the referent or nominative function. As the significative (semantic) aspect of words develops and evolves, a separation occurs between the nominative and significative function of words. According to Vygotsky (1986), it is only when this separation is achieved that one is fully able to formulate his own thoughts.

Piaget (Gruber & Voneche, 1995) was the first to study the functions of language among children. He noted that at first a child merely repeats what she has heard or understood from the speech of others. Next, the child becomes interested in her own speech production and articulates words for the pleasure of talking. The succeeding stage is characterized as a monologue, in which the child talks to herself as though she were thinking out loud. In social settings, this monologue, or, in essence, speech for oneself is also in evidence. Called collective monologue by Piaget (1926), the presence of others serves merely as a stimulus for the child's own verbal productions. The functions of speech are egocentric and serve to provide mental orientation, conscious understanding, and help in overcoming difficulty. In essence, the speech serves to direct the child's conscious thought. It is an accompaniment and reinforcement of individual activity. The child makes no attempt to adapt to the point of view of others or to take the position of someone who doesn't know. The child behaves as if everyone shares the same knowledge that she has. It does not appear necessary that other children either attend to or understand what the child is articulating. "This talk is egocentric, partly because the child speaks only about herself, but chiefly because she does not attempt to place herself at the point of view of the hearer" (Gruber & Voneche, 1995, p. 70). The child's language only begins to resemble that of adults when she is directly interested in making herself understood, for example, when asking questions or making demands. During the period of egocentric speech, a considerable fraction of communication among children occurs through the mechanisms of gestures, movement and mimicry, which accompany or even replace the use of words.

Piaget (1926) makes the point that adult speech is socialized and reflects the contingencies of a social environment. It serves functions such as the exchange of information, criticism, commands, requests, threats, and questions and answers. He notes that even inner speech is often addressed to a hypothetical audience and reflects the recognition of the necessity to see things from the point of view of others and to make one-self understood by others.

Vygotsky (1986) interprets Piaget's (1926) position to be that egocentric speech is an expression of the primary autism of a child's thinking at this stage. With age, the child becomes increasingly socialized by her environment, autism recedes, and egocentrism disappears. The disappearance of egocentric speech is therefore a consequence of the necessary adaptation of the child to the contingencies of her social environment. Vygotsky (1986) disagrees with this and attributes the decline of egocentric speech to the emergence of inner speech. Speech for oneself or speech which acts to direct thought moves from outside to inside the individual. For Vygotsky (1986), the main course of a child's development is one of individuation and differentiation. Speech for oneself originates through the differentiation of speech for others. Egocentric speech is formed out of social speech, but has its own function and structure: directing thought. It represents a transition, therefore, from speech for others to speech for oneself (ultimately inner speech).

Inner speech is not speech minus sound; it is an instrument of individual thought and possesses its own syntax (Vygotsky, 1986). It exhibits the characteristics of predication, decrease in vocalization and predominance of sense over static meaning and agglutination. Vygotsky (1986) makes an analogy with verbal conversation between two people. If the thoughts of two people coincide with respect to subject, understanding is achieved using only predicates. In addition, when the thoughts of two people are coincident and they share apperception, words are reduced to a minimum. Since mutual perception is always a given with inner speech, it is characterized by predication and the use of a minimum number of words. The more differentiated the function of speech (more for self), the more simplified and predicated it becomes. With syntax and sound minimized, meaning rises to the forefront. Inner speech is primarily involved with meanings.

Vygotsky (1986) also ascribes the quality of agglutination to inner speech. Agglutination is the combination of multiple words into a single word such that a complex meaning is created. The German language, for example, is particularly suited for the creation of agglutinations. Words such as Gestalt and Zeitgeist, for example, have such expansive and rich meaning structures that they are used, without translation, by speakers and writers in many languages. A translation of Gestalt into English would require at least a paragraph.

Vygotsky (1986) describes words as having both a meaning and a sense. For Vygotsky (1986), meaning connotes the dictionary definition of a word, or in early language, the impression or association of word and image. For example the meaning of “bow-wow” for a child is the impression of an oblong shape. Vygotsky (1986) describes meaning as "a potentiality that finds its diversified realization in speech" (p. 245). For this potentiality to find its realization we require a context. A word acquires its sense from the context in which it occurs. The sense of the word is the combination of psychological events aroused by the word. Words change in different minds and in different situations (changes depending on context). The context enriches the meaning of the word.

Let me caution the reader that in the entirety of this Dissertation, save the above paragraph and this paragraph, I use the word "meaning" as Vygotsky (1986) uses the word "sense". This is due to the fact that in the other domains studied, the connotation of "meaning" includes Vygotsky's (1986) idea of "sense". Meaning then, in the rest of the Dissertation, incorporates the effect of context. The premise is that "meaning" is imparted by context and, in fact, cannot occur without it. It is context that creates stability and as Vygotsky (1986) states, “allows a potentiality to find its realization”. When, for example, Bateson, Einstein and the philosophers cited in this Dissertation use the word meaning, they include Vygotsky's (1986) idea of sense.

To summarize then, inner speech consists of shortened, predicated, agglutinated, and concentrated packages of meaning. It is semantic. Vygotsky's (1986) system of articulation consists then of thought directed and organized by the semantic of inner speech: first, the introduction of whatever syntactic structures may be required to facilitate communication and understanding of verbal speech and second, a full syntactic imposition for the production of written speech. Language directs thought. It is through language that thought takes its form and structure (comes into existence). Language provides the attributes and qualities by which we characterize the objects and events of our experience, as well as the nature of the relationships we construct between these characterizing attributes. It is the mechanism by which we organize experience and makes sense (create meaning) of the universe (define parts and create wholes). Since language is the articulation of the socio-culturally derived system of meanings of a society, the intellectual development and life of an individual is the product of the socio-cultural history of a society. Such is Vygotsky and Luria's system.

The work of Vygotsky and his collaborator, Luria, is in my estimation one of the great intellectual achievements of 20th century thought. It is an important source of many of the ideas presented in this Dissertation. Like with Freud and Skinner, their work occurs within a paradigm: a paradigm set by context and goal. Vygotsky was a fervent Marxist and worked within the intellectual maelstrom of 1920s Russia. As such, he was naturally drawn to a context which would frame the manner in which societies shaped the minds of the people within them (Gopnik, Meltzoff, & Kuhl, 1999). As noted previously, consistent with the philosophy of Marx and Lenin, Vygotsky believed that conscious mental activity developed from and was guided by the interaction between individuals and their social environment. This postulate naturally leads to historical analysis (phylogenetic and ontogenetic) as the principal investigative methodology, in line with the philosophy of Hegel, Engels and Marx (Luria, 1976). Since language is the mechanism by which a society conveys its socio-culturally derived history of meanings, it became the principal unit of analysis within Vygotsky's framework. His task became one of understanding the ontogenetic progression of thought under the influence of language.

In examining whether we fully subscribe to Vygotsky's conclusions, we can ask whether language derived "knowing" creates a sufficiently comprehensive epistemology. We can begin by characterizing oral speech between two individuals. In oral speech, we see and interpret the facial expressions of the speaker is their body movements and gestures, the tone and inflection of their voices and, sometimes, the feel of their touch. This sensory input conveys and communicates, and therefore it constitutes a form of "knowing." A simple exchange of glances often communicates a wealth of feelings and thoughts. As a child, when I felt my mother's sharp fingernails dig into my arm, I did not require oral speech or inner speech to "know" what had just occurred and what was about to happen next. As Vygotsky (1986) points out, the more two people share the same thoughts and apperception, the more abbreviated is their verbal exchange. We can therefore infer that artifacts such as inflections of speech, gestures and facial impressions invoke "thought" of some kind or form.

Let us look at a hypothetical example which illustrates different forms of knowing. Consider an attractive young woman who finds herself lost on an out-of-town trip. Seeing no one on the street to assist her, she ventures into a seedy, dilapidated bar on the street corner. As she enters, the bar goes silent and all eyes become fixed on her. She sits on the first available barstool and readies herself to ask the bartender for directions to Delaney Street. Before she can get her words out, a grizzled, weather beaten man next to her reaches out and grabs her arm. She instinctively pulls away and runs out of the bar. As she continues running down the street, her inner speech begins. She says to herself: "Oh God, if you get me out of this alive, I promise to be forever faithful."

The above sequence of events, full of action and meaning, could have transpired without either external or internal speech. It is likely that her decision to enter the bar was directed by some internal conversation. But once inside, no words, either external or internal, were required to bring about the actions and events that occurred. The events and actions in the bar scenario were undoubtedly influenced by the young lady’s past associative learning experiences, either conscious or subconscious. The bar going silent and the man grabbing her arm without speaking were events she likely associated with discomfort and potential danger. Her responses to these events were largely subconscious and emotionally driven.

What is known today from neuroscience that was not known in Vygotsky's time is that separate neurological systems are invoked contingent upon the circumstances of an environment. The bar scene invoked the fast acting, subconscious, emotionally energized survival system. This system bypasses the directed attention, logical memory, executive function and language processing areas of the brain. These are precisely the areas involved in the higher psychological functions cited by Vygotsky (1986): those areas whose activities are directed and controlled by language, according to Vygotsky (1986).

All incoming sensory data is sent to an area of the brain called the thalamus. The thalamus sends the data on to the sensory processing areas of the cerebral cortex. For example, visual data is sent to the occipital lobe. In 1996, Joseph LeDoux, a New York University researcher, discovered a direct connection between the thalamus and the amygdala. The amygdala is an emotional processing center that has been directly associated with fight-flight behavioral responses. The amygdala is connected to a great number of areas in the brain. Its direct connections include the hypothalamus, brainstem and motor control areas of the cerebral cortex. The hypothalamus and brainstem, among other activities, produce neurotransmitters that ultimately activate the body systems that respond to stressful situations and increased physical requirements (increased heart rate, increased respiration, etc.). The amygdala receives both highly processed sensory data from the cerebral cortex and raw data coming directly from the thalamus. Data from both areas is monitored for threatening information. Data from the direct path can quickly initiate a defensive response because of the amygdala's direct connection with the hypothalamus, brainstem and motor control areas. The processed sensory data from the slower acting, cortex-involved path to the amygdala goes to the same neurons as data from the direct path and serves to confirm or negate the data directly received from the thalamus. For example, if someone hears a very loud noise, data coming directly from the thalamus is processed by neurons in the amygdala that are sensitive to noise data. If the noise level is beyond a certain threshold, the amygdala will activate a defensive response. The person will initially freeze his motion, heart rate and respiration will increase, other stress-induced bodily responses will occur and the person's attentional and sensory systems will be piqued. Contingent upon the more highly processed sensory content received from the cortex, the amygdala will either settle down or initiate a fight-flight response. The amygdala is an implicit processing area and does not require attention or consciousness to be activated. It also has the capacity to directly store memories with high emotional content. In our example, it is likely that the initial stress of the situation primed and sensitized the young lady's emotional processing circuits. When the grizzled man touched the woman's arm, her amygdala immediately produced a flight response.

Activation of the hypothalamus in response to stress results in the release of a steroid hormone. This steroid hormone finds its way back to the brain, where it binds to receptors in the hippocampus, amygdala, prefrontal cortex and other regions. Hippocampal steroid receptors are part of a control system that helps regulate how much adrenal steroid hormone is released. Signals from the hippocampus to the hypothalamus combine with signals from the amygdala to the hypothalamus and attempt to equilibrate in an effort to match the quantity of stress hormone to the demands of the stressful situation. If the stress level is too high or persists for too long, the hippocampus falters in its ability to control the release of the stress hormones and to perform its routine functions (LeDoux, 1996). The hippocampus and proximal areas are responsible for consolidating and retrieving explicit (declarative) memories. Lesions or damage to the hippocampus prevents the formation and retrieval of new declarative memories (facts and events). Stress hormones interfere with the ability to induce long-term potentiation and hence memory in the hippocampus. This mechanism offers a possible explanation as to why memory failure sometimes occurs in connection with highly stressful events. Combining this mechanism with the amygdala's ability to implicitly record emotional events provides a possible explanation for Freud's repression mechanism. The amygdala can record and induce emotional responses to stimuli without the individual having a consciously retrievable memory in connection with the responses. The above mechanism also explains why modest levels of stress focus attention and facilitate memory and learning, while high levels disable memory and learning [try to stay calm and focus on this SAT test, despite the fact that the next few hours will determine many of the important outcomes in your life].

Many different systems in the brain engage in implicit learning (LeDoux, 2002). For example, classical conditioning and memory for motor skills are believed to be the result of plasticity in the cerebellum. As discussed previously, the hippocampus and associated transitional areas are believed to be necessary for the formation and subsequent retrieval of consciously accessible memories. Patients with a damaged hippocampus can be classically conditioned but have no conscious memory of having been conditioned or of any of the facts or events surrounding the conditioning. Many of the motor skills that we have acquired did not involve conscious processing. Cohen and Squire (1980) showed that patients who were unable to form recallable memories could learn some complicated rule-based strategies required to solve certain mathematical problems or puzzles. For example, with a lot of practice they were able to solve the Tower of Hanoi problem by "learning" the steps of the solution. In all of these learning tasks, the patients had no recollection of the learning experience itself. In cognitive science, this type of memory is termed procedural memory. An additional form of implicit learning is called priming. Priming involves learning which demonstrates the effect of prior experience on performance rather than the subject's knowledge of prior learning. For example, conscious-memory impaired individuals given a list of words cannot recall any of them when subsequently tested. However, if given fragments of the words on the list and asked to complete the fragments, they can do so. They are not consciously recalling the words; the specific letter combinations have been primed by their prior experience, and they are subconsciously making an association.

What Vygotsky and Luria have insightfully evaluated is the functionality of those areas of the brain involved with directed attention, executive function, declarative memory and language processing. They have demonstrated the role that language plays in an ontogeny that ultimately leads to the capacity for abstract rationality. As Terrence Deacon (1997) states, it is this capacity for abstract representation that separates us from the rest of the animal kingdom. It is what gives us our advantage over Bonzi (the world's most literate chimp) and Bonzo (Ronald Reagan's favorite chimp). As the above discussion illustrates, there are other mechanisms of "knowing." As we will more fully discuss later in the Dissertation, a number of learning activities undertaken in schools constitute procedural learning and result in procedural memories. It is the case that mathematics learning many times is reduced to this. As experiments with memory impaired individuals has shown, anything reducible to an algorithm can be “learned” through the brain’s procedural memory systems without the requirement to create meaning in connection with the activity or an overt understanding of the meaning associated with the steps of the procedure. We do not even have to have conscious memory of the learning experience.

As the above also suggests, we rob educational experiences of some of their richness and depth when we fail to take advantage of the multiple mechanisms for human "knowing" and reduce the school experience to reading, writing and computational activities conducted independently by the individual. While these activities are critically important, failing to take advantage of our multiple capacities for "knowing" represents a lost opportunity. Embedding content in the context of a dramatic performance, for example, provides an opportunity for enhanced understanding created through the fusion of multiple mechanisms for "knowing."

In spite of having read numerous books on race relationships and having heard multiple lectures, I truly did not understand that not supporting or attending African-American museums, presentations and events constituted a form of implicit disrespect and disinterest in this culture: a passive minimization of its value. It was only after attending a dramatic presentation and subsequent discussion with the members of my Curriculum Theory class which examined this theme, that I came to this realization. Had I read this conclusion in a book, I would likely have dismissed it. Seeing and experiencing the human exchanges and dynamics that occurred when African art was introduced into what had been a museum of French Impressionist art, created a "knowing" that simply could not be produced in a traditional classroom experience.

Vygotsky (1986) and Luria (1976) conclude that the organizing structural elements of thought, the attributes and characteristics with which we characterize the objects and events of our experience and the logical connectives with which we create relationships and render meaning come from socio-culturally evolved language. This is certainly the case for someone currently in school. In fact, the frameworks of historically developed systems of meaning that currently exist exceed the capacity of any one individual to learn them. This was not always the case. The first archaeological evidence of abstract thought dates to approximately 40,000 years ago. At this time, there were no ready-made templates with which to organize thought, yet we have evidence of abstract thought. What mechanism accounts for the quantum leap from concrete relationships to abstract generalization? In addition, the general syntactic structure of all the world's languages is more similar than not (Pinker, 2007). While there are obvious idiosyncrasies reflecting cultural variation, there are remarkable similarities in the manner in which all known languages seem to organize objects and events. On close examination, there appear to be universals of thought that run through all of the world's languages, including those of aboriginal populations who have been isolated from others for most of their history (Amazonian tribes, for example). Pinker (2007) cites the following characteristics as manifest in all the world's languages:

1) a cast of basic concepts: event, state, place, thing, path, property, manner
2) a set of relationships that connect these concepts with one another
3) a taxonomy of entities
4) a system of spatial concepts
5) a system of temporal concepts
6) a family of causal relationships
7) the concept of goal

The above implies that there is perhaps an inherent logic implicit in how the human mind organizes sensory information and creates meaning from it. Vygotsky (1986) and Luria's (1976) model is fundamentally a nurture model. It appears that we need to perhaps add nature to this equation.

My intent with the above discussion is to illustrate how the goal and context imposed by Vygotsky (1986) and Luria (1976) impacted the results and conclusions of their investigation. We see once again the influence of goal and context on the type, depth and breadth of meaning we can derive from experience. In my mind, three questions still loom large:

1) What is the origin and nature of the types of subdivisions into which humans divide and organize the sensory perceptions of their experience?
2) What is the origin and nature of the connections by which we create the relationship between these characteristics and attributes?
3) What is the mechanism by which higher logical levels emerge (how do apples, oranges and cherries become fruit)?

The answers to the above questions are not ascertainable within any of the contexts we have considered so far. We continue our quest.

Piaget

Jean Piaget, born in 1896 in Neuchâtel Switzerland was, like Vygotsky, considered to be a gifted prodigy. He produced his first publication at the age of 10, which was a detailed description of an albino sparrow he observed in a public park. By the age of 15, he had already decided that his work should be directed toward a biologic explanation of knowledge (Wadsworth, 1989).

Piaget completed his baccalaureate by the age of 18, and three years later, completed doctorates in biology and the natural sciences. As part of his studies, he evaluated the development of mollusks in the lakes surrounding Neuchâtel. After observing several generations of mollusks, he concluded that the structural changes he observed in them were directly attributable to the level of wave action the mollusks were exposed to. He became convinced that development of an organism was significantly impacted by the process of adaptation to the environment (Wadsworth, 1989).

Early in his career, Piaget moved from biology to philosophy and eventually to psychology. Piaget quickly became dissatisfied with the inability of philosophic inquiry to resolve the fundamental issues with which he was concerned. A scientist by training, if not temperament, he came to believe that experimental work might be of assistance in resolving basic philosophic issues. Throughout his life, Piaget referred to his work as genetic epistemology. He visualized his work as the effort to develop a theory of knowledge and the mechanisms by which it is attained through the detailed study of the development of intellect in children. Piaget's interest in the developmental approach was undoubtedly influenced by his work in Binet's laboratory while studying psychology at the Sorbonne in Paris. Piaget became much more intrigued by the reasons for children's incorrect answers than in Binet's goal of developing a test that measured intelligence (Wadsworth, 1989).

For the next 60 years, Piaget produced a profoundly insightful, impactful and voluminous body of work on the intellectual development of the child. He is credited with founding and creating the initial basis for the field of developmental psychology. He is also credited with redirecting the field of psychology, in general, from a principal focus on behavior to that of cognition. As such, he is credited with founding the field of cognitive psychology. The philosophy of education known as constructivism, or the idea that knowledge is an active construction of the child rather than something that can be directly transferred and passively received, also owes its genesis to Piaget.

Piaget's context or paradigm consists of several framing postulates. First, the mind is the articulation of a biologic organism. As such, we should expect the processes that it undertakes to be fundamentally biologic in nature and expressive of the same dynamics that occur in other parts of the body. For example, biologic systems within the body express the principle of homeostasis. They tend to equilibrate and stabilize the body in a manner adaptive to the circumstances of the external environment. As an example, when the body senses that it is low on fluid volume, it will induce a response within the individual which motivates him to seek out and ingest liquids. In general, autonomic systems within the body undertake compensatory actions that serve to conserve the system, maintain integrity of function, and create an adaptive response to the requirements imposed by the external environment.

The implications that result from biological organization are perhaps best articulated by South American biologists Humberto Maturana and Francisco Varela (1998). Maturana and Varela (1998) define a **unity** as anything brought forth by an act of distinction. Distinction is the act of indicating a thing, object, or being. The act of distinction separates the entity from its background. Typically, we use properties or criteria to create the distinction. Maturana and Varela (1998) define **organization** as those **relationships** that must be present in order for something to exist. It is these relationships that define an object as a member of a **class** or, expressed in the language of logic, a **logical type**. We recognize, either implicitly or explicitly, the organization of an object when we indicate or distinguish it. We see an example of this process in how the human eye differentiates one object from another. Cells in the retinas of the eye are activated by light input. When activated, they not only transmit an output, they inhibit the output of adjacent cells. The greater the light input, the stronger this inhibition effect. When moving from one object to another in the visual field, the amount of light reflected from different objects to the retina changes. Let us say that the magnitude of light intensity decreases. This will decrease the amount of inhibition of adjacent cells in the field of vision sensing the less illuminated object. The effect of this is that the cells at the boundary of this change in light intensity receive the stronger light input from the more brightly illuminated object, but are less inhibited by adjacent cells sensing the less illuminated object. This creates an edge enhancement effect and makes the boundary between objects the part of the visual field that sends the strongest signal to the brain. It is in this way that the eye distinguishes one object from another (Reisberg, 2006). It is also the way that the eye, and subsequently the brain, perform an act of **distinction** and create **unities.** The retina uses the property of intensity of reflected light from an object as the **characteristi**c with which to make the **distinction**. The retina also does not send the full visual image to the brain. It breaks the image down into features such as vertical lines, horizontal lines, angular lines, arc segments and circles. In the visual processing areas of the cerebral cortex, these features are recombined according to an implicit relational logic. The manifestations of this logic are the gestalt's or apparent patterns of relationships inherent in human visual processing, discovered by German psychologists in the early 20th century. The brain then, in order to identify objects, **organizes** features through **relationship** and undertakes an act of **organization**.

There are several things to note about this process that are characteristic of biologic information processing. First, what is detected is difference. Distinction is an act of **differentiation.** Said colloquially, we know what something is by what it is not. The idea of difference is crucial to Bateson's (2002) conceptualization of mind. Bateson (2002) characterizes information as news of a difference. This information or news of difference must be such that it can be represented in some information processing entity, such as a brain or computer. It takes at least two things to create a difference. "The stuff of sensation, then, is a pair of values of some variable, presented over a time to a sense organ whose response depends upon the ratio [relationship between values of the variable] between the members of the pair" (Bateson, 2002, p. 64). The sense organ responds to difference or change. Sense organs can only operate with events which we call changes. "Information consists of differences that make a difference" (Bateson, 2002, p. 92).

We can see from the above that the constituent of information and, hence, organization and sense making is news of a difference. In this way, **similarity** and **difference** constitute the basis for the creation of unities, the beginnings of any organizational structure and the foundation of meaning creation. We will see this theme time and again in this Dissertation. For example, it is the mechanism postulated by Bertrand Russell, noted philosopher and mathematician, for how human beings arrive at their sense of number. Russell (1993) calls our attention to the fact that a particular number is not identical with any collection having that number: the number three is not identical with the trio consisting of Tom, Dick and Harry. The number three is a characteristic or attribute that all trios have in common and which distinguishes them from other collections. It is a characteristic **similar** to all trios and different from collections of pairs or quartets. Russell (1993) cites two ways to state a definition or create a collection. We can enumerate all of the specific objects of the collection and thereby create what is called a definition by extension. We can, alternatively, select a distinguishing attribute or characteristic that defines the collection. In this way, our collection becomes all things x, where x is the defining characteristic or property. Such a collection is more properly referred to as a class and our definition is termed a definition by intention. For example, Tom, Dick, and Harry can be said to belong to a class known as men. Russell (1993) points out the difference between a class and the defining characteristic of the class. There is only one class having a given set of members, but there are many different ways in which a class can be defined. "Men may be defined as featherless bipeds, or as rational animals, or (more correctly) by the traits by which Swift delineates the Yahoos. It is this fact, that a **defining characteristic is never unique**, which makes classes useful" (Russell, 1993 p. 18). He defines numbers then as one of the bundles into which **similarity collects classes**.

We can infer from the above, the mechanism by which children conceptualize addition. It is fundamentally what Piaget (1985) would term empirical abstraction of the action involved in creating, for example, a quartet from a trio. By reaching out and adding a marble to a trio, the result becomes **similar** to the perceptual recognition of quartets. This, I believe, explains why children instinctually use their fingers to add. Children are creating a one-to-one mapping between their fingers and objects. There is thus an implied similarity. Next, they make an association between the often heard verbalization of the number and an association between this verbalization and its visual symbolic expression (verbal three to symbol 3). It also illuminates the value of using manipulatives in the teaching of arithmetic.

The fundamentality of the above is illustrated by considering the Semeiotic philosophy of Charles Pierce (Deledalle 2000). Pierce asserts that there are three categories necessary for thought. Category one is complete, undifferentiated infinite totality. What can be said of one? Nothing! It is at once total being and nonbeing. We can view this in the Aristotelian sense or quantum mechanical sense as complete possibility. 17th Century philosophers referred to this idea as substance. Spinoza (1982) states: "By substance, I understand that which is in itself and is conceived through itself; in other words, that the conception of which does not need the conception of another thing from which it must be formed" (p. 355). For Spinoza, substance and God are the same.

Pierce postulates that to conceive of one, it has to have a limit. As discussed above, Maturana and Varela (1998) would characterize this as creating a unity. As we saw above, the act of forming a unity is predicated on the differentiation of one with respect to characteristic or attribute. The act of creating two cannot yet be a thought. For this we require a relationship or a three which mediates between one and two. Pierce (Hoopes, 1991) explains by example:

> The fact that A presents B with a gift C, is a triple relation, and as such cannot possibly be resolved into any combination of dual relations. Indeed, the very idea of a combination involves that of thirdness, for a combination is something which is what is owing to the parts which it brings into mutual relationship. But we may waive that consideration and still we cannot build up the fact that A presents C to B by any aggregate of dual relations between A and B, B and C, and C and A…. thus we see that a triad cannot be analyzed into dyads (p. 192-193).

From this we get a sense of the meaning of Maturana and Varela's (1998) definition of organization as those relationships that must be present for something to exist. In addition, we see the third building block of thought and meaning creation: relationships. If we agree with Pierce, we see that thought and meaning <u>necessarily</u> involve the creation of unities predicated upon differentiation according to attribute and then a form of relationship (three). We also “prove” Vygotsky and Piaget’s premise that intellectual development is the ontogenic progression of the process of differentiation and subsequent organization and reorganization, through relationship, of features of the objects and events of experience.

Maturana and Varela (1998) point out that when creating a definition for living being, it is traditional to do so by specifying a list of characteristics. They depart from this by creating a definition that relates to organization. They define living things as those unities that self produce and possess an autopoietic organization. An autopoietic organization is one dynamically related in a network of ongoing interactions. As such, it is a system. The system of living things is distinctive from other systems, however, because cell metabolism produces the components that make up the network of interactions that the cell undertakes. The system of the cell is self creating, self producing, and exhibits the property of self organization. These transformations produce the cell as a unity. It is a unity whose only product is itself, with no separation between the producer and the produced. Being and doing is inseparable - that is the cell's specific organization.

Without describing the complete dynamics of cellular operation, we can undertake a brief summary description that illustrates Maturana and Varela's (1998) point. A cell is a unity enclosed by membrane. Within each cell there is chemical-containing fluid, called the cytosol, as well as other membrane enclosed structures which serve specific functions, such as the nucleus and other structures or unities referred to as organelles. As Maturana and Varela (1998) state, the cell produces itself and all the components needed to carry out its function. Within the nucleus are chromosomes which contain the genetic material DNA. The DNA in each cell is the same, whether we are speaking of a cell in the brain or in the heart. What distinguish neuronal cells in the brain from heart cells are the specific parts of the DNA that are used to assemble the cell. These segments or parts of the DNA are called the genes. Cell components are composed of various combinations of proteins, which in turn are constructed of different assemblies of 20 different kinds of amino acids.

A specific protein, or the building block of the cell, is constructed as follows. In the nucleus, an enzyme called RNA polymerase attaches itself to a specific area of the DNA molecule, a gene, which has the instructions for assembling a protein. Based on a "reading" of the gene, the polymerase synthesizes a molecule called messenger RNA, which consists of four different nucleic acids strung together in various sequences to form a chain. By analogy, we can think of this as creating a sentence that describes how to assemble a protein. This process is called transcription. The initial reading can contain more information than is necessary to construct the specific required protein. There is a subsequent process called splicing that occurs to put the mRNA into final form. The assembled mRNA (messenger RNA) exits the nucleus through the membrane and enters an organelle called a ribosome. The ribosome "reads" the mRNA and assembles a protein molecule in much the same fashion as the mRNA molecule was assembled: by linking together combinations of 20 different amino acids into a chain. Proteins are undoubtedly the most versatile molecule in the universe. Depending upon the specific amino acids added and their sequence, the protein can exhibit a wide range of electrical, chemical, and physical characteristics. Other organelles within the cell perform various other functions such as processing or shaping newly constructed proteins, or supplying energy for the cells functioning. In general, the cell is a fairly self-contained unit which produces the components it needs to carry out its required functions as part of a larger system or assembly, like an organ.

Autopoietic unities, like cells, generate phenomena that depend on their organization and how this organization comes about, not simply the physical nature of their components. In other words, the organization creates phenomena not inherent in the components - the sum is greater than the parts. If the cell interacts with an entity in its environment and incorporates it into its process, what happens depends on how the entity in the environment is "seen" by the cell. As such, it is contingent upon the cells autopoietic dynamics. Any changes in the cell will be dependent on, and will only be, those changes caused by the cell's own structure as a unity. In other words, the external environment will not disrupt the cell's autopoietic unity. This unity will be conserved.

Maturana and Varela (1998) define ontogeny as the history of structural change in a unity without the loss of organization within the unity. With respect to its environment, the cell unity classifies change and sees it in accordance with its structure. The cell structure changes because of internal dynamics. It is in this way that ontogenic transformation occurs. Interactions between the unity and the environment will consist of reciprocal perturbations (changes). The structure of the environment **triggers** structural changes in autopoietic unities; it does not specify or direct them.

With respect to two or more autopoietic unities, such as cells, these unities can undergo a coupled ontogeny if their interactions take on a recurrent **stable** nature. The result is a history of mutually congruent structural changes. The unities are said to take on a **structural coupling;** structural coupling being defined as the history of recurrent interactions leading to congruence between two or more systems. Please note that congruence or equilibrium between the entities is required. Individual cells of a multi-cellular system, when combined, exist by taking on other cells in close proximity as a medium for realizing their autopoiesis. In the specific case of cells constituting the brain and nervous system (neurons), the organism they integrate, and the environment in which they interact, operate reciprocally as selectors of their corresponding structural changes and are coupled with each other structurally. The functioning organism selects the structural changes that permit it to continue to operate. The implication here is that the unity or cell will take on or assimilate only those inputs that allow it to maintain or conserve its organizational integrity and maintain its basic function. It will not take on anything that disrupts its unity. Also, the change will be articulated in the unity's fundamental structure.

In summary, we can take several of Maturana and Varela's (1998) characterizations of biologic systems, or unities, and impute from them expectations regarding the characteristics of cognitive activities, which are, of course, phenomena consequent to the actions of a biologic entity. First, we would expect to see these activities exhibiting systemic behavior, in fact, the behavior of a nonlinear system. The structure of a biologic entity is not functional, it is relational. The state of a cell, for example, is a co-dependent relationship among all the components of the cell. This is the definition of a nonlinear entity, a co-dependent relationship among components (variables) as opposed to a functional relationship defined by independently acting components that control dependent components (variables). Once we accept the postulate that something exists as a nonlinear system, there are logically necessary attributes that are consequent from this postulate. First, if the relationship between elements is not destroyed, the system automatically compensates and adjusts in such a manner as to conserve the relationship. This is a fundamental characteristic of all things placed in systemic relationship. As Maturana and Varela (1998) describe for biologic systems, all inputs into the system will be articulated in the context of the relationship existent within the system. Second, for systems that are nonlinear, inputs can bring about qualitative changes in the morphology of the structure of the system and still preserve the fundamental relationships existent within the system. The fact that systems are nonlinear permits the creation of qualitatively different structures that exhibit and maintain stability while preserving the relationships that fundamentally exist within the system. Third, there are four overall states that a nonlinear system can take on:

1) the system can reach a state of static equilibrium or zero net change (maximum entropy),
2) the system can be deterministically chaotic (unable to achieve stability),
3) the system can be deterministically chaotic with windows of stability, or
4) the system can reach a state of dynamic equilibrium or stability through the process of self organization.

It is this fourth state that Maturana and Varela (1998) describe as the state that biologic organisms assume. In a self organizing system, the system takes on a form and structure such that there is an equilibration of the relationships within the system, the conditions of the environment, and driving forces impacting the system. It is important to note that self organization requires continuous system input. Without input, the ultimate state of a system is generally a state of static equilibrium and maximum entropy. In the absence of system input and the process of self organization, all closed systems will tend toward this state. This is the genesis of the theory that the universe is ultimately condemned to a state of maximum disorganization (entropy) or a thermodynamic death. Ironically, we can metaphorically characterize the above states, in terms of Freud’s psychic energy sources. The state of static equilibrium is analogous to Freud's Thantos or death, the state of self organization or the formation of new stabilized structures and dynamic equilibrium we can analogize with Freud's Eros or creation. The states of deterministic chaos or deterministic chaos with intermittent stability we can perhaps equate with mental illness. It is important to note in the above discussion, that once we accept the postulate that something exists in the context of a nonlinear system, the above circumstances are logically necessary consequences; they are not theories about what could happen, they are not possibilities or probabilities, they are the articulation of what will happen necessarily as a consequence of nonlinearity. Our decision predicate is whether or not human systems are nonlinear systems.

The above discussion has significant implications for the development of curriculum and instruction. First of all, we can describe the knowledge creation process as a process of creating self organized structures and a state of dynamic equilibrium within the cognitive structures of a learner placed in an academic environment. Second, we can recognize Maturana and Varela's (1998) dynamic of structural coupling, interpreted in the context of learning, as the learner taking on or assimilating those items in the academic environment that are compatible with, or can be accommodated within the context of their existing cognitive structures. These cognitive structures can change and grow through the process of self organization of existing cognitive structures. They cannot be replaced out right. The process is evolutionary and developmental. As Vygotsky (1986) states, an adult cannot pass on to the child his mode of thinking. The educational process is then, of necessity, a development involved with change compatible with the nature of the learner's existing cognitive structures. As Maturana and Varela (1998) state:

1) the structure of the environment triggers structural changes, it does not specify them
2) the ontogeny or development of the organism is the history of mutually congruent structural changes[between the individual and the environment]
3) the organism selects the structural changes that permit it to continue to operate, conserve its organizational integrity and maintain its basic function[those things with which it can equilibrate]
4) the organism will not take on anything that disrupts its unity.

Said in language that is perhaps more familiar, a child's ability to learn is contingent upon his history of past experiences and their impact on forming a child's current cognitive structures. It is upon the platform of these past experiences and their cognitive structures that the **child constructs new knowledge**. New knowledge will be acquired to the extent that a state of dynamic equilibrium is achieved within the child between his goals (driving force), his existing cognitive structures (existing system relationships) and the learning experience (environmental input). New knowledge is created and cognitive structures modified through the process of self organization. When a child says that he understands and things make sense, he is articulating the successful completion of this process: the accommodation of new input within a modified structure that is dynamically stable or equilibrated.

We can see Maturana and Varela's (1998) idea of structural coupling expressed throughout the educational literature. It is expressed in Barbara Rogoff's (1990) conclusion that the educational process is facilitated by letting children guide the course of progress according to their needs and interests. It is also articulated in Kieran Egan's (1998) statement that the learning process is greatly facilitated by developing intrinsic motivation within students and developing lessons around this motivation. The "best practice" literature often emphasizes this idea and summarizes it as "student -centered" practice. This is exemplified by the following quote: "the best starting point for schooling is young people's real interests; all across the curriculum, investigating students own questions should always take precedence over studying arbitrarily and distantly selected content (Zemelman, Daniel & Hyde, 2005). Technically speaking, what these conclusions express is one of the components described above as necessary for the creation of dynamic equilibrium within the individual.

This also calls to mind the issue of **relevance** in education. It is perhaps a regrettable fact of modern society that we surround children with adult content almost from birth. The inescapable and ever present television set, and now the Internet, provide an endless stream of adult oriented input to the cognitive development of the child. I personally began the educational process in the 1950s. To me, teachers were knowledgeable authorities whose wisdom and judgment were to be respected and obeyed. My early life experiences did not build within me any reason to doubt or disrespect these figures. During the extensive time I spent in internships and observation in today's classrooms, I was always startled by the general lack of respect and skepticism that today's students expressed toward their teachers and the authority figures in their schools. In one classroom, for example, I noted that all students referred to the teacher as Miss without attaching her surname. I asked several students why this was the case and received the same answer from all. This practice was their way of expressing their lack of respect for the teacher and depersonalizing all references toward her. To say her name would recognize and acknowledge her as a person, an individual that mattered. The students felt as though their teacher did not care about them as individuals, and they were responding in kind. In fact, this was a recurrent theme in many of my observational experiences. In those classrooms where the teacher was able to affect a structural coupling, such that the students felt that their teacher recognized them, cared about them as individuals and acted in their best interests, I saw learning occurring and students self regulating their behavior. I saw the same students go from motivated and engaged learners to raving maniacs contingent upon the teacher and the relational dynamics of the classroom. Many students that I interviewed expressed that, based on what they felt to be their extensive knowledge concerning the nature of the adult world, the vast majority of their classroom activities were irrelevant and immaterial. They knew for a fact that rhyming sequences in poetry was a bunch of “crap” that nobody cared about in the real world. The classic teacher adage that you'll need this someday and that it is vitally important, something I took to heart as a student, seems to now fall on deaf ears. Many students, particularly those from disadvantaged backgrounds, become skeptical very early about their prospects in life and view school as a form of hazing imposed by the "Man". School is simply something they are forced to endure.

When I reflect upon the differences between my early childhood experiences and those of today's children, I have to think that the amount of adult oriented input they receive, and the way we depict adult life and experience, has a lot to do with the attitude of today's students. These students have seen both a Democratic president and a Republican president overtly lie because it served their self-interest, be exposed as liars, and experience little in the way of consequence. They generally see corporate leaders depicted as self-serving cretins with little interest beyond accumulating wealth and power. They are constantly barraged by messages that politicians exclusively tend to the needs of the special interests that pay for their campaigns and keep them in power. They have seen the competence and commitment of classroom teachers called into question and heard about religious leaders who routinely sexually molest children. I could go on, but I think the reader gets the point. Is it any wonder that children do not automatically respect and trust adults? Have we not given them a depiction that adult life occurs in a world wherein everyone must fend for himself and deal for his own self interests in order to survive? When you think for very long about the way we have robbed children of their childhood and performed an exorcism on their innocence, value systems and possibility for an idealistic worldview, it brings tears to your eyes. One of the characteristics of youth used to be idealism and the perspective that the world could be a better place. The pragmatic consequence of the above is that creating relevance, affecting a structural coupling that imparts a sense of caring, and earning the respect of students, come to the forefront as the first three requisite tasks of a classroom teacher. It has always been the case that these three behaviors represented good practice and increased the effectiveness of a teacher. In times past, the teachers who exemplified these characteristics were the ones we liked; the ones who didn't exemplify them were the ones we disliked. We did learn from both and were taught to respect both. Today, however, a teacher cannot get to square one without undertaking these behaviors. If all a teacher wants to do is to explicate their extensive content knowledge, then that teacher needs to obtain an advanced degree and teach graduate students. That is about as close as they will get to a classroom experience that resembles the "good old days". This type of teacher will not last very long in today's K-12 environment.

Returning to Piaget after this long but perhaps important interlude, we can now examine the premises that that are the foundation for his biological model of intellectual development. Piaget considered intelligence as an extension of certain fundamental biological characteristics. He interpreted two fundamental mechanisms of functioning to be invariant over the whole developmental span of the individual: organization and adaptation. We begin with a general heredity or initial organization upon which cognitive acquisitions are made and cognitive structures are built. We also begin with a set of properties which we hold in common with all organisms (Flavell, 1963). Piaget's sense and meaning of the term organization is precisely the same as the one we discussed in connection with the work of Maturana and Varela (1998). A cognitive structure or organization Piaget terms a **schema.** Piaget wrote over 100 books and never precisely defined schema. Various authors have interpreted his meaning of this term from the various contexts in which he used it. The discussion to follow most closely coincides with the interpretation of Flavell (1963).

There are several paradigmatic elements, in Piaget's systems, which influence the construction of his theory. Piaget visualizes a continuous connection between all organic life forms. The difference between various life forms is a reflection of the varied responses or adaptations that lineages have made to the contingencies of the environment they found themselves in. In addition to a relational continuity between various life-forms, Piaget also postulates continuity within each life form between the various organized entities or organs that carry out the functionalities required to sustain the organism and carry out its intentions in an environment. Each "unity" within an organism possesses a structure which defines it and which, to varying degrees, is adaptable to the circumstances of an external environment. The digestive system, a collection of interrelated and coordinated unities (organs), carries out a function and articulates an organization or structure. There are certain objects and items in the environment with which the system can affect a structural coupling (commonly referred to as food). These items can be **assimilated** into the organism, thus permitting it to carry out its function and actualize its intention (goal) or, as Maturana and Varela (1998) would state, achieve its autopoiesis. The brain is a similar collection of unities (organs) carrying out functions, enabling the actualization of intentions, and articulating an organization or structure. These organizational structures Piaget terms **schema**. An obvious difference between the digestive system and the brain is the level of plasticity or adaptability in **accommodating** to the contingencies of an environment. The human brain demonstrates the penultimate adaptation: the capacity for abstract rationality. Where for Vygotsky (1986) this penultimate adaptation is articulated in the form of the genuine adult concept, for Piaget (Gruber & Voneche, 1995) it is articulated in the form of the development of logical-mathematical structures in the brain. For both Vygotsky (1986) and Piaget (Gruber & Voneche, 1995) logical relationships and logical structures represent abstracted relationships and structures constructed through the interpretations of the individual and not physically manifest in the objects themselves. They are the creations of the individual crafted from interpreted relationships between objects of consideration rather than physically observable characteristics or attributes. For example, number and equality are abstract interpretational characteristics of objects. We cannot physically look at two groups of objects and see numeracy or equality. They are qualities we interpret based on our conceptions of numeracy and equality: abstract generalizations. We cannot ask what color or shape is equality or where is it located.

Piaget (Gruber & Voneche, 1995) and Vygotsky (1986) differ in their interpretation of logical relationship and logical structures. For Vygotsky (1986), a logical relationship is any relationship that involves a judgment. As such, logical relationships would encompass a large set of relationships denoting connections such as part-whole, time- space, and causality. For Piaget (Gruber & Voneche, 1995), logical relationships and structures are the logical relationship and structures of formal logic.

Piaget (Gruber & Voneche, 1995) believed that knowing the laws and relationships of mathematical logic enabled one to understand the structures of the mind. They were one and the same. With this as a postulate, he interpreted mental schemas in this context and saw development as a progression whose teleos (ultimate goal of development) was the evolution of logical-mathematical structures. As we will see later, this is perhaps the Achilles' heel of an otherwise extraordinarily insightful and beautifully constructed theory of intellectual development. Vygotsky (1986) and Piaget (Gruber & Voneche, 1995) would both concur that the capacities enabled by abstract rationality, such as planning, strategy development and the general capacity for "what -if" analysis represent the unique adaptation of the human lineage and the capacity that separates us from other organic lineages. They differ on their interpretation as to how this representational and relational ability comes about and how it is ultimately articulated in the mind

As we have seen, Vygotsky (1986) ascribed a seminal role to language in the formation of cognitive structures. His paradigm directed him to a context that was social in nature. Vygotsky (1986) asserts that the child is surrounded by language from the beginning and that language exerts its influence throughout the child's development. Piaget would likely retort that the development of motor skills in the first two years of life demonstrates the beginnings of intelligence and cognitive functions such as representation, generalization and the creation of cognitive schemes. We don't tell children how to walk, grasp and manipulate objects, or how to conceptualize basic causality relationships that enable them to obtain a cookie from a box on a countertop. Any theory of intellectual development must explain the development of these phenomena, all demonstrative of intelligence and, in fact, show how subsequent development is built upon these beginnings in a continuous progression. In addition, a language predicated theory ignores the basic organic nature of the human and the necessary consequences of this organic nature. What all things organic have in common is that they undertake

actions in order to actualize motivated goals, while conserving their unity and autopoiesis. For Piaget then, the basic unit of analysis is action.

Considering the above, we can better understand Flavell's (1963) definition of schema, derived from his interpretation of Piaget: "A schema is a cognitive structure which has reference to a class of similar action sequences, these sequences of necessity being strong, bounded totalities in which the constituent behavioral elements are tightly interrelated" (P. 53). The schema is not the consistent behavioral manifestations themselves but the mental structure or organization that brings them about. When an infant acquires a grasping schema, they have generated a specific cognitive structure, a specific organized disposition to grasp objects. This implies that there has been a change in cognitive organization such that the new behavioral unity is part of the child's intellectual inventory. It also implies that a psychological "organ" has been created functionally equivalent to other organs. And, like the organs of the digestive system, it is capable of incorporating elements of the external world (Flavell, 1963).

An action sequence, if it is to constitute a schema, must exemplify cohesiveness and be able to maintain its identity as a temporarily stable and repeatable unit. The component actions of which it is composed are tightly interconnected and governed by a core **meaning.** It must possess a recurrent and identifiable **pattern** against a background of less organized behaviors (Flavell, 1963).

Even at the first stage of development, which Piaget terms the sensorimotor stage, independent schemas combine and coalesce, or in Piaget's terms, assimilate with each other, in order to carry out functions. For example, the schema of grasping consists of interconnected reaching, finger curling and retracting sub schemas that together constitute an identifiable and repeatable unit.

In keeping with the above description, Flavell (1963) states that:

> A schema is kind of a concept, category, or underlying strategy which subsumes a whole collection of distinct but similar action sequences. Schemas therefore refer to classes of total acts, acts which are distinct from one another and yet share common features (P.54).

It is this attribute, or the nature of motor schemas as a system of relationships and classes, that facilitates the application of this idea to actions that are strictly internal mental activities. Many authors, including most writers of Educational Psychology and Child Development textbooks, equate schemas with concepts. It is important to note, however, that schemas are in fact relational connections of **actions** that manifest themselves in incarnations such as rules, concepts, motor schemes, habits, theories, strategies, plans and expectancies. While all of these manifestations share a concept like structure of elements connected through relationship and, hence, of expressing a **meaning**, they are not sufficiently equivalent to enable them to be synonyms. When authors equate schemas with concepts, I believe a great deal of the underlying structure and context of Piaget's theory is lost. A concept is the manifestation of a schema, involving mental actions or thought in the same way a set of consistent observable motor behaviors is a manifestation of a sensorimotor schema.

For Piaget (Phillips, 1969) action is the source of all knowledge. Whether completely internal and characterized as thought or external and characterized as behavior, an individual is always acting. Through these actions, the individual takes raw ingredients from the environment, and through the adaptational functions of assimilation and accommodation (to be discussed shortly), creates the organizational structures known as schemas (Phillips, 1969). It is these organizational structures that explain the occurrence of particular internal (thought) and external behaviors. The foundation of Piaget's methodology is the premise that through a careful description and analysis of the manifestations of these structures throughout the developmental sequence of the child, we can come to an understanding of their nature and how they are constructed. In summary, we can derive a developmental epistemology: a general understanding of the nature of knowledge and how it is constructed.

Piaget subdivided knowledge into three categories. His first category was physical knowledge derived from sensory perception of physical objects in the world. Objects themselves, or more correctly feedback from objects, tell the child what objects are and what they can and cannot do. The second type of knowledge he categorized was logical-mathematical knowledge. This type of knowledge is not inherent in objects. It transcends the specific objects themselves. Knowledge of this type is the consequence of mental action on objects. Relationships in this type of knowledge are logical and not physical as are the meanings derived through these relationships, such as number, equality, order and conservation of mass. As we will see, Piaget's (1985) thesis is that this knowledge comes about by abstracting consistent relationships that exist among objects after undertaking actions on the objects, rather than abstraction of physical object attributes. It is a **reflective abstraction** of our actions rather than object observables. Piaget’s third category of knowledge was social knowledge. This is knowledge of the rules, laws and codes of conduct, language, morals, and values of a society. This knowledge is formed by experiencing the actions of other people or, in other words, through social interaction.

As discussed previously, Piaget's (Gruber & Voneche, 1995) model of the development of cognitive structures is an adaptational model. In his theory, intellectual adaptation is accomplished through two functionally invariant processes which he terms **assimilation** and **accommodation.** Assimilation, or a cognitive taking in of an object of consideration, refers to the fact that a cognitive encounter with the environmental object necessitates some kind of cognitive structuring of the object in accordance with the nature of the individual’s existing intellectual organization. As Piaget (Gruber & Voneche, 1995) summarizes, assimilation is the basic functioning of a system in which organization is the fundamental aspect. Flavell (1963) states: "Every act of intelligence presupposes an interpretation of something in external reality, that is, an assimilation of something to some kind of meaning system in the subject’s cognitive organization. To adapt intellectually to reality is to construe [assimilate] that reality and to construe it in terms of some enduring construct [exiting cognitive structure] within oneself" (p. 48). Note here the congruence with basic biologic functioning. In the abstract sense, assimilation is utilizing something from the environment and incorporating it into the biologic entity. As the ingestion of food constitutes an assimilation of something of the external environment into the autopoietic unity of the organism, intellectual assimilation is the taking in (utilization) of an object in the environment into the mental structures of the individual. It is the process by which the individual integrates new perceptual or conceptual matter into existing schemas.

A new environmental stimulus cannot always be assimilated into existing cognitive structures or schemas. To assimilate an object of consideration that is initially incongruent with existing cognitive structures requires a change to those structures that **accommodates** the reality of the new object. This adaptive change to cognitive structures, Piaget characterizes as the functional invariant **accommodation.** The new object presents the individual with idiosyncrasies that are unaccounted for in existing cognitive structures. The accommodation process therefore begins with a differentiation or recognition of difference. Note here the correspondence with Vygotsky's (1986) notion of development involving progressive differentiation and Bateson's (2000) idea of information as news of a difference. Once differentiated to accommodate the new object, there is a reintegration or construction of a modified structure that reflects the adaptation to the new object and permits the new object to be assimilated. The newly re-integrated cognitive structure or schema exhibits the property of **generalization**. We can better understand this by considering what would occur at the extremes of assimilation and accommodation. If assimilation occurred without a process of accommodation, an individual would have only a few large schemas. They would be unable to detect the differences between things. For example, if the first four-legged animal they saw was a dog, then all four-legged animals would remain dogs. Accommodation without assimilation, conversely, would result in a great number of small schemata. There would be no generality and no ability to detect similarity between the objects and events of experience. Piaget (Gruber & Voneche, 1995) resolves this dilemma by stating that there is an equilibration between the processes of assimilation and accommodation. In fact, a substantive part of his theory is predicated upon this equilibrium. He does not offer a very specific mechanistic explanation for how this equilibration comes about. He ascribes it to the conservative and systemic nature of organic systems. The hypothesis that I would offer is predicated upon the manner in which biological organisms process information. As we have discussed previously, our sensory mechanisms fundamentally process unities of similarity created by detection of differences. In this manner, similarity and difference are the fundamental constructs of sensory processing. Perception, of necessity, requires an organization of sensations into stable unities predicated upon similarity of feature or similarity of relationship. Since sensation and perception are constituted as a nonlinear system, the system will tend toward a state of dynamic equilibrium and the articulation of an organized structure that represents a balance between the stimulus, the immediate goal of the individual, and their existing cognitive structures (schemas). These organized and stable structures can be viewed as expressing a generalization. The characterization of the phenomenology created through systemic combination is the generality. In this way, the system acts to differentiate and reintegrate into a stable structure that can be characterized as equilibrium between assimilation (combination) and accommodation (differentiation).

Flavell (1963) points out this tendency toward generalization in the development of an infant's sensori-motor schemes. The primary reflexive structures that the infant is born with, such as grasping, sucking, seeing, touching, and so forth, are modified in order to accommodate themselves to a variety of objects and enable assimilation of them. They are in addition generalized. The child learns that there is a large variety of objects that can be sucked, pulled and visually scanned. A new object may necessitate a variation in the way these activities are undertaken or an accommodation. Cognitive structures are, however, not only differentiated as a consequence of these idiosyncratic demands, they are generalized into overall pulling or sucking schema with differentiated parts. As we can see, the combined adaptational mechanisms of assimilation and accommodation are Piaget's mechanisms for the growth and development of cognitive structures.

Any adaptation presupposes an underlying organization or structure. Adaptive and directed behavior does not proceed from chaos and completely differentiated sources (Flavell, 1963). This leads directly to another Piaget postulate that is predicated on the concept of an organic entity. There can never be a discontinuity between the new and the old; there is gradual, continuous and developmental character to intellectual growth. Piaget (1985) states two postulates which incorporate this idea:

1) every assimilatory scheme tends to incorporate external elements that are compatible with it
2) every assimilatory scheme has to be accommodated to the elements it assimilates, but the changes made to adapt it to the objects peculiarities must be effected without a loss of continuity

The first postulate is fairly evident in meaning. The second postulate provides that modifying a scheme must not destroy its prior powers of assimilation and must conserve the closure of the schema as part of a system of interdependent processes. The second postulate also affirms the necessity of equilibrium between accommodation and assimilation, but does not specify the nature of the process. The conservation element discussed above can be understood with the following example. If an original scheme A constructed to assimilate environmental object a is accommodated to enable assimilation of new object b, thereby creating structure B, the original structure A is conserved and still performs its role in any future assimilation of a, even though it served as a source for and is a part of B.

Accommodation here serves two roles: differentiating schemes and facilitating assimilation of a new external object.

Piaget differentiates three forms of equilibrium. The first is between subject and object. This form of equilibration leads to physical knowledge. The objects are necessary for action to take place, and the action confers meaning on the objects when they are transformed by the individual (ordering objects, counting objects). Piaget doesn't elaborate this point, but it merits emphasis. It is truly the individual through his action who confers meaning to objects. For example logical-mathematical meaning is not intrinsic to objects.

The second equilibration occurs among subsystems or schemes within the total system. This process is not automatic and may be lengthy. Subsystems are initially independent of each other. Incorporating all suitable elements occurs gradually, and various schemes develop at different speeds, depending on environmental inputs. All of these factors can cause disequilibrium. Eventually these subsystems do, however, accommodate and assimilate to each other.

The third kind of equilibrium occurs between subsystems and the total system or between differentiation and integration. This is different from the previous equilibration in that it involves a hierarchical dimension absent when equilibrating subsystems of the same rank, and it involves its own laws of composition that are not part the subsystems being coordinated. Piaget (1985) provides the example of relative motion where an individual is moving on an object like a moving train. In this case, the motion of the individual with respect to the moving object constitutes one system or schema, and the motion of the moving object with respect to the ground constitutes another. To ascertain the motion of the individual with respect to the ground requires that the two frames of reference or systems be brought together into a total system. Assimilation is responsible for the integration, while accommodation facilitates consideration of the two separate motions. Since there is mutual conservation of both the whole and the parts, there is **reciprocal assimilation** (Piaget's term) and **accommodation**. It occurs, however, along hierarchical rather than collateral lines.

These three types of equilibrium have two features in common. They all incorporate equilibrium between assimilation and accommodation and they all involve only the positive aspects or characteristics of schemes, subsystems, or totalities. The latter attribute can bring about disequilibria without the involvement of additional mechanisms (such as regulations and compensations, which will be discussed subsequently). In Piaget's model, only exact correspondence between affirmations and negations can ensure stable equilibrium. He ascribes the primacy of positive characteristics to the perceptual system. He states that only positive observables are registered. Where actions are concerned, during the early stages of a child's development, the focus is on the goal to be attained, not on the starting point. Movements in space are first conceived in terms of point of arrival. This is the same principle involved in failures to conserve quantities (consideration of only positive aspects). Conception also begins with the coordination of positive attributes. It is to these factors that Piaget ascribes the large initial frequency of disequilibria in the early stages of development. What is positive has primacy during this period. Negations arise from constructions laboriously produced over time.

Piaget's case for the importance of negation goes as follows: In equilibrating a subject's schemes, say A, B, C with external objects A', B', C' on which their actions bear, it is necessary that the objects possess characteristics a', b', c' and that the subject can distinguish that they do not possess different characteristics x', y', z'. Likewise in order to seriate or classify objects, it is necessary to use scheme A and differentiate from other schemes that are considered not A. From the above, it follows, according to Piaget, that there will be as many negations as affirmations in time, a circumstance Piaget (1985) feels is necessary for the establishment of a stable equilibrium.

The same mechanism is involved in the equilibration of two subsystems. If we have two subsystems S1 and S2 that are to be coordinated, it is necessary to discover what they have in common. This process generates the partial negations, S1 and not S2, as well as S2 and not S1, which are indispensable to the coherence and stability of the coordination. In analogous fashion, to differentiate or integrate a totality requires both what each system possesses in its own right, as well as what is excluded from it, to be processed, creating both affirmations and negations.

Piaget also exemplifies negation consequent to operations. When some prediction is contradicted by fact or an object fails to be accommodated, it is necessary to distinguish positive properties, *a*, from their absence and to justify the negation in order to understand the failure and turn it into a success. As for the scheme A employed to make the prediction or accommodate the object, it must be dissociated into Schemes A1 and A2 according to whether properties, *a,* are present or not. This creates a new substitute class B =A1+A2, for the initial class A. The new subclasses A1 and A2 would include not only positive characteristics but also negations of characteristics in other schemes. Piaget's prior investigations have shown how slow such constructions are in coming about. They become stable only when accompanied by quantification. This means that the subject understands that B = A1+A2 means that all A1's are B's, but only some B's are A1's. This ability is ultimately linked to reversibility and awaits the onset of the stage of cognitive development he calls concrete operations. Although it is slow in developing, when a subject seeks to regulate the process and to attain coherence and stability, it becomes necessary to use negations in a systematic way.

The mechanics of the operation of equilibration and re-equilibration are addressed by Piaget through the mechanism of regulation. A regulation occurs when the results of an action, physical or mental, modify the subsequent repetition of the action. It is therefore feedback. As such, it can be positive and reinforcing or negative and correcting.

Let us look at regulation first from the subject's perspective. The subject's **scheme confers meaning** on the objects it assimilates and **assigns a goal** to the actions it organizes. If we define a perturbation as anything that creates an obstacle to assimilation and accommodation, or achieving a goal, then regulations are simply responses to perturbations. Please note that this is not the usual sense of the term perturbation. Two classes of perturbations are experienced by the individual. First are perturbations that inhibit accommodation. These are experienced as failures or errors. The regulations that ensue from this are some form of negative feedback. The second class consists of lacunae (things lacking) that leave the individual's needs unsatisfied. These are experienced as something that is missing. These could be objects or conditions that are missing in order to carry out an action or a lack of knowledge. The regulations that ensue are positive feedback or a prolonging of assimilatory activity. It is important to note that we are not talking about simple repetition of the same scheme. A regulation involves a modification in response to a perturbation. It immediately follows that most responses would entail a combination of both correction and reinforcement. For example, the development of a constructive habit is a trial-and-error process that involves both positive and negative feedback. Most regulatory activity includes both components and is iterative. Note also that regulations can act to conserve a state or act to create a new state not yet attained.

Regulations pertain not only to subject–object interaction but also to the relationship of schemes or subsystems to each other. The latter has to do with coordinating action schemes or conceptual schemes that the individual has in his inventory. Regulations at this level act to assimilate and accommodate schemes within the system. Piaget cites an example from Inhelder, Bovet, and Sinclair (1974) which illustrates the process. When children are asked to compare the length of two lines created by putting little sticks of unequal length together, a conflict occurs depending on whether the children evaluate the lines utilizing a spatial schema or utilizing a numerical schema of counting the number of sticks in the line. Resolution of the conflict requires that the spatial and numerical schemes be completed or modified in order to be integrated (coordinated in a way as to create congruence of meaning). This example is an illustration of the way integration and differentiation occur at the level of schemes or subsystems.

Piaget infers a hierarchy of regulations that relate directly to levels of abstraction. First order regulations of subject-physical object interactions involve **empirical abstraction** or seeing physical patterns. They constitute the first form of **abstraction**. More complex relationships between subsystems require what Piaget (1985) terms **pseudo-empirical abstractions** which evolve properties like order or number, properties that the subject's actions have introduced into objects. This is in contrast to **empirical abstractions** which isolate the physical properties of objects such as they are (pre-intervention). Regulations become active when the subject has to change the method he uses or when the subject chooses among possible methods. This type of regulation gives rise to consciousness and lies at the source of abstract conceptualization. The progression of regulations from simple regulations to regulations of regulations culminates in what Piaget (1985) calls **auto regulations.** Auto regulations are capable of enriching their program by differentiating, multiplying and coordinating goals and by integrating subsystems into a total system. It is the conservation of the integrity of the whole that is the source of regulation and also the ultimate regulator of regulators. Assimilation and accommodation are operations, therefore, under the dynamic control of a total system that demands its own conservation.

The process of reflective abstraction is an important insight and seminal to Piaget's (1985) theory. Based on his extensive studies of the development of logical mathematical structures in children, Piaget (1985) theorizes that reflective abstraction is made possible by the assimilation of frameworks abstracted from patterns of coordination inherent in a subject's actions.

In a series of lectures delivered by Piaget at Columbia University in 1968, he elaborates the development of logical structures in children. He begins by making a distinction between two aspects of thinking that are different but complementary. He calls these aspects the **figurative aspect** and the **operative aspect.** My apologies to the reader, but Piaget is fond of creating his own unique vocabulary. I have made bold these terms, in hopes that it will allow the reader to better keep track of them. The figurative aspect, Piaget (1968) characterizes as an imitation [representation] taken as momentary and static. In the cognitive area, the figurative functions are based upon perceptually driven imagery, which Piaget refers to as interiorized imitation. The operative aspect of thought deals not with individual states but the transformation from one state to another. It includes not only the actions which transform objects or states but also intellectual operations, which are, in essence, systems of transformation. These actions are capable of being interiorized and therefore can be carried out through representation; they do not require a physical actualization. Any change in state can be understood as a result of certain transformations. To Piaget (1985), the essential aspect of thought is its operative aspect and not its figurative aspect. For him, human knowledge is essentially active. Piaget (1968) states:

> To know is to assimilate reality into systems of transformations. To know is to transform reality in order to understand how a certain state is brought about. Knowing reality means constructing systems of transformations that correspond, more or less adequately to reality. Knowledge, then, is a system of transformations that become progressively adequate (p. 9).

I call to the reader's attention that Piaget's (1968) position can be generalized as knowledge derived from a description of state (figurative aspect) or a causal description of a change of state (operative aspect). I ask the reader to keep this in mind as this is an important theme that we will encounter again.

Piaget (1985) lists two possible sources for the accumulation of logical and mathematical knowledge. One is knowledge derived from the object itself. This is the point of view of empiricism and is valid in the case of empirical knowledge, or as he has termed it, the **figurative aspect** of knowledge.

The second is knowledge derived from acting upon an object, wherein we take into account the action itself, since the transformation can be carried out mentally. **The abstraction is drawn not from the object that is acted upon but from the action itself**. For Piaget (1968), this is the basis of logical and mathematical abstraction [abstract rationality].

Piaget (1985) provides a wonderfully clear example of these two different forms of abstraction:

> In cases involving the physical world, the abstraction is an abstraction from the objects themselves. A child, for instance, can heft objects in his hands and realize that they have different weights - that usually big ones weigh more than little ones, but that sometimes little things weigh more than big ones. This he finds out experientially, and his knowledge is abstracted from the objects themselves. But I would like to give an example, just as primitive as that one, in which knowledge is abstracted from actions, from the coordination of actions, and not from objects. This example, one we have studied quite thoroughly with many children, was first suggested to me by a mathematician friend who quoted it as the point of departure of his interest in mathematics. When he was a small child, he was counting pebbles one day; he lined them up in a row, counted them from left to right, and got 10. Then, just for fun, he counted them from right to left to see what number he would get, and was astonished that he got 10 again. He put the pebbles in a circle and counted them, and once again there were 10. He discovered here what is known in mathematics as commutativity, that is, the sum is independent of the order…. but the order was not in the pebbles; it was he, the subject, who put the pebbles in a line and then in a circle. Moreover, the sum was not in the pebbles themselves; it was he who counted them. The knowledge that this future mathematician discovered that day was drawn, then, not from the physical properties of the pebbles, but from the actions that he carried out on the pebbles. This knowledge is what I call mathematical logical knowledge and not physical knowledge.

Piaget (1985) states reflective abstraction consists of two steps. The first is a reflection or projection onto a higher level, things borrowed from a lower level. The second step is the process of mental reflection; at the level of thought, a conscious reorganization of what has been transferred or reflected occurs. Individual actions generally give rise to abstractions from objects or empirical abstractions. Reflective abstractions, however, are not based on individual actions but on coordinated actions. Actions can be coordinated one of four ways:

1) They can be joined together -additive coordination.
2) They can have a temporal order -sequential coordination.
3) They can have a correspondence between one another [mapping].
4) There can be an intersection among actions.

Piaget (1968) points out all of these coordinations have parallels in formal logical structures and therefore, coordination at the level of action seems (to him) to be the basis of logical structures.

Negation is also seminal to Piaget's (1985) theory. He provides an explanation of how regulations act to effect negation. Negative feedback consists of suppressive correction. For example, sensorimotor schemes are modified by decreasing the amount of force used or one motion is eliminated in favor of another. Although positive feedback is reinforcement, it acts to negate something that is negative or lacking and therefore constitutes a negation of a negation. It is in this sense that both forms of regulation work toward the development of negations and ultimately toward the development of reversibility.

If we define compensations as actions that are opposed to some effect and that tend to neutralize it, we can say that negative feedback regulations are compensations. A simple example is how we tend to compensate imbalances in developing a sensorimotor scheme for riding a bicycle. When developing a scheme to move or get around an obstacle, we are also compensating for a perturbation through a negation, like we did on the bicycle, where we changed the position of our body to remove an imbalance. Such compensations result in differentiating a scheme into sub-schemes, driven by the difference between our initial action and our goal. This is an extremely important point. It expresses the importance of goal and identifies the stimulus for compensation as the difference between a goal and the consequence of action. In intellectual activity, a similar dynamic is found. If objects are encountered that cannot be assimilated with current schemes or if observed facts conflict with a prediction, a compensation results. Either the fact is overlooked or repressed. (Piaget (1985) calls this a type alpha reaction) or scheme(s) are modified (type beta reaction). The latter compensation results in the original scheme being differentiated in order to accommodate the perturbing element.

Compensation in the form of a positive feedback regulation often carries the implicit assumption that reinforcement implies a prior correction. Recourse to reinforcement implies, in other words, some difficulty in which a correction was initially required. In active regulations, the two act in unison to change the means by which some goal is achieved. Positive feedback can also act straightforwardly to remedy an insufficiency by providing more power to an action. In this mode, the feedback is regulated by the value or importance the subject places on a practical or cognitive need. Piaget (1985) reminds us that Clarapede presented satisfaction of need as the driver of the quest for equilibrium.

Regulatory compensations have three common elements. The first is the one already discussed: they either cancel perturbations (inversion) or neutralize them (reciprocity) in order to overcome an obstacle or fill a need (lacunae). The second shared attribute is that they involve an evaluation of the success or failure of the compensatory activity. Compensations are set in motion when perturbations, which get in the way of reaching a goal set by a scheme, bring about disequilibrium of assimilation and accommodation. All compensations are evaluated for the progress made toward a goal. In sensorimotor activity, this is simply recognized when it occurs. As will be elaborated subsequently, in many cases assimilation and accommodation are ultimately rebalanced by incorporation of the perturbation into a revised scheme.

The third characteristic is that they conserve schemes and subsystems during transformations. Regulations and the compensations they provoke, constituting the principle mechanisms of attaining equilibrium, are both conservative and constructive. A regulation is constructive through the action of the feedback loop which adds retroaction to the linear path of an action. In addition to imparting stability, perturbations, and compensatory accommodation to them, add new knowledge concerning objects and the subject's actions themselves.

No system is ever in a state of final equilibrium. Each new construction brings with it the possibility of a new construction in response to a future problem or issue. In order to express this idea of continuous improvement, Piaget invokes the term optimizing equilibrations. Optimization is expressed in two ways: 1) momentary equilibrium created by the success of regulatory compensations, and 2) new transformations created by reflective abstraction of the mechanisms of the regulation. In the first optimizing equilibrium, the field to which the system applies is extended in order to assimilate a perturbation which heretofore could not be accommodated. In a previous study, Piaget referred to this as widening the referential. This means the extension (number of items) of a scheme is increased. An example would be when a subject considers both the position and the heaviness of weights in comprehending a balance scale. The subject has added an additional component or element to a scheme and increased its extension.

The second optimization occurs when inassimilable perturbations give rise to compensations that result in new sub-schemes or subclasses of the scheme that was initially unsuccessful. Since the system is conservative, this differentiation requires a vertical assimilation or integration to maintain cohesion and system integrity.

In describing a third way that regulations and equilibrations enrich a system, Piaget points out that the creation of new subsystems through the regulatory process increases the number of accommodations that can be accomplished. This is because, as the number of schemes and subsystems increases, the probability of connections between them increases, as do the number of regulations that ensue from the newly created structures. Also, as the number of schemes expands, so does the chance for reciprocal assimilation between schemes and the possibility of creating new subsystems. As new subsystems are formed, a necessary relativization occurs. In his previous study on contradiction, he saw that both an extension of the referential and a relativization of predicates were required to overcome a contradiction.

Descriptions of regulatory mechanisms thus far have been of an essentially retroactive nature or after the fact of the action. Piaget also invokes a type of anticipatory or feed forward mechanism he terms indexing. This mechanism depends on “indexes” announcing what is to come. As an example, Piaget points out how cues in a mother’s behavior announce to the infant that a feeding is about to occur and create the anticipation of the feeding for the infant. He also interprets that the trial and error behavior involved in developing schemes for seriation show evidence of both reflective activity and anticipatory activity combining to create success. He generalizes indexing as the important mechanism that transitions simple trial and error retroactive activity into programmed or rule-based behavior.

In summarizing his discussion of the mechanisms and fundamental processes of equilibration, Piaget (1985) re-emphasizes the crucial role of reflexion as a regulator of regulations. Since reflexion occurs on what has been acquired previously, it constructs and hence constitutes a regulation of the lower level systems from which it was derived. It subsequently takes control over what has been previously inadequately controlled by these lower level systems. It is this mechanism that constitutes active conscious regulation and ultimately forms the basis of action being directed by conceptualization rather than reflex. This is also the process by which auto regulation comes about. Every subsequent system controls the regulation of the prior system, and with recursion, auto regulation is ultimately involved. This level by level evolution of regulation constitutes the central process of cognitive growth or operations on operations and, as such, is central to his thesis. This unlimited process allows new operations to always be applied to a given operatory system. The endpoint of the process for Piaget is the formation of operations and the direct and reversible actions they express.

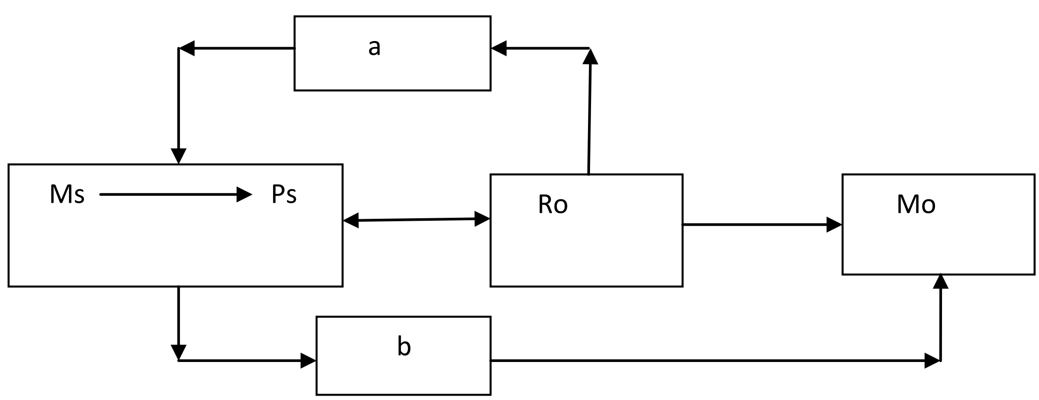
Piaget’s prior studies have shown that the first entities to be equilibrated are the observable features of objects and observable features of the subject’s actions. Observable features of objects can be subdivided into those belonging to the objects themselves, as ascertained through empirical abstraction, and those, like order, sorting, or correspondence, that result from the actions of the subject. Second to be equilibrated are the inferential coordinations derived from the properties of the actions of the subject as well as inferential coordinations that result from the subject’s attempts to explain observations causally. As we will be shown, perturbations begin as external stimuli and, when neutralized, end up as internal components. When integrated into operations, they become predictable and deducible variations of objects.

We now describe Piaget's (1985) final model for the equilibration of cognitive structures. Let's begin with a definition of the components of the model. **Observables** are anything that can be established by experience of the facts. Observables are what the subjects believe they have observed, not the complete set of what it is possible to observe. This definition acknowledges that what is observed is contingent on the mental scheme which controls the perception. Since these same schemes are used to derive coordinations, current observables are influenced by past coordinations. An example of the difference between **action** and **object observables** is provided by a child taking a ball of clay and rolling it in his hands to create a sausage shape. The act of rolling the sausage out is the **action observable** and the elongation and thinning of the clay are the **object observables**.

Coordinations are inferences, implicit or explicit that the subject considers or utilizes. They are the product of logical operations and go beyond generalizations such as “all” or “some.” In fact, coordinations involve constructing new relationships that go beyond what can be observed. The need to make such inferences could be a vague feeling that an explanation is required or the sense that the situation creates a logical necessity to do so. Piaget provides the example of three balls hanging from a string and touching each other that are struck by a fourth ball. When only the last ball moves as a result of the contact, pre-operatory children will report that all balls moved. This happens because the children cannot make the operatory coordination that force can be transmitted through the objects without motion. Their faulty coordination hence results in a flawed object observable. An accurate coordination in this situation would involve an inference beyond what can be observed. Errors of this type result from well defined but faulty coordinations.

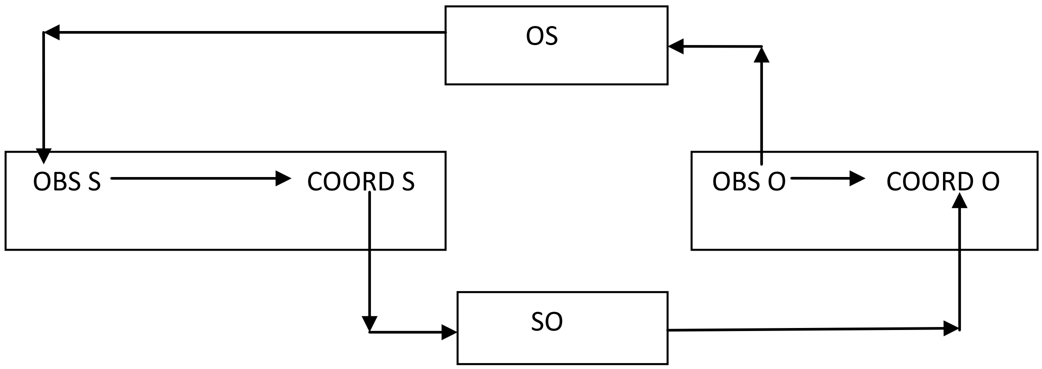
To help understand how action observables are put into relation with object observables, Piaget describes a Type I model which is, in effect, a subset or component of his fully articulated Type II model. The following specific illustration of the Type I model concerns sensorimotor activity and is described as follows:

Shown below is a pictorial form of the model.



Let “Ms” be a movement the subject executes toward an object and “Ps” the push that the movement exerts on the object. It is possible to distinguish two types of observables relative to the object. The first is the objects resistance to the push, designated Ro and the second is the object’s movement designated Mo. Mo depends on both the object’s resistance and the subject’s push. The picture above shows a feedback loop “a”, which serves, in this simplified model, to put facts concerning object observables into a relationship with action observables. In this case, the sensation of the object’s resistance is put into a perceptually verifiable relationship with the subject’s action of moving and pushing. The forward arrow “b”, puts the subject’s action observables in relation to the object observable Mo or the movement of the object and serves to monitor progress toward some goal of movement. In the model above, regulation occurs between the forcefulness of the movement and the motion of the object. This simple model shows both how object observables are put into relation with subject observables and how simple equilibrium between subject and object, the double arrows in the above picture, can come about by assimilation of an action scheme (Ms + Ps) and accommodation to an object (Ro + Mo).

Piaget (1985) discusses a model he designates model IB, in which the action observable consists of the imposition of a logical mathematical scheme on objects. Since this type of exchange invariably involves coordination, I will just move on to how we expand the causal model discussed above into the fully developed Type II model, which incorporates coordinations. From the fact that the subject’s action, in the example above, is impacted by the object’s resistance, and from the fact that the object’s movement reciprocally depends on the subject’s action, the subject can infer that something is transmitted between his hand and the object. Since this transmission of force is not something actually seen or directly observed, it is a deduction that goes beyond the physical observables and hence constitutes, by definition, “coordination” on the part of the subject. This then brings us to Type II interactions. A pictorial representation of the model is shown below.



Type II interactions involve both observables, as discussed in Type I interactions, and inferential coordinations. The coordinations are designated above as COORD S and COORD O. These represent inferential coordinations relative to the subject's actions and inferential coordinations relative to observation of objects. In addition, the action observables, Ms and Ps, in the Type I model are combined in the Type II model and simply designated OBS S. In similar fashion, the two object observables of the Type I model are combined and designated OBS O. Feedback loop OS between object observables and subject observables has to do with taking consciousness of the adequacy or inadequacy of the subject's actions. Taking consciousness here implies internalizing actions in the form of representations that are conceptual rather than simply mental images of motoric steps. Since initial actions may be inadequate or erroneous, they must be put in relation to object observables, which represent the observable consequences of the action. It is also useful to point out that two different types of space are connected. The object's space consists of the dynamic behavior or state of the object consequent to action, while the subject's space consists of operations undertaken by the subject to execute the action. The pictorial representation above is relational and does not represent the order in which the interactions take place. For example, the first step is OBS O or observation of the object. This is followed by OBS S or the observation of the actions which led to the object observables. Connection OS facilitates taking consciousness of these actions in the manner described above. This immediately gives rise to COORD S, which are inferences regarding the consequence of action that the subject feels are subjectively or objectively necessary.

The process SO or the relation of inferences regarding actions and inferences derived from object properties, or dynamics, express the fundamental fact that to discover or understand causal relationships among objects, the subject has to use the intermediary of his own actions. The reason for this is that causal relationships go beyond what is observable and presuppose the use of inferences necessary for providing an explanation. These are beyond relations that are inducible or simple extensional generalizations, since these inductions lack logical necessity and simply verify observations. What is required in defining causality, according to Piaget (1985), is the derivation of logically necessary relationships or, in other words, relationships determined deductively. He also asserts that, as a consequence of this, they can only be derived by operations creating actions such as seriation, ordering, class inclusion, correspondence, and transitivity. Piaget’s position here is derived from his experiments and studies on causality. In these experiments subjects invariably resorted to using their operatory compositions in order to construct coordinations or make inferences about objects. The inclusion of COORD S and its forward connection to COORD O through connective SO is thereby explained. In time then, the sequence of activity, in order, is OBS O, OBS S, COORD S and then COORD O.

Current observables are guided by past coordinations. In addition, the first set of interactions may be incomplete or faulty and lead to incomplete equilibration. There is also the likelihood that COORD S and COORD O will lead to new observables or that their inferences will still lack intrinsic necessity. Piaget therefore envisions a succession of states, represented by a recursive or repeated application of the interactions of the Type II Model, to be required to reach a state of optimized equilibrium. Each stage represents a form of equilibrium that is improved upon by the succeeding stage. The OBS S and COORD S of the previous stage provide the input for OBS S of the succeeding stage. Likewise, the OBS O and COORD O of one stage provide the input for the next. As an additional note, before moving on to modifications to the above model, Piaget (1985) states that one of the big improvements the above described model has, in contrast to his prior models, is differentiation of empirical abstraction used in connection with observables from reflective abstractions used to effect coordinations. As a final note to the general model, Piaget (1985) points out, without extensive elaboration, that his model does not preclude, but in fact assumes, local regulation between the constituents of the model connected by arrows: for example between OBS S and COORD S.

The model just described was formulated to explain interactions leading to the development of relationships of causality. The same model is used to interpret actions that are of a logical mathematical nature. The terms are interpreted somewhat differently for this case. OBS S represents taking consciousness of the subject’s operatory or pre-operatory schemes. An example of these schemes could be the empirical seriation of pre-operational children or an operational seriation scheme constructed by an older child.

OBS O represents changes produced in objects by fact finding activities. These have to do with new ways that objects have been arranged by the subject’s actions: like seriation, collection into groups, in relations of correspondence and so forth. Subsequent to comparison of OBS O with OBS S, COORD S represents discoveries or verifications the subject makes after the fact of their action. These coordinations will vary depending on the subject’s level of cognitive development.

Since the subjects pre-operatory or operatory compositions are imposed upon objects, COORD S and COORD O are identical. Objects are not independent operators, but possess the properties that the subject’s operations actions confer on them. As such, it is only at the pre-operatory level that movement from one state (application of the process model), for example, n, to another n + 1, is due to contradictions. After the emergence of concrete operations, the movement is motivated by new needs or when operatory constructions are inadequate to deal with a situation. New constructions do not destroy past compositions; they enrich them by integrating them to form new compositions. As discussed previously, this is an important postulate in Piaget's (1985) theory. New operations are constructed out of prior operations but are not substituted for them. The teleos of this process is the coordination of coordinations, due to reflexive activity that leads to abstract generalizations.

At the more advanced level where mental activity becomes operations on operations, the connections between level n and level n + 1 change (recursive application of the process model). In the causal model, the empirical abstractions of OBS S (at level n) were mixed with the reflective abstractions of COORD S (at level n) to provide input into OBS S at level n + 1. At advanced levels, in the currently discussed model, only the results of COORD S are input: the results of the subject's reflective abstraction from the prior level. Because the subject's activities, OBS S, merge more and more into the realm of construction of new coordinations; in the final model, COORD S of one stage directly supplies the input to COORD S of the subsequent stage. This is the only connection between stages. Mental activity becomes exclusively the reconfiguration of abstracted forms. As Piaget points out, this is the type of thought involved in pure mathematics. In addition, we can see how in this general progression, objects take on less significance and it becomes easier for the subject to replace concrete objects with symbolic ones.

To summarize, the first Type II model discussed, involved a mixture of experimental observables and logical mathematical structures applied or attributed to objects in order to explain causality. The second model starts with experimental actions that the subject induces on the objects. An abstraction is then derived from a coordination of these actions. As this model progresses, it frees itself from dependence on empirical data and ends up as a construction made entirely of forms (abstractions), when the subject is at higher levels of cognitive development.

There is a final model that needs to be elaborated. This model covers the case where subject – object interaction is purely observational and objects interact with each other, rather than with the subject. In this model, OBS S is replaced with OBS X: observables relative to putative factors. We can view these as independent variables. OBS O becomes OBS Y: results established with respect to dependent variables, as in a functional relationship Y = f (X). Feedback loop OS becomes XY: putting results Y in relation to variable factors X. A synthesis of the relationship of X and Y ends up in a logical or mathematical form when constructed by the subjects operations through COORD S. This causal explanation is then related through loop SO to COORD O to verify the formula's causality. If the causal relationship expressed by the formula agrees with COORD S, then we have equilibration. If it does not, the next recursion (n + 1) is undertaken.

When a new fact confronts a subject it may produce no reaction or it may produce a perturbation. The first possibility occurs when the subject has a scheme that readily assimilates the new fact: for example, one more item in an existing classification scheme. The second possibility would occur if the fact conflicts with either a prior description the subject has given, or the fact requires a different explanatory relationship than what has been used in the past. One form of reaction to counter the disequilibrium induced by the perturbation is what Piaget calls a type alpha reaction. If the perturbation is small, it is compensated by modifications in a direction opposite to the perturbation.

If the perturbation is strong, as judged by the subject, he will cancel it by ignoring or removing what is bothersome. Alternatively, the subject might deform the perturbation to fit an existing assimilatory scheme. There are many examples of type alpha reactions. The child who does not take all the differences in objects into account when creating a classification is one. The child in the previously described experiment concerning a ball striking three balls in contact with each other such that only the last ball moves, who insists that all the balls moved "just a little," is another.

The next stage of compensation is called a type Beta reaction. Instead of canceling out the perturbation or ignoring it in order to preserve existing assimilatory structures, the perturbing element is integrated into the system. Compensation of this sort involves changing the structure of the system. It can involve reorganizing a classification, extending a seriation in more than one dimension, completing an explanation or developing an entirely new explanation. As seen in these examples, the change effected is conceptual. What began as a perturbation became a variation in a reorganized structure because of the construction of new relationships that connect the perturbing element with those previously organized. Type beta reactions modify the assimilatory scheme in order to accommodate the object. They do so in a way that minimizes loss and maximizes gain. By minimizing loss, Piaget (1985) means that that the original assimilatory scheme is conserved, to the extent possible. Maximization refers to the growth that occurs through incorporation of the perturbation. In this sense, type beta reactions are an important production and growth engine for the cognitive system.

The final stage of compensation is termed a gamma reaction. Possible in logical mathematical and highly elaborated causal explanations, gamma reactions consist of anticipating possible variations. Because they can be predicted or deduced, they are not perturbing. Instead, they cause transformations within the system. Through the development of negation and ultimately reversibility, the system becomes symmetrical, allowing perturbations to be assimilated as internal transformations of the system. Retroactions in this way become anticipations.

To illustrate the development of logical mathematical structures, Piaget uses the example of the development of the concept of conservation. He begins by translating the rolling out of a ball of clay into a sausage in terms of the Type II model. The first analysis is of a Level I (pre-operatory, age 2-7) child. The child centers his attention on the length of the sausage. OBS O, the first step, consists of the child observing the increase in length of the sausage without considering any other dimension. Second, he focus on actions that caused the elongating of the clay – OBS S. COORD S and O are the same and consist of the child's belief or inference that the quantity of clay increases as the ball of clay is rolled out. This evaluation is made in ordinal fashion by simple comparison of initial and final states.

At subsequent stage of development, called Level II [Piaget (1985) does not correlate these levels directly with his stages], there is a transition. OBS O and S result, because of more careful observation and denoting of contrasts, in the discovery of both lengthening and thinning associated with the action. COORD S and O remain in unstable equilibrium. When the child focuses on elongation, he infers that the amount of clay increases. When he focuses on the thinning, he reasons that the quantity decreases.

Progress continues at Level III. The thinning feedback supplied by OBS O results in differentiation of OBS S, and the action of rolling out is now associated with thinning as well as elongation. They see what their action has done to the ball of clay and have taken consciousness of both aspects of the action. Putting OBS O and OBS S in relation is the source of COORD S. At this level, COORD S and O include the inferences that elongation and thinning are no longer separate changes but the concomitant effects of a single action. Piaget indicates that subjects often anticipate the possibility that the clay can be returned to its original state and therefore their thought shows the beginnings of reversibility. What is missing from children at this level is the concept of quantitative compensation. They know that there are two qualitative changes that are proceeding in opposite directions. They do not know that they cancel each other out, so as to conserve the total quantity. They understand the bipolar nature of the action and have some inferential intuition about the reversibility of the action, which permits a glimpse of conservation. They do not yet, however, have a way to justify such an inference or judgment.

With OBS S and O at the next level, level IV, we have prediction and anticipation of lengthening and thinning before the clay is rolled out. This implies that the COORD S and O of the prior level have changed the OBS S and O of this level by facilitating a logical relationship between them. For Piaget, the proof that inferential necessity is dominant at Level IV is the fact that, as the subject rolls out the clay, the two transformations of lengthening and thickening are seen to compensate quantitatively, even though the subject uses no measurement or other attempt to verify this judgment. At this stage then, COORD S and COORD O have the character of necessary inferences that go beyond what can be observed. This also shows why conservation cannot be inferred strictly from observations. In viewing the entire progression of the development of the concept of conservation, it is clear transitions from stage to stage result from feedback regulations that cause the child to focus on the transformations that their actions bring about.

The subject, after having in unstable fashion arrived at the fact that the sausage is getting thinner, at the next level (III) comes to understand that thinning and elongation go together regularly and constantly. Piaget (1985) concludes that the incompatibility of these two changes prevents their inclusion within the same class or original scheme and requires compensation that forms separate classes or schemes connected through a relationship. The subject has widened the referential by including both variables and relativized the predicate by crafting a relationship between these differentiated variables. The final result is the creation and closure of a cognitive structure. The process consists of the creation of equilibrium through compensatory regulations that derive from the system's conservative nature. The foregoing then is Piaget's mechanism for the creation of cognitive structures.

No discussion of Piaget would be complete without some coverage of his identified stages of development and the cognitive abilities that are present in each of those stages. This is the contribution for which Piaget is perhaps most famous. His documentation of stages of development represent the first recognition and elaboration of the qualitative changes that occur in psychological functions and demonstrate cognitive abilities during the developmental progression of the child. Mainstream thought, prior to Piaget, was that development consisted of quantitative change; all psychological mechanisms were in place at birth and did not change with development. What was believed to change was the number and stability of associations an individual could make with time. Learning was viewed as the creation of associations among things in the environment. Piaget and Vygotsky's conclusion that psychological functions, cognitive processes and consequent behavioral manifestations of these functions and processes exhibited a developmental progression were revolutionary in their time.

Piaget's first stage of development he termed the sensorimotor stage. Before summarizing Piaget's conclusions regarding this stage, it is beneficial to take a brief look at what we know today about the neurological basis of sensorimotor skill development and functioning. This provides, perhaps, a different context in which to view his interpretations.

At the functional level, goal directed motion involves:

1) knowledge of where the body is in space and where it intends to go,
2) creation and selection of the plan on how to get there,
3) the capacity to hold this plan in memory until the appropriate time for execution,
4) the specific instructions issued to muscle groups,
5) a feedback and compensation system for in-progress, active adjustments, and
6) a memory system to record successful and often utilized motor programs.

Information from the brain to the spinal cord, and ultimately to various muscle groups, moves through two generalized pathways called the **lateral pathway** and the **ventromedial pathway**. These pathways control different motor groups. The **lateral pathways** are involved in movement of the distal musculature (e.g. fractionated movements of shoulders, elbows, wrists and fingers). These areas are under the direct control of the cerebral cortex. The **ventromedial pathways** are involved in the control of posture and locomotion. They are under the direction of the brainstem. Bear, et al. (2007) use the example of a baseball pitcher. The ventromedial pathways enable the pitcher to stand erect on the mound and make a balanced forward motion toward the batter. The lateral pathways enable the pitcher's arm and hand to successfully throw a curve ball. The **ventromedial pathway** consists of four separate tracts that divide up the tasks required for balance, posture and locomotion. One tract receives input from the inner ear and provides direction to muscles that help to maintain balance. Another tract receives input from the retina, visual cortex, somatosensory area (touch) and auditory processing areas. This information is used to construct a sensory map of the world surrounding the individual (in the superior colliculus). Stimulation at a site on this map (in the colliculus) leads to an orienting response that moves the head and eyes so that an attended-to stimulus is centered in the retina (fovea). The other two tracts of the ventromedial pathway serve to balance and compensate for the effects of gravity on the body.

As stated previously, the lateral pathways control the distal musculature. Input to these pathways comes from Brodmann areas 4 and 6 of the frontal lobe, which are collectively called the motor cortex, and from the somatosensory area of the parietal lobe. Originating in the cortex, these tracts are the longest and largest of the central nervous system, containing 10 million axons.

Planning and directing voluntary movements involves extensive areas of the cerebral cortex. Motor maps or plans for voluntary motion are assembled in area six of the motor cortex. Input to the construction of these plans is provided, in large measure, by the prefrontal and parietal areas of the cortex. The two areas of the parietal lobe involved are area five, which receives processed sensory input from somatosensory (touch) areas 1, 2 and 3, and area 7, which receives input from higher order visual areas (like area MT). The function that these two areas of the parietal lobe carry out is to create a mental body image, create a perception of spatial relationships in the individual's immediate environment, and to orient and relate the individual to the environment spatially. This area has been called the "where" area of the brain. These areas of the parietal lobe are directly and strongly connected to area eight in the prefrontal cortex. Area eight in the prefrontal cortex has been found to be important in processing abstract thought, developing strategies, making decisions, and anticipating the consequences of actions (Bear, Connors, & Paradiso, 2007). We can perhaps think of this area as the "what if" area of the brain. Using information from the parietal cortex, area eight constructs the motor plan. The plan constructed by area eight is not in the form of specific instructions to specific motor groups. This translation comes about in area six of the frontal lobe, or what is called the pre-motor cortex. Both the prefrontal lobe planning area and the parietal cortex send axons, carrying information, to area six. Once this translation has occurred, the motor plan, articulated in terms of specific instructions to specific muscular groups, is sent to the primary motor cortex, area four of the frontal lobe. This area is also designated as M1 in the literature. When the transfer to this area occurs, the motoric action is immediately implemented. A way to characterize this is that the prefrontal cortex and parietal lobe provide the "get ready" function, area six provides the "get set" function, and area four provides the "go" function of motoric activity (Bear, Connors, & Paradiso, 2007).

The involvement of area eight of the prefrontal cortex in the construction of motor plans has profound implications. The fact that this area is involved in both the processing of activities involved in abstract reasoning and the creation of motor plans implies that it is a generic processor or functionality capable of operating on a variety of representations. There are a number of implications that arise from this. First, this functionality is in place from the beginning, it is not developmentally contingent. Most developmental theories have concluded that the human "what if" capacity is developmentally constructed.

I would like to call the reader's attention to the fact that what is typically interpreted as a sign of intelligent activity is activity carried out in accordance to an apparent plan that has been constructed in order to achieve a goal. Steven Pinker (1997) cites science-fiction author David Alexander Smith's characterization of intelligence in responding to the question, "What makes a good alien?"

> One, they have to have intelligent responses to situations. You have to be able to observe the alien’s behavior and say, "I don't understand the rules by which the alien is making its decision,

> but the alien is acting rationally by some set of rules." The second requirement is that they have to care about something. They have to want something and pursue it in the face of obstacles (p. 61).

Pinker (1997) summarizes, "intelligence, then, is the ability to attain goals in the face of obstacles by means of decisions based on rational (truth-obeying) rules" (p. 62). He also points out that computer scientists Alan Newell and Herbert Simon flesh this idea out further by characterizing intelligence as consisting of specification of goal, assessment of the current state and how it differs from the goal, and applying a set of operations that reduce the difference. Please note that this articulates a feedback compensation mechanism. We see then, that the accumulation of basic motor skills qualifies as an act of intelligence. Every human born into the world has the capacity to develop motor skill programs that enable him to interact with his environment. These skills are so critical to the survival of the organism that they are not left to chance interactions between the organism and the environment. They are not environmentally contingent or left to the vugarities of nature-nurture ontogeny. The functional capacity to acquire these skills is imprinted in the DNA sequences of the species. The same can be said for the capacity for speech.

The development of environmentally adaptive basic motor skill programs requires a representational mechanism, a planning function, a rule-making capability, a feedback compensation mechanism (as we will see subsequently) and a memory function. These are also, in abstract, precisely the components required of a system capable of generating what we would regard as any intelligent behavior. It appears then, that the evolutionary adaptations which enabled motility also created the basic mechanisms required for other forms of intelligent action. As Vygotsky’s (1986) work shows, the evolutionary adaptation that led to speech, ultimately leads to the capacity for abstract rationality.

An additional implication is that more primitive circuits were co-opted or adapted in order to process higher level representations like abstractions (e.g. words representing concepts). We can characterize the human as a rule making organism. These rules (schema) represent our organization or construction of beliefs concerning the nature of our external environment. These rules constitute the plans by which we intelligently carry out our activities, in the effort to close the gap between our current state and a state which represents the actualization of a motivated goal. The rule could be Einstein's special theory of relativity that guides the activity of predicting the behavior of an electron in a nuclear accelerator, or a rule concerning how to pick a small speck of potato chip off of a table. What differs between these rules is the form in which reality is represented and the nature of the relationships within and between these representations. As Vygotsky (1986) shows us, adult words are a specific form of representation that exhibit both a nominative and a semantic aspect. They are the representation of abstracted characteristics connected through logical relationships. In this sense, they are both representations and rules (concepts). If we view the human in the context of a rule-making entity, and we accept the premise that the basic mechanistic functionalities required for intelligent action are a-priori, and the manifestations of functionalities required to construct basic motor programs, then development can be characterized as the construction of rules or an organization of the environment, consequent from adaptational activity (as per Piaget), wherein the developmental variables are the form of representation and the nature of relationships within and between those things represented. An additional implication is that the **developmental progression of the individual is an articulation of the changing nature of representations and rules rather than the emergence, through ontogenic adaptation, of different mechanistic functionalities.** Let me point out that this position is a significant departure from the mainstream.

I would like to elaborate an additional reason why I have taken this position. To begin, the prevailing wisdom in biology is that a change in the configuration of DNA is the result of a chance mutation. This mutation creates some variation in the structure of the organism. If the ensuing structural change winds up being adaptive to the contingencies of a changing environment, the mutated variant has an increased probability for survival. If the non-mutated variants of the lineage perish and the mutated variants survive, nature is said to have selected this variation of the species. There is not a currently known or documented mechanism whereby an environmental contingency can reconfigure DNA sequences.

As Maturana and Varela (1998) point out, DNA does not create an organism that is completely determined. It creates a structure with a great deal of plasticity. The specific ontogeny of an organism, in a generation, is the reflection of the history of structural couplings, and the equilibration of this plastic structure to environmental contingencies. This coupling and consequent equilibration must preserve the autopoietic unity of the organism. If we use the analogy of a term paper, DNA provides the outline, while adaptational processes or equilibrations write the sentences. It is this nature -nurture dialectic that determines the ultimate structure of the organism. Maturana and Varela (1998) use the analogy of a governmental structure of a nation. If we specify that the country operates under a democratic form of government with a constitution, we do not deterministically define all of the activities individuals operating under this structure will undertake or the final form that a society will take on. We have simply specified the context, framework and basic structure within which this will occur. The point of this discussion is that environmental contingency does not create new biologic structures or cognitive hardware, it modifies, through the plasticity inherent in the hardware, the final form and function this hardware takes on and the consequent behavior it demonstrates. To use a computer analogy, DNA creates hardware and experience writes software.

Let us now complete our discussion of the neurologic motor system. In addition to the brain areas discussed above, there are other areas that impact the functioning of the motor system. These areas are constituted in the form of feedback compensation loops. The first feedback loop begins with a connection from the previously discussed motor plan construction areas: prefrontal lobe (area 8), frontal lobe (area 6) and parietal lobe (areas 5, 7) to the basal ganglia. The basal ganglia and its associated structures connect to the ventral lateral nucleus of the thalamus, which then connects back to frontal lobe (area 6). The function of this feedback loop appears to be the selection and initiation of willed movements (Bear, Connors, & Paradiso, 2007). This viewpoint is supported by the consequences of human diseases that impact upon these areas. Parkinson's disease brings about slowness of movement and great difficulty in initiating willed movements. Huntington's disease is the other end of the spectrum of basal ganglia disorders. It is characterized by hyperkinetic activity and the inability to control motion. The basal ganglia are a poorly understood area of the brain. This area is known to have inputs from areas involved with declarative memory and other cognitive functions. In summary, however, it is apparent from the above that this feedback circuit serves a **decision-making** function of choosing between alternative motor plans and sending a "go" signal to area 6 of the frontal lobe, the holder of the detailed motor plan.

The second feedback loop involves the cerebellum. As discussed by Bear et al. (2007), an activity like throwing a curveball requires more than a simple motor plan. It requires a detailed **sequence** of muscle contractions timed with great precision. In addition, many motor activities require in-progress compensations and corrections that narrow the gap between action and intended goal. These functions are undertaken by the feedback loop involving the cerebellum. Lesions to the cerebellum result in uncoordinated and inaccurate movements, a condition known as ataxia (Bear, Connors, & Paradiso, 2007). Alcohol intoxication depresses the function of cerebellar circuits. Watching the movements of a drunk will give one an idea of the functions undertaken by this area of the brain. There are a number of originating circuits from the cerebral cortex to the cerebellum. In addition, there are direct inputs from the brainstem to the cerebellum that communicate information from the muscles themselves. One of the circuits originating in the cortex begins at sensorimotor cortex areas 4 and 6, discussed previously, and extends to a gathering area called the pontine nuclei; from there axons expand to the cerebellum, from the cerebellum to the thalamus and from the thalamus back to area 4 of the motor cortex. Once the signal for movement intent has been received from area 6, the activity of this feedback loop appears to be to instruct the primary motor cortex, area 4, in regards to changes in movement direction, timing and force. In the case of movements that are too fast for feedback, predictions are based on past experience or previous motor programs that have been stored in the cerebellum. This illustrates another attribute of the cerebellum. It is the place where successful motor programs from past experience are stored. The cerebellum undertakes both a compensatory function and a memory function (Bear, Connors, & Paradiso, 2007). There are no connections between the cerebellum and areas involved with declarative memory (facts and events). Stored motor programs are therefore part of the tacit or unconscious memory system.

We return now to Piaget's explication of ages and stages. As mentioned previously, Piaget's (Wadworth, 1989) first major stage is called the sensorimotor stage. This stage covers developments between birth and age two. As was discussed before, organization requires differentiation on the basis of attribute, as a first step. Developmental progression shows increasing levels of differentiation and reintegration in order to create organized wholes or unities. At birth, a child experiences an undifferentiated whole. All information that a child can structurally couple with is assimilated. The child has no self-constructed schemes that can be differentiated so as to effect an accommodation.

A child is born with certain reflexive behaviors such as grasping, sucking, and crying in response to need or discomfort. The child also has a- priori reflexive schemes that enable it to move its arms, legs, trunk and head. The first month is one of self discovery and the beginning of motor program construction for the control of the parts the infant has discovered.

Piaget second period of sensorimotor development, covering ages 1 to 4 months, shows increased levels of differentiation. The child can, for example, discriminate between different sounds. In addition to differentiation, we can see the beginning of the coordination of motor programs (reciprocal assimilations). The child can move his head and follow objects with his eyes. He can bring objects to his mouth in order to suck on them, reflecting coordination of motor programs for the mouth, arms and hands. In terms of spatial processing ability, the child is developing his capacity to locate objects in space. He has the ability to return to the position or location of an object after it leaves his field of vision. The child is also increasingly aware of separate objects as unities. From behavioral observations, it appears that intentional goals are often set after motor sequences begin (Wadworth, 1989).

In period three of the sensorimotor stage, covering ages 4 to 8 months, the child begins to demonstrate repetitive use of motor schemes. He will repeat an action sequence over and over again if the outcome is interesting or amusing to him. We can view this as the refinement, calibration and perfection of motor schemes the child deems useful to his intentions. In the prior stage, the child's behavior was elicited by stimulation. In this stage, it is clear that behavior is goal driven and intentional. The child undertakes motor schemes to make something happen.

Knowledge of spatial relationships continues to develop and, by 8 months, the child will look for objects where he thinks they might have moved to (Wadworth, 1989). He is gaining the recognition that objects change their position in space and move along a trajectory. At this stage, the child views himself as the cause of all changes.

Sensorimotor period four, ages 8 to 12 months shows increased variety in the use of means to attain ends. Various motor schemes are combined to achieve goals. For example, the child will remove an obstacle such as a pillow in order to access an object he desires. In the prior stage, an imposed obstacle would cause the child to abandon his goal. There is now evidence of planning or the selection of means (motor schemes) before the initiation of behavior. There is more clarification of means/ends relationships (Wadworth, 1989).

Beginning in this period, the child's thought process exhibits the ability to make inferences through associative connections. This enables the child to anticipate events. Piaget (1954) provides the example of a child who cries upon seeing alcohol because of association, from prior experience, between the application of alcohol and pain. Another example is a child who cries after seeing her mother put on a hat. Here the child has made the association between the mother putting on a hat and the mother leaving. In the above two examples, the association is between an action sequence and its outcome. Recognition of the action sequence permits inference with regard to outcome. Piaget (1954) interprets this as objects being recognized as signifiers of events. We can also interpret the above as the emergence or recognition of meaning. A certain sequence of actions or events has a resultant outcome which becomes the meaning of the sequence. In this view, mother picking up and putting on her hat "means" she is leaving. It is interesting to note that motor schemes, associative learning through classical conditioning, and habituation (habit development) are all resident in tacit or subconscious memory. Prior to the age of two, declarative memory systems (consciously recallable memories for facts and events) are not yet operative. This is why we have infantile amnesia or a lack of recallable memories prior to the age of two.

During this period, there is now recognition that other objects can cause things to change state. Also, there is recognition that physical contact in space is a form of cause and effect relationship (impact makes something move). Refinement of spatial concepts includes a refined notion of ideas concerning size and shape. There is greater recognition of dimensionality and dimensional constancy: sizes and shapes remain constant. In prior stages, changing perspectives, such as viewing things from different angles, seemed to change their dimensions (size and shape).

During period five, ages 12 to 18 months, we see the emergence of a problem-solving strategy, trial and error experimentation. The child develops new schemes to solve problems through this process. When a motor scheme fails, trial and error is used to modify an existing scheme or create a new one. The child also experiments with familiar objects in new situations. Needless to say, trial-and-error experimentation facilitates considerable accommodation and coordination of various action schemas.

Also during period five, the child can first follow a series of sequential displacements. In period four, if an object was consistently hidden in a specific place during a series of trials of an experiment and then placed in another spot in the last trial, the child would still look for the hidden object in the place it was usually hidden rather than the place it was actually hidden (in the last trial). The child will look for the object in the correct place during period five. In the former case, the child cannot overcome the initial associations. At stage five, there is greater flexibility in choosing to use an association and in choosing among associations.

Causal relationships show growth also. Not only is there increased recognition of other people and objects as causal agents, evidenced by the increased invocation or adults to execute actions on the child's behalf, but also the recognition that properties of objects can cause actions or outcomes. For example children at this stage will often look at their hands to see if an object left a stain, recognizing that certain objects can cause this result.

At age 2, or the completion of period six, and the sensorimotor stage of development, the child has a large inventory of differentiated (accommodated) and calibrated motor plans (schemas) that can be combined (assimilated) in order to undertake a wide variety of activities and actions (just ask any parent of a 2-year-old). In addition, he has well formed ideas regarding spatial relationships: object forms and dimensions, locations and changes in location, and a generally good sense of how objects exist and relate to each other in three-dimensional space.

In terms of reasoning, the child is able to use his inventory of associations to make inferences. He has developed a sense of "motor meaning": that a specific sequence of actions has a specific outcome. He has acquired the ability to carry out an action plan (schema) in his mind and anticipate the outcome. He can compare these plans and anticipated outcomes in order to make a judgment as to which plan to use before initiating the actual actions. Please note that this is internalized trial and error problem solving, the child has yet to develop the capacity for generalizing a relationship between different action plans. We also see evidence of analogy use. The child can transfer action plans from one activity to another if he views them as having a similar requirement. This is a big first step toward developing the ability to generalize.

The 2-year-old's ideas concerning causality are well-developed also. He understands that there are a variety of causal agents that can bring about a change in state: himself, other people, and objects themselves. He understands that properties of objects can cause actions or outcomes (e.g. stickiness, sharpness). By age two, the child has the ability to mentally predict effects in the absence of direct perception of actions. He can also infer possible causes from an effect.

The second major stage in the cognitive development of the child Piaget termed the **Preoperational** stage. The stage covers the period from age 2 to 7. The major developmental change during the stage is the ability to represent objects and events (Wadworth, 1989). Representation is the ability to re-create an absent object or event. The object or event exists in the mind. The capacity for representation therefore facilitates the ability to think about objects and events without the need for actually experiencing them in the present. If represented, we can think about them whenever we wish. Piaget (1954) referred to the capacity for representation as the symbolic or semiotic function. He distinguished two types of representations. Symbols are representations bearing a similarity to an object, while signs are representations that bear no resemblance. For example, words he would consider signs rather than symbols.

Piaget and Inhelder (1969) discuss three important exemplifications of representational or symbolic activity during this stage. The first is an activity they refer to as deferred imitation. Deferred imitation is when a child carries out an activity by himself that is an imitation or copy of an activity previously carried out jointly with another. An example would be a child who plays patty-cake by himself. The child here remembers and re-creates a prior activity.

A second activity characteristic of this stage is symbolic play. A child may use a wooden block, for instance, and play with it like it were a car, imparting the car's properties to the block. Behavior in symbolic play exhibits an egocentric nature, much like speech during this stage. Constructed symbols, like the block, express attributes as the child wishes them to be, not as they are. This is self-expression, with self as the audience. Piaget and Inhelder (1969), make the interesting observation that in symbolic play, children create symbols to express things in their lives that they cannot articulate through language. It is an alternative outlet and forum for thought and ideas. This observation is noteworthy for educators. It implies an important role for play in the early years of schooling, as a mechanism to create ideas and organization that overcome the language limitations of early childhood.

Children's drawing at this stage also expresses a symbolic attribute. The child's drawing expresses what he "sees" in an object or how it is represented in his mind. Drawing depicts a representation rather than a copy of reality. In a sense, we can characterize art in this way for every artist at any age.

The preoperational child, with the emergence of declarative memory, has access to mental images of objects and events. For Inhelder and Piaget (1969), these are not photographs but representations of reality and hence symbolic in nature. During pre-operations, the images are static and drawing-like. Piaget (Gruber & Voneche, 1995) documents many instances, in his experiments with children, where children at this stage solve problems and answer questions by reference to a single static image or memory of a situation. It is not until the succeeding stage, concrete operations, that children are able to consider multiple images or a succession of images in formulating thought.

The development of language skills begins at this stage. Obviously, words are symbols and a form of representation. From age 2 to 4, a remarkable growth in the ability to use language occurs. From the use of single words, the child progresses to where, at age 4, he has mastered the use of spoken words and the rules of grammatical construction. Language aids the rapid conceptual development at this stage. As discussed previously, egocentric speech in evidence at this stage serves, in large measure, to guide the child's thought.

Piaget (1967) described three functions of language essential to development in all stages:

1) use of words as communicative devices that allow socialization of actions
2) internalization of words as guides for thought through a system of signs, and
3) internalization of action transformations which can then be represented in mental experiments

Inhelder and Piaget (1958) ascribe three benefits that representational thought provide over sensorimotor thought. The first is speed. Rather than thinking through a sequence of actions, symbols (like words) can represent many actions and therefore quicken thought. Sensorimotor adaptations are limited to immediate actions in the present. Representation allows actions to be carried out mentally, at any time, before action ensues. The third benefit is that many elements can be considered in an organized fashion with representation. Sensorimotor thinking proceeds one step and one action at a time.

For Piaget (Gruber & Voneche, 1995), language is just another form of representation. He ascribes a unique role only in its communicative aspect. In this aspect, it allows the socialization process of refining and improving thought through the comparison of one's thoughts with the thoughts of others.

He does not feel that language is either necessary or sufficient for the development of logical structures, based on his and Inhelder's review of studies of deaf and blind children (Inhelder & Piaget, 1958). He ascribes the development of logical structures to the reflective abstraction of action sequences associated with transformations (Piaget, 1985). The reader should recall that it is part of Piaget's paradigm or guiding framework that development consists of the acquisition of the structures of formal logic. On this premise, Piaget and Vygotsky dramatically disagree.

The succeeding developmental stage, called Concrete operations, is characterized by the emergence of logical thought. Inhelder and Piaget (1958) see certain attributes of preoperational thinking as obstacles to logical thought. One obstacle is the egocentricism of this stage. Because they have not completely differentiated themselves from others, children at this stage cannot see the perspective of others. They presume that their thoughts are also the thoughts of others. They also presume that their thoughts are correct and accurate representations of reality. There is no metacognition or reflection on one's own thought. If evidence is contrary to their thought, it is presumed that the evidence must be wrong. Recall that Piaget calls this an alpha reaction to a perturbation. It isn't until around age 7, or the beginning of the stage of concrete operations that children begin to compare their thoughts to the thoughts of others and seek verification through social interaction. It is only then that they begin to question their thoughts and attempt to accommodate discrepancies with the thoughts of others. This egocentricism acts to inhibit disequilibrium and therefore cognitive growth.

An additional limitation of preoperational thought is the inability to undertake transformational reasoning. The preoperational child cannot reason about transformations or changes in state. As mentioned previously, they reason in terms of relationships manifest in a single static image. Their focus is on elements at each stage of a process and not the transformation by which one state is changed to another. The child can go from one representation to another but cannot integrate a series of events and connect them to beginning and ending states. I would like to call to the reader's attention that this inability implies that the child has yet to develop what cognitive psychologists and neuroscientists refer to as **working memory** for declarative representations. This is a theme or observation I will expand upon shortly in the Dissertation. It is my explanation for the differences between the preoperational and concrete operational stages.

Preoperational thought also exhibits what Inhelder and Piaget (1969) call centration. The child fixates on a limited perceptual aspect of a stimulus, usually one aspect. He is unable to de-center and explore multiple aspects of an event stimulus. Again, thought is perceptually driven and predicated upon relationships expressed within a single image. An illustration of this type of thinking, is the Piaget (Wadworth, 1989) experiment where a researcher forms two lines with the same number of objects in each line, has the child count them and agree that they are the same, spreads one of the lines of objects farther apart, and asks the child which line has the greater number of objects. Preoperational children will report that the expanded line has a greater number of objects. This is because their thought is image-based and centered on one aspect of the image: length. For them, greater length equates with more. They cannot coordinate a counting schema with their schema that relates size and extension. Such coordination requires holding both in memory simultaneously, a capability not yet evident in preoperational thought.

Preoperational thinking does not demonstrate reversibility or the ability to follow a line of thinking back to where it started. Since thinking is image-based rather than derived from reflection upon a series of transformations, the child cannot reverse the action sequence and relies upon relationships in the final representation. The child's physical environment does not contain many examples of reversibility. Reversibility is a concept constructed by the child (Wadworth, 1989).

A way to contrast operations or logical thinking with preoperational thinking is that logical thinking corresponds to or is guided by rules, relationships and theories, whereas preoperational thinking is guided by perceptual relationships. A good example is provided by Piaget's (Wadworth, 1989) classic experiment involving the conservation of liquid. In this experiment, the contents of two identical cylindrical glass containers with the same liquid volume are poured into two other containers with different dimensions. One has a smaller diameter but is taller, while the other has a larger diameter but is shorter. Since the volume poured in each container is the same, the volume in narrower container will rise to a greater height than the height observed in the original container, while the volume in the wider container will rise to a lower height than what was observed in the original container. Children are asked which of the new containers has the most liquid. Preoperational children will report that the container in which the liquid reaches the greater height has the most liquid. Again, we see centration on a single physical attribute, reliance on perceptual relationship, and inability to mentally reverse the operation.

The incremental mental capability that Piaget ascribes to the preoperational stage of development is the capacity to create perceptual-based (image) representations for facts and events. This capacity is coincident with the emergence of declarative memory and, in my estimation, the articulation of this neurologic capacity. It is therefore useful to review what is known about the neurologic basis of declarative memory, as an aid in understanding the second stage of cognitive development. We begin with Hebb's hypothesis (Bear, Connors, & Paradiso, 2007), still considered valid by most practitioners in the field of neuroscience. Hebb proposed that the internal representation of an object consists of all of the cells (cell assembly) of the cerebral cortex that are activated by the external stimulus (object). Hebb hypothesized that if the specific cell assembly was activated long enough or often enough, the reciprocal connections between the cells of the assembly representing the stimulus would become stronger, more effective and more permanent: "neurons that fired together would wire together" (Bear, Connors, & Paradiso, 2007). In the decades following Hebb's proposal, a molecular level mechanism has been discovered that explains how this could occur. We will discuss this mechanism later in the Dissertation.

Hebb's hypothesis has two implications: 1) the representation (engram) is widely distributed among the cells of the assembly, and 2) it involves the same neurons that are involved in sensation and perception (Bear, Connors, & Paradiso, 2007). This implies that visual memories are stored, for example, in visual processing areas of the visual cortex and likewise for other sensory areas.

A series of experiments performed on Macaque monkeys (Bear, Connors, & Paradiso, 2007) seems to bear out these implications. Monkeys trained to associate a stimulus shape with a food reward were given lesions in the infero-temporal cortex (area IT), a higher order processing area in the inferior temporal lobe. Once lesioned, they could no longer perform the association between the visual image of the shape and the reward, indicating that the visual memory for the shape was stored in this higher-order visual processing area.

Recordings of the response levels of neurons in the infero-temporal cortex of Macaque monkeys were made to study neural responses to face stimuli. When first presented with a group of faces, a specific neuron of the infero-temporal cortex responded moderately to all faces. As the faces were repeated, the specific neuron responded more strongly to some faces than others, indicating that the neuron was part of a cell assembly for the representation of specific faces. With time, and continued presentation of faces, this neuron's response became stable and consistent in responding to specific faces. The implication is that this neuron is part of a distributed system for the representation of some faces, but not all faces. A particular face activates a distribution of neurons which constitute its representation. Please note here that the neurons are exhibiting the behavior of a "productive" system. Like words in a sentence, a neuron participates as a building block for a variety of representations. I would therefore speculate that the neuron is encoding something like a feature or part of a feature common to multiple faces. In any case, the above experiments confirm Hebb's hypotheses. Studies on humans, using fMRI recordings, confirm that the infero-temporal lobe of humans is also highly activated during object recognition tasks such as face recognition. It is reasonable to presume that the same dynamics occur in the human brain.

A visual representation of a stimulus, however, does not a declarative memory make! Our declarative memories encode not only individual objects but their relationship to each other in a context, as well as the complete inventory of associated sensory information in the event: smells, sounds, touches, and tastes. If sensory memories do reside in the higher level association areas of the sensory processing areas of the cerebral cortex, how and where do they get consolidated into the composites we consciously experience as declarative memories?

The first answer to this question came from detailed studies conducted by Dr. Brenda Miller, over a 50-year period, of a patient known in the neurologic literature as H. M. (Kandel, 2006). The patient suffered a disabling level of epileptic seizures. Physicians treating H. M. removed an 8 cm length of his medial temporal lobe including the hippocampus, associated temporal areas of the cortex and the amygdala.

The surgery relieved the epilepsy and left his perception, intelligence and personality intact, but eliminated his ability to form new declarative memories. For example, after 50 years of association, Dr. Miller has to re-introduce herself to H. M. before each appointment (Kandel, 2006). H. M. lost the last two years of memory before the surgery, but retained all memories before that time. This finding is consistent with other subsequent cases where lesions or damage has occurred to the hippocampus. It appears that about two years of declarative memories are stored directly in the hippocampus and surrounding structures. Longer-term memories (more than 2 years before) appear to reside in the sensory cortex association areas.

Other capacities retained by H. M. were working memory, sensory motor memory, procedural memory and subconscious, classically conditioned memory. We have noted previously that the above systems are uninvolved with consciously recallable declarative memory.

Considerable research has been done on the hippocampus and its role in memory consolidation and retrieval. There are several areas directly associated with the hippocampus that are involved in the consolidation process. Inputs to the medial temporal cortex areas associated with the hippocampus come from all of the higher level association areas of the cerebral cortex involved in sensory processing. This data comes first to the para-hippocampal cortex and the perirhinal cortex of the temporal lobe. Processed information from these two areas then goes to the hippocampus, as well as to an area called the entorhinal cortex. The entorhinal cortex further processes the information and also inputs into the hippocampus. Together with the hippocampus, the above-mentioned structures perform the critical function of assembling sensory information from the association areas and consolidating it into recallable declarative memories. There is currently limited information available regarding the specific role that each of the auxiliary structures plays in this process. The connections between the hippocampus and the sensory processing areas of the cortex are reciprocal. Pathways carrying information from the cortex to the rhinal areas and then to the hippocampus are mirrored by pathways coming out of the hippocampus to the rhinal areas and ending in the same areas of the sensory cortex that originated the inputs. In this way, cortex areas involved in processing a stimulus can participate in long-term storage of memories of stimuli (LeDoux, 2002). The rhinal areas associated with the hippocampus act as convergence zones where information from many sensory domains is integrated to create representations that are independent of the domain from which the information was obtained (LeDoux, 2002). Sights, sounds, smells, and touch sensations are put together in the form of a consolidated memory of a situation. LeDoux (2002) discusses an interleaved learning hypothesis of hippocampal functioning. In this theory, a memory is initially stored via synaptic changes in the hippocampus. When some aspect of the stimulus situation re- occurs, the hippocampus participates in reinstating or re-creating the pattern of activity or activation in areas of the cortex that occurred during the original experience. Each reinstatement strengthens cortical synapses of neurons that make up the representation of the stimulus. In this theory, old memories are the result of accumulations of synaptic changes in the cortex as a result of multiple reinstatements of the memory. Once sufficiently strengthened, they no longer rely on the hippocampus for reconstitution or reinstatement. Since new memories depend on the hippocampus for reinstatement, damage to the hippocampus affects recent memories and not older ones. This theory would imply that older memories, now independent of hippocampal function, retain the relational connections originally imparted by the hippocampal areas. This would explain why certain sights, sounds, or smells could trigger an entire memory of an event. Since hippocampal activities are closely associated with attention and consciousness, it would also explain the almost subconscious and automatic manner in which older, well engrained (not requiring hippocampal involvement) memories are recalled. Recall that in expert performance, recall is virtually subconscious and automatic as a result of certain experiences being repeated again and again.

The hippocampus outputs information into a bundle of axons known as the fornix. The fornix connects to the hypothalamus (mammillary bodies). Neurons from this specific area in the hypothalamus then project to the anterior nucleus of the thalamus (the brains major data distribution center). The circuit from the hippocampus to the anterior nucleus is half of what is known as the Papez circuit (Bear, Connors, & Paradiso, 2007). This circuit is believed to be involved in processing emotional experiences. It is well known that declarative memories have emotional content. We can hypothesize then that this emotional input is provided through the functioning of this circuit. Connections to the dorsomedial nuclei of the thalamus, which connects to the cingulate cortex, that in turn connects to virtually every area of the frontal cortex, facilitate a connection between the hippocampus and a great number of processing areas in the frontal and pre- frontal cortex. Declarative memories are also impacted by attentional circuits or the part of the stimulus upon which we focus our attention, as well as schemas which represent a consolidation of past experience. We can perhaps presume that these connections enable these inputs to the formation of declarative memories and bring about the behavioral attribute of memory that we recognize as **remembering what we pay attention to and think about** when processing a stimulus experience. It is interesting to note that damage to the output circuits just discussed prevents the formation of declarative memory in general. The damaged circuits do not simply impact the aspect of declarative memory they are presumed to contribute to it. This implies that these interconnected areas are part of a **system** which equilibrates the various inputs to form a declarative memory. A break in any part of the system will prevent this memory consolidation from occurring. For example, Korsakoff's syndrome, associated with chronic alcoholism and resulting lesions in the dorsomedial thalamus and mammillary bodies, will prevent the formation of declarative memories.

Understanding the form of organization imparted by the hippocampus comes from studies of rats. In the 1970's John O'Keefe and colleagues (O'Keefe & Nadel., 1978) showed that neurons in the hippocampus of a rat selectively respond when the rat is in a specific location in its environment. Different neurons in the rat hippocampus that responded at a specific location stopped firing when the rat left that location. When the rat returned to the location, they began firing again. Because these neurons appear to be encoding the spatial position of the rat, they were termed the place cells. Subsequent experiments by other researchers have shown unequivocally that the hippocampus is involved in spatial memory (LeDoux, 2002).

Other experiments with rats have implications in regard to how the spatial orientation is constructed (Bear, Connors, & Paradiso, 2007). In those experiments, rats were placed in environments where a visual stimulus was associated with specific locations. For example, a star might be painted at a specific spot. In the first stage of the experiment, place cells that responded to specific locations were recorded.

The maze was rotated 180°, and the rat was reinserted. When the rat was proximal to the visual stimulus, the place cell responded in spite of the fact that the place was opposite to the position where the neuron had originally responded. The implication here is that the place cell records relative position with respect to objects in space rather than absolute position. This conclusion is still controversial. There is still disagreement as to whether place cells record absolute position within a mental grid of space or whether they record the relationship that objects bear to each other in space. Cohen and Eichenbaum (1993) developed a hypotheses that attempts to integrate the full range of experimental findings. They propose that declarative memory should be defined by the kind of processing requirements it makes. Declarative memories are relational. For example, the activation of a declarative memory leads to the activation of other related memories. Declarative memories can also be activated independent of the context in which they were established. For example, a sensory stimulus such as a smell in a new environment can trigger the memory of a previous environment. The implication then is that the hippocampus engages in relational processing.

Projecting from this the form of organization imparted by the hippocampus, I think we can presume that relational organization is strongly spatial. What was originally a space processing demand was evolutionarily co-opted to serve a more general capacity expressed as declarative memory. Declarative memories record what goes together and how (the thing and its context). They record attributes of extension: sizes, shapes and relative positions of objects. They also record the attributes and properties of things as derived from sensory input (unities and their characteristics). As a consequence of their connectivity to higher-order processing areas in the frontal and pre-frontal lobe and emotional circuits, there is an emotional valence attached to declarative memory as well as a connection to previously formed schemas. By organizing event memories sequentially as they are experienced, a temporal attribute can be imposed analogous to how temporal relationships are created in a timeline. In terms of organizational principles, I think we can summarize them as: 1) **space-time**, 2) **part–whole**, and 3)

unities and their defining characteristics. In addition, I believe that **declarative memories enable the specific cognitive abilities cited by Piaget** (Wadworth, 1989) **for the preoperational stage of development**.

Piaget's (Wadworth, 1989) next stage in the cognitive development of the child is termed the stage of Concrete operations. This stage describes children from the ages of 7 to 11. During this stage, intellectual activity is described by Piaget (1952) as an internalized system of mental actions guided by logical relationships. Piaget (Gruber & Voneche, 1995) characterizes operations as possessing the following characteristics:

1) they can be carried out in thought as well as physically
2) they are mentally reversible
3) they always contain the supposition that something is **conserved** or **invariant**
4) they never exist alone; they are related to a system of operations.

Logical operations are an internalized series of cognitive actions that allow the child to arrive at conclusions that are logically based. Actions are directed by cognitive activity rather than perceptual characteristics. As mentioned previously, one of Piaget's beginning postulates is that the world is an orderly place and possesses an inherent logic expressed by its orderly organization. Schemas that the individual organizes through his experience of the world ultimately become expressed as logical relationships in the mind of the individual. And, by this, Piaget (Gruber & Voneche, 1995) means the rules of formal logic. These are the individual's expression of the logic inherent in nature.

At this stage of development, the child can use logical operations on real, observable objects and events. He has not yet developed the ability to use logical operations on problems that are hypothetical, purely verbal or abstract. In addition he can consider only one variable at a time. He cannot solve problems in which two variables are changing. For example, he cannot solve the volume conservation problem previously discussed. The solution to this problem involves understanding the reciprocal relationship between diameter and height or two variables that both change. The solution to this problem occurs in the next stage of development, which Piaget terms Formal operations.

Children in the concrete operations stage are free of egocentrism, can take the viewpoint of others, and seek others for validation of their thoughts and ideas. They have the ability to de-center their perception and attend to different aspects of a stimulus. This allows them to undertake transformational reasoning. Children at this stage can solve problems involving concrete (physical) transformations. They begin to develop the ability to understand the relationship between successive steps of a transformation, when reasoning about how an effect comes about. For example, in social contexts, they understand how a change in someone's feelings comes about.

The thought process of children at this age shows that they can reverse mental actions. Not only can they follow a series of transformations or actions, they can reverse those actions in their minds. Piaget (1952) interprets these abilities as manifestations of the emergence of certain logical structures in the mind of a child. I would offer an alternative view: it is the emergence of the ability to create rules from **invariant relationships** and to use those rules as guides for thinking. Piaget's basic mechanism for the development of logical structures is reflective abstraction applied to transformations that are consequent to actions. He provided the example of the young man counting the same number of pebbles, in spite of the fact that he had rearranged them into different geometric forms and counted them in both forward order and reverse order. The young man had executed a series of actions or created a series of transformations on the objects. Something remained **invariant** through these transformations. The invariant was the number of objects counted. The young man had discovered the commutative law of addition by reflecting upon the transformation or actions and noting the invariance in outcome. We can generalize this story to any experience which can be characterized as a series of actions or an experiment which has an outcome or result. For example, if we measured the diameter and circumference of a large number of circles or circular objects, there is an invariant relationship between these two measurements. It happens to be that the division of the circumference by the diameter is always a constant (π), independent of the individual values of these variables. Once the invariant is identified, we can inductively arrive at a relationship or **rule** which summarizes the actions. In this example, our rule is mathematical ($C = \pi d$). Once in rule form, our relationship has predictive and inferential capabilities. It also expresses knowledge that is **not physically observable** in circles. It is knowledge that is arrived at by **generalizing the relationship between characteristics or attributes** of a circle. Practically all scientific experiments can be viewed as exemplary of this process. Rules can also be social or psychological. A child at the level of concrete operations will easily generalize that a series of actions makes his mother angry. The invariant in this circumstance is mother's response to a specific sequence of actions. Rules can be generalized as expressions of invariant relationships. It is this **invariance that gives them their inferential or predictive power**. Rules also articulate knowledge or information not present or explicit in physical observations. They are derived from consistencies in relationships. They are therefore a **manifestation that arises within the individual recognizing and constructing the relationship and not a physically observable characteristic**. As Piaget (1952) points out, they therefore transcend the physically observable. I would differ from Piaget in concluding that this process results in cognitive structures which articulate the rules of formal logic. I believe that any rule constructed in the above fashion provides the structural elements necessary for deductive reasoning. The **logic is implicit within the relationship**. Deduction, as undertaken by humans, can be characterized as the application of constructed rules (schemas) to a circumstance beyond the initial experience from which the rules were constructed. Recall, that for Piaget (Gruber & Voneche, 1995) the teleos of development is the capacity for abstract deductive logic. **I would therefore restate Piaget's logical operations as rule-based thinking**. In this context, I believe we can generalize rules to include concepts and theories. The above discussion constitutes a central premise of this Dissertation.

Children in the concrete operations stage of development acquire the ability to seriate or sort things according to size, weight or volume. Between ages seven and eight they employ a trial and error strategy (absence of rules). At around age 9, they develop the notion of transitivity or, if A is less than B, and B is less than C, then A is less than C. This enables them to create a rule or strategy for searching, for example, for the smallest stick, then the next smallest stick and so forth. The ability to classify on the basis of similarity also shows progression during this stage. Children begin by classifying objects according to a single physical attribute. Toward the end of the stage, children show the ability to consider differences as well as similarities in classification and to reason about relationships between classes. They begin to understand class inclusion concepts and the relationship between collections and sub-collections. This clearly illustrates the shift in thinking toward <u>relationships</u> between attributes. It is interesting to note the progression in children's thought concerning the idea of speed or velocity. Preoperational children, working with a static image, focus on point of arrival and surmise that the fastest object was the one that arrived first. Concrete operational children, whose thinking is now more relational, use overtaking relationships as the basis of determining the fastest moving object. It is not until the advent of Formal operations, or age 12, that children can understand that velocity or speed is the distance traversed per unit of time. This idea requires a relationship between two abstracted entities ($Distance/Time$). It therefore involves the capacity both for abstraction and a relationship involving two simultaneously changing variables.

Marvin Minsky (1985) illustrates a series of human intellectual capacities by pointing out the tasks involved in rearranging the furniture in a room. Attention is shifted back and forth between pieces of furniture and locations in the room. Different ideas and images come to mind, with some interrupting others. The individual is comparing and contrasting alternative arrangements. Attention and concentration may be fixated on a small detail at one moment and then on the whole room at once at another moment. How does the mind do all this juggling and still keep track of options? The answer is

working memory. This vital capacity enables activities such as holding a conversation and reading, solving mathematical problems or any situation in which pieces of information have to be held in the mind simultaneously for some period of time.

The functional operation and characteristics of conscious working memory were first described by George Miller (1962), and Baddeley & Hitch (1974). A large number of mental tasks involve processing stimuli that are stretched out in time, for example, reading a sentence. This creates a requirement to hang on to early stimuli while we work on what comes next. There appear to be several working memory systems in the brain specialized for specific tasks as well as the general-purpose system, defined by Baddeley & Hitch (1974) and Miller (1962) that serves conscious mental processing. Nonverbal specialized systems, like sensory systems, have the capacity to retain processed stimuli for a few seconds. This capacity allows, for example, a system to compare what it is seeing or hearing presently to what it saw a moment ago. This aids in clarifying perception.

The general-purpose system described by cognitive scientists consists of a workspace or temporary storage area and a set of operations called executive functions that are carried out on information held in the workspace. The workspace can hold on to and inter-relate information from a variety of specialized systems in the brain. The capacity to hold and integrate information ultimately creates the capacity to form abstract representations (with time and development). Information in working memory consists of what an individual is currently paying attention to and thinking about. Working memory is also directly connected to long-term memory. There is a back-and-forth exchange between the two. As such, mental schema or organizations invoked from long-term memory and connected to the workspace of working memory impact thoughts and actions. There are numerous documented examples in the literature of how pre-existing schemas exert an influence on our interpretation, organization, and perception of stimuli (Reisberg, 2006).

George Miller (1962) determined that working memory can generally hold seven pieces of information. The range, for people tested, was five to nine pieces of information. In general, the number is seven for most individuals. Miller (1962) also determined that the capacity of working memory can be effectively expanded by chunking or grouping information. Amazingly, working memory can hold seven ideas as readily as seven letters. For example, an individual can hold in working memory the number sequence 1 4 9 1 6 2 5. If the individual detects the pattern that the number sequence can be generated by squaring whole numbers (1, 4, 16, 25,) the relation x^2 can be placed in one space of working memory, freeing the other six spaces for additional information. Working memory can hold seven terms of a mathematical relationship as easily as it can hold the individual numbers above. The ability to abstractly represent things at higher logical levels exponentially increases the information that can be held in working memory. Information stays in working memory for a limited period of time. The area of the brain that executes the executive functions loads the working memory. This content fades away unless it is refreshed by the executive function or becomes consolidated into a long-term memory. For example, when trying to memorize a new telephone number (seven digits), we typically repeat the number over and over again in our minds until it consolidates into a long-term memory. This repetition serves to refresh working memory until the consolidation occurs.

In addition to refreshing the workspace or temporary storage areas of the brain, observation of human mental functioning indicates that executive functions of the brain consist of the following additional activities (LeDoux, 2002):

1) **directing attentional circuits** to attend to specific stimuli and ignore others, as required by the demands of the current task
2) moving relevant information to the workspace from long-term memory (**activating schema** pertinent to the current situation)
3) **planning and executing** the sequence of **mental operations** required by the current task

4) invoking and **scheduling** the participation of specialized brain areas required to process and execute the current task
5) **switching** between brain activities and focusing attention as needed
6) **decision-making**: choosing between different courses of action (confluence between perception of the current situation, cognition of its relevant characteristics, and inference regarding outcomes based on schemas in long-term memory)

Cognitive scientists evaluating the functionalities of the working memory/executive function system noted an analogy between the operation of this system and the operation of a digital computer. For example, long-term memory can be considered as analogous to computer permanent memory or ROM. Working memory can be considered to be analogous to the active memory of a computer or RAM. A computer's operating system (DOS, Windows) which controls the flow of information, scheduling of tasks and the interaction among processing areas of the computer, is analogous to the executive functions of the brain. Information processing therefore became an important metaphor that provided models and guided investigations and experimentation in cognitive science. Reisberg (2006) explains it as follows:

> The computer metaphor provided a new language for describing psychological processes and explaining psychological data. Given a particular performance, say, on a memory task, one could hypothesize a series of information processing events that made the performance possible. In this way, the computer metaphor allowed us to run the Kantian logic: Given a set of a data, one could propose a particular sequence of information processing events as the hypothesized source of those data.

Reisberg (2006) is referring to the transcendental method of philosopher Immanuel Kant (1724 - 1804). In this method, the investigator asks how observations could have come about. The investigator tries to ascertain the necessary causes required to produce the observed effects. As Reisberg (2006) points out, this is the thought process used by a police investigator on a crime scene or by a physicist observing the behavior of an electron. In each case the investigator is looking at visible effects from an invisible cause and is in the position of inferring cause from effect.

Needless to say, the use of a computer as a metaphor for the human brain has its share of detractors who take umbrage to the reduction of the mind to a mechanical device. Here is how I look at it. We cannot reduce the human to a passive, evolutionarily formed entity that operates according to principles of operant conditioning either, as Skinner presumed. Nevertheless, Skinner described an important human behavioral mechanism and contributed to the understanding of an aspect of human functioning. Another aspect of human functioning is information processing. To the extent that the human is engaged in an information processing activity, information theory is applicable and a source of insight. In fact, once we invoke the postulate that an activity consists of information processing, there are logically necessary consequences that emanate from this postulate. The human brain implements this information processing biologically. Once we invoke the postulate that a system is biological, an additional set of logically necessary consequences result. We have discussed a number of them previously. Biological implementations create nonlinear systems. There are additionally logically necessary consequences of nonlinearity. I should point out that a computer is a linear machine. I would also point out that information in the mind is distributed among billions of neurons that constitute a productive system. This distribution implies that the laws of probability and statistics will play a role in human information processing. A full description of the mind then requires consideration of all of these attributes and aspects; this is no small task. We can also see that a computer metaphor is likely to fall short of this requirement. However, as an approximate model of a given functionality, it can and has provided insight into this human activity, as did Skinner's work with operant conditioning. As long as we understand that it is an approximate model that incorporates only certain aspects of a system and that there are more attributes and characteristics than are explicit in the model, we can use the model prudently and intelligently within its specific context. The brain has enormous plasticity and modifies its structure continuously as a consequence of adaptation to experience. In addition, its nonlinear connectivity allows it to self organize to higher logical levels and implement a process such as abstraction. Digital computers do not possess these capacities. When evaluating the mind with any type of limited model, we must always keep in mind, at least qualitatively, the perspective impact of the confluence of qualities and characteristics of the brain and understand that there are emergent phenomenologies that models are incapable of capturing.

The specific operation of the mind's executive function and working memory system has implications for curriculum and instruction. A considerable number of instructional activities involve verbal processing. The mind's working memory holds seven pieces of information simultaneously for a limited period of time. This enables the mind, for example, to hold seven words in working memory while it assembles the relationship between the words. It is the relationship between the words that gives the sentence its meaning. Reading or listening to verbal speech is the process of ascertaining meaning through word relationships. If we, for example, string seven adjectives before we get to the noun of a sentence, we should expect that the individual receiving this information would have great difficulty making sense of it. We have exceeded the holding capacity of working memory. Many of the sentences in this dissertation are greater than seven words long, yet the reader can make sense of them. I hypothesize that what occurs is: as soon as the mind understands the semantic of a collection of words or a segment of a sentence (e.g. phrase), it clears working memory space for the next series of words. For example, consider the sentence: she went to the store with her friends. As soon as we read the first two words, we instantly create the semantic of a female departing for some as yet unspecified destination. Having created this semantic, we no longer require the working memory space and it is available for the rest of the words in the sentence. Having created the semantic from the first two words, we also immediately anticipate the specification of destination and rapidly add it to the original semantic. By the time we get to the final phrase (with her friends), we are likely to have all seven memory spaces still available for processing. We need three spaces to create a semantic for this phrase. The words with and her do not have meaning, given the semantic we have generated thus far for the sentence, until we read or hear the word friends. It is important to note also that the process of creating meaning or creating a semantic involves invocation of and congruence with our inventory of pre-existing schemas or prior sense-making organizations. It is within the context of these schemas that we interpret and make sense of the currently considered sentence. For example, if we hear that she rode her bicycle from New York to Paris, we would immediately dismiss the sentence as nonsense. The reason being that the semantic generated by the relationship of the words in the sentence is incongruent with our schemas for bicycle and the ocean that lies between New York and Paris. Note that, as per Vygotsky (1986), the words are representative and invoking of our conceptual schemas. We could, perhaps, create stability and congruence with prior schemas, and meaning for the sentence, by invoking the thought that perhaps she rode around the deck of an ocean liner on her bicycle, as it traveled from New York to Paris. Best that we know, a bicycle cannot be ridden across a body of water. The point being that the creation of a semantic requires equilibrium with our pre-existing schemas.

A similar phenomenon occurs with collections of sentences, or in comprehending a speech or verbal presentation. If a speaker wishes to confound an audience, he need only present a dozen or so distinctly different ideas without connecting them in any fashion or to express them in a way that is devoid of context, making it hard for the listener to connect or summarize them. A mistake many speakers make is to presume that listeners can connect an idea presented in the first five minutes of their speech to one presented 25 minutes later. Such a speaker forgets that the ideas are already related in his mind, but must be connected, through the presentation, in the listeners mind. In fact, this is the key to presentation: to organize the presentation in such a way that the listener can construct a relationship between the ideas in his mind. As with words, there is a time and space limited retention capability. Sentences must be relationally combined into a semantic at a higher logical level or summarized into a meaning. This greatly facilitates transfer to long-term memory and informs the brain as to where to place this information in memory. To use the computer metaphor, failure to combine sentences or a series of ideas communicated by the sentences, into a semantic is equivalent to placing the sentences of this dissertation into random spots in the memory of a computer. If this were done, it would be virtually impossible to retrieve all the sentences and reconstitute them as a meaningful whole. As we will see when we cover memory dynamics later in the Dissertation, learning with meaning is the most powerful technique for creating recallable and usable memories. An often quoted statistic is that listeners retain only 10% of the content of a 30 minute verbal presentation. I would submit that this could be dramatically improved if speakers relationally combined ideas into a higher logical level semantic periodically throughout their presentations and also summarized, through relationship, these higher-level semantics in their conclusions, so as to communicate the theme or the super-ordinate concept of their presentations. Alternatively, the speaker could articulate the relational structure between the ideas within a context; this would cue the listeners as to how to craft their own relational structure and meaning. The key to learning is the creation of organized structures or relationships that create meaning. For K-12 instructional settings, several auxiliary activities can be highly beneficial. For example, breaking periodically in the presentation and having students organize what they have heard using drawings, sketches or graphic organizers can be of assistance. Note taking is often considered to be of assistance. The problem with note taking is that most students are fully occupied parsing and making sense of the spoken sentences. Note taking is often reduced to transcription and actually strains working memory, as the mind goes back and forth between the listening and writing activities. The idea that students will listen and write only those things that represent important points and summarizations of the presentation is a fallacy. Unless sufficiently knowledgeable of the topic before the presentation, a student generally does not have sufficient knowledge base to know how to create a summary of the information as it is rapidly presented during a presentation. Summarization is a time-consuming activity that generally occurs ex post facto the presentation of the information. To think that it could occur in real time, as the student hears the information for the first time, is presumptive. I believe the sense making process could be facilitated, for example, by giving students a structured handout that contained the main points of the presentation and was configured in the form of an organizer. Student note taking would then consist of drawing connections between the boxes containing the main points, denoting the form of relationships, and writing out to the side or on the top, the summary meaning imparted by the main points connected through this series of interpreted relationships. The construction of instructional methods and tools is limited only by the imagination. The guiding principles relevant to the above discussion are that:

1) Working memory is a limited resource,

2) The fundamental cognitive task is the identification of relevant elements (e.g. concepts) of the task and the relationship of those elements in a way that creates meaning,

3) The process involves the invocation of prior cognitive schema and their modification through assimilation or accommodation – creating a modified schema through enlargement of the number of elements and modification of relationships between them.

Learning activities must be structured in a way that recognizes this process and enables it rather than impedes it. Importantly, as it relates to working memory, activities should allow the closure and consolidation of information into semantic structures or units of meaning before the information is lost or beyond the mind's capacity for retaining and connecting it.

I have no experimental evidence to bolster my claims. I do have four years of recent experience as a student who furiously wrote down most of what teachers said not knowing what was likely to be on the test, straining to think about the content and meaning of what was said, because of the distraction of transcribing, and trying to put it all together after class. I refer here primarily to classes taken outside the College of Education. I kept thinking, as a student, that there has to be a better and more efficient way to communicate and assimilate information. There has to be a more productive and effective use of class time than teacher talk and student transcription. Regrettably, outside of Colleges of Education, teacher talk or lecture is the primary mechanism for information transmission in university classrooms. As Dr. Judy Groulx, a member of my dissertation committee states: "talking isn't teaching."

The functional structure and operation of the executive function/ working memory system has implications for the suite of teacher-student interactional activities that come under the heading of scaffolding. A way to view these activities is as supplementation or compensation of naturally occurring executive functions and working memory interactions. In terms of supplementation, we can view scaffolding as enhancements to the following activities:

1) **attention**: helping students focus on and attend to the relevant aspects of the instructional task and the information within it
2) **invoking long-term memory**: assisting students in recalling and applying their existing knowledge base or schemas to the task at hand
3) **planning and executing**: demonstrating or modeling the process of meaning creation involved in the specific instructional activity
4) **scheduling**: helping students invoke multiple modalities in representing and connecting information (graphic presentation, discussion with peers, drawing, outlining)
5) **switching**: learning is a feedback compensation process involving changing tactics (eliminating some and amplifying others) and the stabilization of meaning structures; teacher intervention can help guide this process

6) **decision-making**: helping students choose among courses of action and understand the inferences and deductions implied by their constructed meaning structures

The above discussion has within it the implicit assumption that **knowledge is a teacher-assisted student construction**. It is not the teacher's knowledge structure directly transmissible to the student via language (spoken or written).

Completing our neurological interpretation of Piaget's stages requires that we look a little more deeply into the anatomical implementation of working memory and executive function. The first individual to implicate the frontal lobe and prefrontal lobe areas of the brain with executive function was Russian psychologist A. Luria (LeDoux, 2002). We discussed some of Luria's work earlier in the Dissertation. While working with soldiers during World War II, who had sustained gunshot wounds to the head, Luria determined that those with damage to the frontal and pre- frontal lobe area were unable to plan and execute goal-directed behavior. In the more recent past, numerous PET and fMRI scans of humans show increases in brain activity in the frontal and prefrontal lobes when individuals perform tasks that require temporary memory storage and executive functions (LeDoux, 2002). All mammal brains have a frontal cortex, but for most, its function is principally movement control. The prefrontal cortex is found only in primates and humans. Tests of neuronal activity in monkeys confirm that neurons in their prefrontal lobes are active during tasks that require temporary storage or retention of information (LeDoux, 2002).

The prefrontal cortex is a convergence zone. It receives input from all the higher-level sensory processing areas, the hippocampus and associated declarative memory circuits, the emotional processing circuits and motor control areas of the brain. In summary, it receives all the necessary informational input required to carry out the functionalities associated with executive control. Functional imaging studies by several groups have shown that the prefrontal cortex is activated when environmental stimuli present a conflict condition, for example, when the word green is presented in red letters and an individual is asked to either name the word or state the color. Separation of visual and language processing systems, which are both experiencing the stimulus, requires executive control and the direction of control to the system processing the task required by the instruction. Patients with damage to the prefrontal lobe cannot perform this separation (LeDoux, 2002). In other tests, researchers determined that activities which required subjects to keep track of two different types of stimuli or to perform two tasks simultaneously activated the prefrontal cortex. A single and separated verbal identification task or visual identification task did not activate the prefrontal area. Activation occurred only when these tasks were combined (LeDoux, 2002). These results confirm that executive functions are being undertaken in the pre-frontal cortex.

The connective pathways involved in visual processing are fairly well understood. Recognition of objects occurs in a temporal lobe area directly connected to a high level processing area of the occipital lobe (visual processing area). This occipital-temporal area is called the "what" area of the brain. Determination of the spatial location of an object relative to other objects in the visual field occurs in a parietal lobe area termed the "where" area of the brain. The end-stage of both the "what" and "where" areas are directly connected to the prefrontal cortex (LeDoux, 2002). Researchers have determined that, in monkeys, neurons in the prefrontal region are active during delay periods in both spatial position tasks and object identification tasks, indicating that neurons in the prefrontal lobe provide a temporary storage function.

There are pathways back to the visual processing areas from the prefrontal cortex that inform the visual areas to attend to and stay focused on the objects and spatial locations currently being processed in working memory (LeDoux, 2002). Attentional signals from the prefrontal cortex, therefore, control activity in the lower-order visual areas and determine which stimuli are processed, in top-down fashion.

Similar types of relational structures have been found by other investigators for the other sensory processing functions (LeDoux, 2002).

Imaging studies indicate that different aspects of executive function, like stimulus response selection, conflict resolution, and decision-making, engage different areas of the prefrontal cortex to different degrees. This implies that executive function is a distributed system. Executive function may be achieved through an interconnection of circuits spread over several prefrontal lobe areas. Areas implicated in working memory and executive function include: 1) the lateral prefrontal cortex (outside surface of the prefrontal cortex), 2) the medial prefrontal cortex and anterior cingulate cortex (inside surface of the prefrontal cortex and proximal areas) and 3) the ventral prefrontal cortex (implicated in emotional processing). These areas are extensively connected and could easily act in a distributed fashion contingent upon the specific demands of a task (LeDoux, 2002).

Researchers have found evidence that the temporary storage aspect of the working memory/executive function system may be domain specific. I believe that behavioral evidence bears this out. Young children demonstrate working memory for language processing very early. Piaget's descriptions of pre-operational children (ages 2 -7) indicate that they operate on single representational images. I hypothesize that this indicates that working memory for multiple declarative memories has not yet fully developed. In fact, **I hypothesize that the emergence of Concrete operations is the result of the maturation and development of working memory for the temporary storage of declarative memory representations**. This capacity enables abilities such as the consideration of transformations rather than reliance on static images, transitivity relationships, reversibility of action sequences, and the formation of rules (logical operations) derived from relational invariance manifest in transformations (reflective abstractions).

There is one human intellectual capacity that is left to neurologically account for: abstract rationality. This is the capacity which separates us from primates (Bonzi and Bonzo).This is also the transition from Piaget's Concrete operations to Formal operations stages. Regrettably, we run out of evidence from neuroscience to account for this transition. The pieces of hardware we possess that Bonzi does not are the lateral pre-frontal lobe and language processing circuits. I would like to propose a hypothesis that relies on the work of Vygotsky. Vygotsky (1986) noted that egocentric speech, which directs thought in the younger child, becomes inner speech. Inner speech directs thought through words which are representations of concepts or dense semantic units in their inner speech incarnation. As Vygotsky (1986) points out, these concepts are abstracted characteristics related by logical (judgment derived) relationships. They are the manifestations of abstract rationality. As discussed previously, they can also be characterized as rules expressing invariant relationships. This generalization would interpret a word like fish to have implicit within it the rules as to what constitutes a fish (has fins, swims, etc). It is in this way that we can synonymously view rules and concepts. I hypothesize that the lateral pre-frontal lobe functions as a working memory/executive function that operates on the product of lower level executive function/working memory systems. These memory systems produce concrete rules (physical elements connected through perceived invariant relationships). I hypothesize that these rules can be stored in the lateral prefrontal cortex, compared and related. The lateral pre-frontal cortex, however, utilizes the representational capabilities contained within the verbal processing system. A word can represent an object, the content of a single event, the content of a series of related events or an entire culture. I hypothesize that the lateral pre-frontal cortex exploits this capacity through reciprocal connectivity with the language systems of the brain. The fact that the stored units in the lateral prefrontal cortex are rules (concrete concepts) facilitates the ability to abstract and create perceived invariant relationships between concrete rules or, in other words, the ability to abstract relationships themselves. These abstracted relationships are then given a designation as a word. Please note that what is being abstracted and generalized here are relationships (rules). The classification or categorization created is: x equals all things conforming to a specific relationship or rule. Note also that this creates the capacity for metaphor and analogy.

Let us construct an example. Let's say that we conduct an experiment whereby a stationary billiard ball of known mass is struck by another billiard ball of known mass and velocity. Both billiard balls move on a surface which is virtually frictionless. Subsequent impact, the originally stationary billiard ball begins to move with a certain velocity. The impacting billiard ball continues to move, but with less velocity. We consider two characteristics or variables: mass and velocity. We look at the state of these variables before and after impact and attempt to create a concrete relationship that connects the state of these variables before and after impact. Sure enough, there is an invariant relationship between states before and after impact that summarizes the events. The relationship is that the mass multiplied times the velocity of the moving billiard ball before impact is equal to the sum of the mass times the velocity of the two billiard balls after impact. At this stage, we have a concrete relationship or rule. Let us now repeat this experiment a number of times, each time changing either the mass or the velocity of the impacting (initially moving) billiard ball. We will, as before, attempt to ascertain whether the events can be articulated in terms of an invariant concrete relationship for each experiment. We could also vary the mass of the stationary billiard ball and do likewise (look for an invariant relationship). We now look at all of our experiments in aggregate, to see if there is a relationship between all of the experiments considered together. Note that we are looking for a relationship between concrete relationships (relationship of relationships). Our summarizing activity has generated a new metric or parameter: mass multiplied by velocity. In that this constitutes a relationship between these two variables, it exists at a higher logical level. We can exploit language’s capability to represent and name this specific relationship. Let's say that we call it momentum. Using our new metric to summarize the changing masses and velocities, we find that the relationships of all of our experiments results in a generalizing relationship that is invariant and summarizes all of our concrete relationships. This relationship can be articulated in terms of our new parameter or metric: the combined momentum of objects before impact is equal to the combined momentum of objects after impact. Again, using our language capability, we summarize this as conservation of momentum.

Let us note several things about the above process. First, our initial relationships were concrete and based on physical measurements or observables. I cheated a little bit, in that mass and velocity are in fact abstractions and not directly physical observables. If we assume that the experimenter has a scale and a radar gun, then we can consider them physical observables for purposes of the experiment. When we combined our "observables" to create an invariant concrete relationship, a specific combination of our observables, mass times velocity was **emergent** as a recurrent **parameter**. We "chunked" this parameter and gave it a name or verbal representation: momentum. When we considered all of the experiments collectively or the sum of all of the concrete relationships, we abstracted our emergent parameter as the element of our relationship of relationships. We were then able to create an invariant relationship summarizing or generalizing the collective concrete relationships using this element. Importantly, what we generalized were relationships: relationships generalized in the context of our emergent parameter. My hypothesis is, then: **abstract rationality is the generalization of relationships and the chunking or representation of these generalizations through language**. In this visualization, the lateral prefrontal cortex provides the relational mechanism and the language processing function supplies the chunking mechanism or **representational form** for the working memory segment of the lateral prefrontal cortex executive function. In other words, **words are the representational structures** – the chunks of working memory. These language represented generalizations are the concepts, theories and principles of abstract rationality. They constitute the **rules** by which we undertake rational thought. Rather than summarizations of sequences of visual images (concrete observations), they are summarizations of relational structures. In this sense, we can understand Vygotsky's (1986) premise that language directs thought. Another thing to note is that **generalizations of relationships are not physical observables; they are mental constructions and stabilizations of relational structures**. We cannot see, hear, feel or touch equilibrium, conservation, or adaptation. We can only represent them verbally. I stand by my original premise that a justifiable characterization of development is the change in the nature of representation of a cognitive organization and the nature of relationships within that organization.

We still have a bit of a "chicken and egg" problem here. Does the executive function of the lateral prefrontal cortex enable language's capability to represent concepts or does language's capability enable the lateral prefrontal cortex to operate on working memory chunks that represent concepts. The solution to this problem involves getting away from the notion of linear causality. As the systems are biologic and reciprocally connected, they constitute a nonlinear system. I hypothesize that the two systems achieve a state of dynamic equilibrium through self organization. Once effectively connected, they collaboratively interact in a manner that autopoiesis is maintained within each system (each fulfills its function), a structure at a higher logical level (that of abstract rationality) is emergent, and a new functionality is created.

My hypothesized neurological explanation then for Piaget's final stage of development is the connection and solidification of circuits in the lateral prefrontal cortex with those in the language processing area. Piaget (Wadworth, 1989) characterizes Formal operations in terms of the ability to use reason and logic to solve problems, free of the requirement for direct physical experience. This capacity begins at around age 12. Interestingly, several studies have concluded that no more than half of the American population develops all of the capacities of Formal operations (Kohlberg & Mayer, 1972). During this stage, the ability to solve verbal problems involving propositions, hypothetical problems and problems involving projections into the future emerges. Children in this stage of development are capable of metacognition, have full consciousness and introspection. They can think of their own thoughts and feelings as objects and evaluate their own thought process. They can employ theories and hypotheses when solving problems. They have the ability to bring several intellectual operations to bear simultaneously when solving problems. Children in the prior stage, Concrete operations, cannot integrate solutions into a general theory. Each problem is solved in isolation using a single mental operation uncoordinated with other operations.

Piaget and Inhelder (1958) discuss several types of reasoning as being characteristic of Formal operations. Children in this stage are said to be able to undertake scientific reasoning and hypothesis building. Inhelder and Piaget (1958) conclude that children, at this stage, form hypotheses, experiment, control variables, collect data and form conclusions from their results in a systematic manner, much like scientists. This reasoning process also shows the ability to reason about a number of variables at one time. This contrasts with concrete operational children who can only consider a single variable and causes directly determined from observation. Formal reasoning is exemplified by the creation of relationships between variables constructed through an inductive reasoning process and verified through experiment (Wadworth, 1989).

Another reasoning capability characteristic of formal operations is hypothetical-deductive reasoning. This reasoning involves deducing conclusions from premises that are hypotheses rather than the facts of experience. Using a concept, theory or rule, the individual can infer or conclude the necessary consequences that follow from the premises. They can also do this for problems that are purely hypothetical in nature and not currently experienced. Another feature of this type of reasoning is the ability to reason about hypotheses that are known to be untrue. Wadsworth (1989) provides the example of a logical argument that is prefixed by the statement "Suppose coal is white". The concrete operational child will immediately declare that coal is black and the question cannot be answered. The child with formal operations will accept the assumption and proceed to reason about the logic of the argument. He exhibits the ability to evaluate the logical structure of the argument independent of the truth or falsity of its content, according to Piaget and Inhelder (1958).

A third type of reasoning exhibited at this stage is reflective abstraction. Discussed previously, reflective abstraction is the construction of logical mathematical knowledge from reflection of the transformations that occur consequent to physical or mental actions on objects. Reflective abstraction transcends the observable and results in relational knowledge and characteristics derived through relationship that are not physically manifest in the objects themselves. One of the facilitation's of reflective abstraction is the ability of children at this age to learn through analogy. Analogy is a comparison of relationships and transcends what is observable. According to Piaget (Gruber & Voneche, 1995) analogy relationships can only come about due to reflective abstraction.

Inhelder and Piaget (1958) take the position that reasoning during formal operations is similar in many respects to the propositional logic used by logicians. Note that this is in keeping with one of Piaget's founding postulates. As I stated previously, this assumption is probably the Achilles' heel of Piaget's theory. In actuality, it turns out that errors in abstract logical reasoning are ubiquitous and well documented in the cognitive science literature (Reisberg, 2006). For example, Chapman and Chapman (1959) gave research participants a number of syllogisms including: all A are B, all C are B, and therefore, all C are A. The answer to this syllogism is false because the set B can be large enough to contain both A and C without overlap between the two sets. A total of 81% of the participants said that the syllogism was true. Two types of consistent errors that cognitive scientists have documented concerning human error on logical reasoning problems are called **matching strategy** and **conversion errors**. A matching strategy error occurs whenever an individual endorses a conclusion as true if the words in the conclusion match those in the premises. Conversion errors occur when people interpret all: A are B as equivalent to all B are A. They are presuming here that the sets are identical and can be converted to each other. Either one of these errors could account for the 81% incorrect answers cited above. If people are given a logically equivalent syllogism in concrete terms such as:

All Christians are humans

All con-men are humans

Therefore, all Christians are con-men,

they will conclude correctly. This brings up another artifact of logical thinking termed **belief bias**. If the syllogism's conclusion is something people believe to be true they will judge that the conclusion follows logically from the premises (Oakhilll & Garnham, 1993). Conversely, if the conclusion is something they do not believe, they will reject it as invalid, regardless of the underlying logical structure of the argument. It is clear to me from the above that people's **reasoning is dictated by the semantic content of the premises** rather than underlying logical structure. It is based on their schema for the words in the sentence and the meaning created through the relationship of the words in the sentence, as well as the congruence of this meaning with their prior knowledge.

Common logical errors involved with conditional statements include: affirming the consequent, denying the antecedent, and a generalized difficulty with modus tollens constructions. Some studies have documented error rates for people drawing conclusions from conditionals, as high as 80% or 90% (Reisberg, 2006). Reisberg (2006) summarizes the situation as follows:

> This seems highly problematic for the claim that logic reflects the way people think. Instead the evidence is driving us toward the view that thought is influenced by the content, the **meaning**, and the pragmatics of the material we are contemplating (P. 448).

Regrettably, it appears that propositional logic is something we must learn in school, like calculus. We can agree with Piaget that Formal operations represent logical thinking if we consider the logic to be implicit within the relational structures of the concepts, theories and rules constructed during this stage.

The logic is in the semantic (meaning). Perhaps a better characterization of this stage is the stage of concept or rule-based thinking. This would coincide with Vygotsky's (1986) position.

Cognitive Psychology

The next area to be reviewed is the raging debate in psychology concerning whether humans have one or two systems of reasoning. The seminal, often quoted, summary paper on this subject is that of Steven Sloman (1996), *The Empirical Case for Two Systems of Reasoning*. Sloman (1996) begins the drama with none other than William James (1982), who describes two systems of thinking. He describes associative thought as empirical and consisting of "trains of images suggested one by another." An example of this type of reasoning is the creation of a design. Here, images old and new are compared and contrasted to provide a basis for ideas. He felt that this type of reasoning was simply a representation of elements or, at best, consisted of empirical abstractions from past experience. As such, there must be another system which is productive and can deal with novel data and unprecedented situations (James, 1982).

In modern contexts, James' (1982) intuition is expressed by two competing schools of thought. One group of adherents visualizes an associative system which utilizes similarity and temporal structure, while the other espouses a rule-based system operating on mental representations. Here again, we have another unnecessary dialectic that appears to be a circumstance in desperate need of Bateson's strategy of searching for the pattern that connects. What makes such a synthesis difficult to achieve is that each faction has extended and modified its system over time to the point where the system can model and explain a large amount of experimental evidence. For example, the associationists have evolved recurrent connectionist networks that exceed the capacity of a rule-based Turing machine. Recall that a Turing machine has the capacity to implement any algorithm (Church's Theorem) (Morton, 2003).

An associative system works as follows. Such a system encodes statistical information from the environment: frequencies, distributions, and correlations. The system divides perceptions into reasonable clusters on the basis of quasi-statistical regularities. The degree to which an association is made is proportional to the similarity between the current stimulus and the associated prior stimuli. Rather than relying on causal or mechanical structures, inferences are based on statistical structures like similarity, variability and co-variation. An example of such reasoning is forecasting weather. When the weather person says that there is a 30% chance of rain, he is saying that, historically, when measurable variables like pressure, temperature and humidity were as predicted for the succeeding day, it has rained about a third of the time. Associative systems can exhibit rule-based attributes. For example, the rule: if an object has wings (X), then it can fly (Y), can be generated associatively as the contingent probability of Y given X (Sloman, 1996).

As observed by James (1982), mental processing exhibits a productive as well as a systemic nature. Theorists such as Fodor and Pylyshyn (1988), as well as Chomsky (1968), have postulated rule-based mental systems, wherein mental representations are processed in accordance with a syntax or set of combinatorial rules which impart logical structure. Please note that this was Piaget's (Gruber & Voneche, 1995) position also. Such systems are productive in the same sense as language or DNA. In our language, 24 letters are combined in different arrangements to produce an enormous number of words. These words, in turn, are combined according to a grammar/syntax (set of rules) to express a virtually unlimited number of ideas. These systems are systemic in the sense that they exhibit reversibility, flexibility and readjustment. For example, one can reason about how Larry feels about Linda, as well as how Linda feels about Larry. In addition, new information about their relationship will create a systemic adjustment to this reasoning (Sloman, 1996). If representations are abstract, such a system creates the flexibility to alter the values or attributes of the representation and perform "what if" analysis. In addition, abstraction facilitates transference among domains of application. As such, rule-based systems describe a wide range of human mental performance.

The problem for reconciling these two systems is the existence of sufficient experimental evidence to confirm or condemn either perspective. If mental systems are rule-based, we should expect either a -priori mechanisms for logical constructions or a developmentally derived capacity, as postulated by Piaget (1954). The experimental evidence, however, shows that humans perform very poorly on tests of logic. People do relatively well on tests of modus ponens, or: If A, then B; A; therefore B. Modus tollens, or: If A, then B; not A, therefore not B, poses problems, as do more complicated relationships involving multiple connectives or negations. In tests involving abstract logical reasoning devoid of context, errors in logic are typically on the order of 80% to 90% (Reisberg, 2006). [This material is repeated from the prior chapter so that this chapter can be stand-alone]

There are three types of errors: believe bias, matching, and conversion (Reisberg, 2006). Matching errors occur when individuals endorse the conclusion if the words in the conclusion match those in the premise. For example: all A are B, all C are B, therefore all A are C. In context, this would produce: all plumbers are mortal, all sadists are mortal, and therefore, all sadists are plumbers (Reisberg, 2006). Believe bias is the term that describes the fact that people will judge the conclusion based on their beliefs rather than the logic of the argument. Conversion occurs when people interpret statements like: all A are B, as A=B. Out of context, the possibility that A is a subset of B does not come to mind. In summary, the experimental evidence does not support the existence of either an a-priori or a developmentally created logic processing capacity, devoid of context. In fact, I think Bateson's (2002) position that knowledge exists in a context and is judged by the evidence relevant to the context is the epistemic demonstrated by the data.

The prominent theories in support of rule-based mental processing emanate from Johnson – Laird (1975), Braine (1990) and Rips (1983). All systems share the characteristic of a sequential application of formal rules of inference. The ease with which subjects use certain logical constructs (modus ponens, for example) led these theorists to the conclusion that the mind must contain corresponding rules of inference. This position is expressed by Rips (1983):

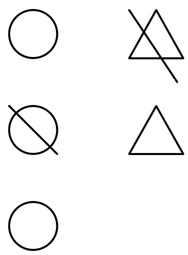
> … Deductive reasoning consists of the application of mental inference rules to the premises and conclusions of an argument. The sequence of applied rules forms a mental proof of the conclusion from the premises, where these implicit proofs are analogous to the explicit proofs of elementary logic (p. 40).

Rip's (1983) position expresses what is termed a proof- theoretic approach to explaining deduction, wherein formal rules of inference are used to derive conclusions from premises in a syntactic fashion. Please note the, in my estimation, **problematic assumption** implicit here is the existence of an a-priori or developmentally constructed logic processor. The systems vary in the specific rules used to model reasoning and the mechanics of how the rules are invoked.

Problems, such as those cited previously, led Johnson- Laird et al. (Johnson-Laird, Byrne, & Schacken, 1992) to abandon their earlier model and to develop a model- theoretic method of reasoning based on **semantics rather than syntax**. The new premise is: **deduction does not depend on a syntactic process that uses formal rules but on procedures that manipulate mental representations**. Semantic processes construct representations (models) of the premises, formulate parsimonious conclusions from them, and test their validity by ensuring that no alternative representations (models) refute them. Models have a structure that corresponds to the structure of the situation. Verbal premises or perceptual observations are used to construct a set of mental models, typically a single one. The model is constructed on the basis of **meaning (semantic)** and any relevant general knowledge. In the case of observations, the model is a transform (representation) of the physical world. Next, an attempt is made to formulate a conclusion from the model. The conclusion will **express information that is not directly expressed by the premises**. During this process, all semantic information is retained. If a conclusion cannot be formed or requires extension beyond what is explicit in the premises, the subject reports that nothing follows. Lastly, the conclusion is checked to see if there are alternative conclusions that can be formulated from the model. If not, the conclusion is viewed as correct. If such an alternative does exist, then the process is iterated. If no definitive conclusion can be reached, a tentative conclusion is made on a probabilistic basis [based on associational inference, in my estimation].

Considering deduction is a conscious process, it is subject to the limitations of working memory. This implies that reasoners limit the amount of information represented explicitly in the model and represent as much information as possible implicitly. In addition, the use of symbolic expression where possible, is inferred.

The following example illustrates how the model works. The reasoner is presented with two premises: there is a circle or there is a triangle, and there is a circle. The reasoner constructs [subconsciously and neurologically in my estimation - Johnson- Laird et al. (1992) seem to imply that this may be conscious] three separate representations which reside in working memory: one in which a circle exists and there is no triangle, one in which a triangle exists and no circle, and finally one that is a circle. A scan of the model for a conclusion not directly stated in the premises would reveal that there is not a triangle. The reader should note that this is a **similarity comparison or a check of invariance among the contents of the spaces in working memory**. The system of models requires that the model for no circle and a triangle be eliminated since it is inconsistent (represents a difference or variance) with the second premise. The information that there is a circle is incorporated in the remaining model to produce a single model (assimilated as congruent or invariant). From the single model, the conclusion: “there is not a triangle” results. In this sense, the process is a synthesis of initially separate models into a single consistent model by addition and elimination of models and a subsequent scan for conclusions. The model as described retains semantic content, semanticizes the connectives as the number of models required to specify all of the states of the represented objects and thereby creates what is in effect an iconic truth table of object states. The goal seems to me, to be the creation of a consistent set of iconic representations, wherein an icon cannot be in more than one state. Johnson – Laird, et al. (1992) represent the above process as follows:



Model 1: circle, no triangle

Model 2: triangle, no circle

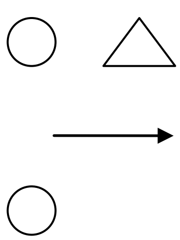
Model 3: circle

Process: 1) eliminate model 2 – it is inconsistent [dissimilar] with model 3

2) Consolidate model 3 into model 1 [on the basis of similarity]

The conclusion then results: there is no triangle. There is no alternative model of the premises that refutes the conclusion, so it is considered true. The conclusion emerges from a semantic procedure [similarity comparison] that evaluates the models based on the meaning of the premises. While depending on rules, they are not the formal rules of logical inference. They are the rules of relationship implicit in the semantic.

A conditional is modeled as follows. If there is a circle, there is a triangle; there is a circle; has the following representation:

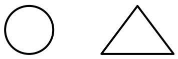


Model 1

Model 2 – placeholder; premises do not specify all the states of the objects

Model 3

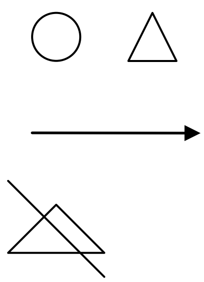
Process: 1) model 3 conforms to model 1 and is consolidated to yield:



A conclusion not explicit in the premises, that there is a triangle, is reached. Again, there is no other alternative that satisfies the premises; therefore the conclusion is viewed as true.

The case where a negation exists in the second premise is modeled as shown below:

1) if there is a circle, there is a triangle
2) there is not a triangle

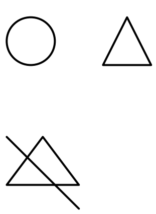


Model 1

Model 2 –placeholder; incompletely specified state

Model 3

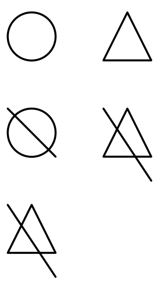
Process: 1) add model 3 to model 2 as a partial specification of the incompletely specified Model 2



Model 1

Conclusion: Since there is not a match of states in the iconic truth table, the conclusion is: nothing follows.

This conclusion is incorrect. In order for a correct modus tollens conclusion to be drawn, the models must exhaustively represent the states. Most individuals will incorrectly answer abstract logical questions in the manner illustrated above. A correct modus tollens conclusion requires the recognition that: if there is a circle, then there is a triangle, also means that if there is no circle, there is no triangle. This recognition yields the following model and the correct modus tollens conclusion.



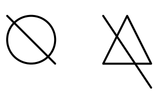
Model 1

Model 2 - implied by premise 1

Model 3

Process: 1) eliminate model 1, as inconsistent [dissimilar]

2) Add model 3 to model 2 [combine on the basis of similarity] to yield:



Correct modus tollens conclusion: There is no circle.

We can see the benefit of context in the above process. If the premise is of the form, if it is raining, then the baseball game will be canceled, and it is not raining, a correct modus tollens answer is evoked: the game is not canceled. In this case, the reasoner's past knowledge of the relationship of games and rain (the nature of relationships in this context), evokes the necessary negation model (model 2 above) - no rain, the game is on. Contrast this with: if A then B; which has no context whatsoever. It is not surprising that people, who are not formally trained in logic, do not immediately form the relation, if not

A then not B. There is no context from which this logic can develop, hence the mental models are incompletely specified, and poor logical conclusions result.

The previous discussion solidifies Bateson's (2002) epistemic that knowledge, constructed by the individual, occurs within a context and is predicated on the relationships within that context. If we accept Johnson – Laird et al.'s (1992) model of deduction, we find that Bateson's premise is true by virtue of the mechanics of mental processing.

Johnson – Laird et al.'s (1992) model addresses and explains virtually all of the experimental artifacts previously mentioned: believe bias, conversion and matching. In the above cited paper as well as their more recent paper (Johnson - Laird & Goodwin, 2005), Johnson – Laird and Goodwin report great success in matching both classical experimental data from other researchers, and their own experiments, with a computer implementation of their model. In their most recent paper, five principles were reported as emergent:

1) The structure of mental models is iconic as far as possible.
2) The logical consequences of relations emerge from the models constructed from the meanings of relationships and from prior knowledge.
3) Individuals tend to construct a single typical model.
4) Individuals develop their own strategies for relational reasoning.
5) The difficulty of an inference depends on the process of integration of information from separate premises, the number of entities that have to be integrated to form a model and the depth of the relationship.

The results of the rule-based camp, however, do not address the entire range of observed human reasoning behavior. For this, we must return to the associationists and accommodate a dualistic conception of reasoning. Let me state that the **above model of Johnson Laird et al. is seminal to the**

thesis of this Dissertation. In the prior chapter, I took the position that the logic of a mental organization or schema was implicit in its conceptual representation, or moreover, its relational structure. The **logic was in the semantic** (meaning) created through relationship of elements. Adopting the above model, which would be straightforward to implement neurologically, allows me to envision and model a reasoning process which is free of separately existing logical mathematical structures, syntax, or specialized a-priori mental hardware. To say it colloquially: "I**t's all about the semantic."** This conclusion also allows me to explain the experimental results of psycholinguistic research and to accommodate requirements imposed by the principles of information theory (to be discussed later). That rule-based mental processing occurs according to the above model is a seminal conclusion and constitutes an important building block in my proposed epistemological scheme or model of the learning process. I am using this model for explanation at a neurologic level and not a conscious level. I do not believe people conceptualize little triangles and circles in their minds consciously.

It is clear that many reasoning tasks involve associations and are virtually free from conscious rule-based reasoning. Sloman (2005) provides a good example. Decoding the anagram *involnutray* happens automatically by association, without any conscious effort. We automatically know the answer to be involuntary. The anagram *uersoippv* (purposive), however, requires invocation of a rule-based conscious process, like putting each unique letter first and mental permutation of the other letters in sequence. Unlike the first anagram solution, you are consciously aware of the process, and it involves rules. The literature is replete with examples where both systems of reasoning are invoked. For example Ross (1989, as cited by Sloman, 2005) showed the successful use of a strategy to teach probability theory required the iterative application of similarity-based retrieval as well as rule-based inferences. This research, as well as the research of others, reflects a subtle connection between associative and rule-based reasoning in many cognitive tasks, as well as both conscious and subconscious processing. For example, many report innovative rule-based solutions to problems that come to mind spontaneously when they are consciously engaged in other activities, such as relaxation (Nesbitt & Wilson, 1977, as cited by Sloman, 2005).

In a certain respect, we can view the two systems as two separate circuits, one parallel and simultaneous in processing associative patterns, and the other serial in examining properties and making decisions sequentially, according to rules. Smolensky (1988) summarizes the same perspective. In his proposal, two systems exist, the conscious rule interpreter that algorithmically processes rules which can be described using a symbolic language and an associative system that matches patterns. In his view, the rule-based system processes knowledge in the form of production rules or instructions in the general form: If the condition is satisfied, then perform some action. Smolensky (1988) states only a portion of our total knowledge base comes in contact with the rule-based interpreter. It is the portion that is publicly accessible and can be hence verified; it is the part that is formal and symbolic [expressed through language]. In essence, it is the part that exists as a part of our cultural community.

This is very close to Vygotsky's (1986) conclusion. For Vygotsky, language is the mechanism through which concept formation, abstraction, and ultimately all thinking, occurs. Vygotsky would differ from Smolensky in excluding any knowledge from ultimately being symbolically represented and subject to rules and formal manipulation. Vygotsky (1986) theorized that all learning is initially associative. As language develops and formal instruction occurs, the socially and culturally transmitted rules and systems of a society are internalized and form the templates into which associations are organized into concepts and ultimately represented by words. For Vygotsky (1986), words are the placeholders of associations organized into mature concepts which have relational structure-subordinate, ordinate, and subordinate hierarchical construction. Vygotsky would agree that rules operate on knowledge that is socially constructed and transmitted. He would argue, though, that such knowledge is not a restricted subset of what we know.

For Vygotsky (1986), abstraction, representation and relational manipulation represent the teleos of development. This is all accomplished by inner speech (in the conscious mode) which serves as representation of the rule-based processing system. Since language is socially constructed, this forms the Vygotskian posture that all knowledge is ultimately socially constructed, a position subsequently adopted by all social constructivists. To summarize, the representations of rule-based systems are words which connect to associations organized according to socially transmitted (through life and formal instruction) templates.

Smolensky's (1988) intuitive processor is separated from his rule-based processor, as previously described. It operates at a sub-conceptual level, a level more atomic. Representations at this level are distributed in the sense that concepts for Smolensky are represented by one or more patterns are constructions from a distributed network and hence participate in a productive system, each of which has features that can participate in a number of other patterns or concepts. For example, wings can participate in airplane, bird, or even automobile patterns. Sub-conceptual representations have four advantages: 1) They allow more information to be coded into a single representation, 2) They represent some of a concept's internal representational structure, 3) They provide simpler and faster processing since they mainly associate and generalize (by virtue of association); The analysis is part of the representation, that is, required (relational) information is in what is processed and not part of the processor. The disadvantage is the analysis is limited to what is represented (no "what if" analysis is facilitated as when there is true conceptual or abstract representation). Finally, 4) They **generalize automatically on the basis of feature overlap** and by definition connect through feature commonality. This is the basis of associational inference (for example, "where there is smoke, there is fire"). It should also be pointed out that sub-conceptual representations are context dependent and include the features of not only the object but the context in which the object exists. This results from the fact that they are formed from declarative memories and retain the links of these representations.

From discussion above, and from the descriptions of the nature of exemplars and prototypes as exemplified in numerous experiments (Rosch, 1978; Reisberg 2006), I hypothesize as follows: As we experience numerous examples of objects associated (and therefore categorized) under a linguistic specification (logical type), and since the brain internally represents these examples as relationships among features, those features most commonly and therefore frequently occurring become most strongly consolidated and solidified (long-term potentiated) in accordance with Hebb's hypotheses. Let us take the example of birds. Under this linguistic representation or category, we experience tens of thousands of examples of commonly occurring birds such as robins, sparrows and blue jays. We rarely experience eagles or ostriches. In that representations are mental re-creations or the re-experiencing of the neurologic activations (representations) evoked by the original stimuli (re-created through the relational mechanisms of the hippocampus), the re-creation invoked by the word bird will be a re-creation of those features most strongly potentiated (consolidated, stabilized) by prior experience or a prototype or exemplar of the class. This explains why the word bird almost subconsciously creates within us the image of something like a robin and not an ostrich. The evoked image can be either a prototype or exemplar contingent upon our perception of the requirements of the cognitive task. As discussed before, neuronal representation occurs within a distributed system in which features are encoded and subsequently recombined. Certain neurons participate in reconstructions in accordance with the features they encode. The more frequently used features are the ones most strongly potentiated (stabilized). They are also the ones more strongly connected to other features, as a result of their frequent activation. It is in this way that the system takes on a **statistical or probabilistic character: The level or degree of potentiation is directly related to the number of times a specific stimulus is experienced (frequency distribution)**. I also hypothesize that neural networks configure in such a way as to create the most efficient organization. The implication here is that **connectivity springs from and is centered on the most frequently occurring feature(s)**. For example, spherical shape is likely to be the feature upon which other features, invoked in connection with the word ball, are centered on. This is why thinking of the word ball is unlikely to render an image of a rugby ball without conscious effort (except in Australia, perhaps). This hypothesis has instructional implications. In assisting students with the process of building new concepts or mental organizational structures (schemas), the best strategy is to build from elements and relationships the student has most frequently encountered in the past. The best analogies will be the ones most firmly ingrained by prior experience. For example, sports analogies should be very useful with middle school and high school children.

Smolensky (1988) summarizes: "The intuitive processor is a sub-conceptual connectionist, dynamical system that does not admit a complete, formal, and precise conceptual level description" (p. 7). Intuition, which I believe is subconscious, linked association, is attributable to this system. Also, by nature, logical necessity is not evolved directly by the system. It would of necessity to operate more in the probabilistic fashion previously described for associative systems. Logical necessity is a manifestation of the rule-based system. I hypothesize that this occurs when the executive function areas of the brain operate on representations that are incarnated as either concrete or abstract concepts.

It is straightforward to see how exemplars and prototypes are evolved from such a system. The use of exemplars and prototypes in reasoning is strongly documented in the research literature on concept formation (Reisberg, 2006). Rosch (1978) provides a good summary. Exemplars and prototypes (reconstituted physical representations) however, must be augmented by the invocation of **theories** to account for the results documented in many concept application experiments (Reisberg, 2006). While people use exemplars and prototypes to quickly, and in some cases tacitly, solve problems, for example: is an ostrich a bird? (this involves a similarity relationship between ostrich and the bird prototype), this strategy represents a heuristic. For certain problems, reasoners exhibit that they have previously formulated **explanatory theories** consisting of a network of beliefs or linked concepts. For example, to understand counterfeit money, one must understand the concepts of money, governments and crime. These concepts are then linked into a theory. There is no direct perceptually originated association for counterfeit money. The understanding of counterfeit money invokes the conceptual or rule-based system (Reisberg, 2006). Again, depending on the task, it appears that two systems or processes are involved.

From the above discussion, I have generated two theories. First, I believe that the two systems are co-existent throughout life. The use of one or the other, or both in tandem, is conditional on the circumstance encountered or the requirements of the cognitive task. As documented by Piaget (1952), the rule-based system is developmentally contingent. However, in contrast to Piaget, I believe that rather than evolving to the use of a purely rule-based system, adult thinking is a synthesis of both systems contingent on the context or circumstances of the environment in which individuals find themselves. For example, new information (educationally or occupationally) must begin in the associative system before it can be processed by the rule-based system, regardless of age or experience. The new information requires a context and a relationship with what is previously known. In this sense, I find coherence with Bateson's (2002) position that knowledge is constructed by the individual, knowledge is constructed in context, meaning is created through relationship and all initial knowledge is subjective. I believe rethinking any proposition or undertaking a creative activity requires dropping back to the associative system to take advantage of the four attributes previously cited. I think artists predominantly operate within the associative system.

Pedagogically, the previously described dualism contributes to an understanding of why it is much easier to understand a concrete example than an abstraction. It also explains why a **dual process of inducing an abstraction from a concrete representation and subsequently deducing additional concrete examples from the inducted abstraction, is preferable and more successful instructionally than simply teaching an abstract theory**. For example, Bateson's (2002) premise that logic is a poor model of cause-and-effect is virtually impossible to comprehend without the benefit of an example. I spent many years as a manager in the workplace giving people theories and being perplexed as to why they were not carried out or acted upon. Ultimately, I empirically came to understand the value of concrete example and the benefit of induction of theory from a pattern among examples, as a preferable communication mechanism.

Two systems of associative thinking need to be described to make more comprehensive our inspection of research bearing on reasoning. Let us first describe Parallel Distributed Processing, the currently preferred mode of computationally representing mental processing in the cognitive science community. In PDP, all the relevant attributes of a problem--characteristics, beliefs, hypotheses, facts, goals, and sub-goals-- are represented by units or nodes. A network is then constructed to solve a problem by putting connections (associations) between these nodes to represent relations between problem features. If attributes are supportive, like a hypotheses and a fact, then positive excitatory connections are put between them. If two features are contradictory, such as conflicting hypotheses, an inhibitory connection is made (circuit deactivated). Each unit is a variable that takes on quantitative values. The set of all unit values is conceptualized as a vector. What this means is a state, like a position whose state is specified by its x, y, and z coordinate values. The system is dynamic, in that its units and vectors change value in time. The vector evolves according to a set of activation equations after being initialized by activating all those units that represent problem-relevant knowledge. The network dynamically sends activation back and forth until it stops and reaches a state called coherence, minimum energy or maximum harmony. If all goes well, the state represents the desired inference or the result of a constraint satisfaction process defined by the activation equations (Sloman, 1996).

Hinton (1990) has proposed an alteration to the above conceptualization, to create a combinatorial association and rule-based model. His position is that a single settling of a PDP model into coherence represents a single association. Real-life thinking involves multiple "settlings" of intuitive associations, guided by a rule-based or rational process. In Hinton's view, people generally perform a few sequential rule-based computations, (a few steps) at which they are good. Each step, however, relies on computationally intensive intuitive (associative) inferences. The rule-based inferences involve symbols. To Hinton, the symbol is a small summarization of an object that provides access to a fuller representation contained in the associative system. It is a symbolic link that retains some of the internal (although abbreviated) structure of the represented object and serves as an access point to the fuller version. By analogy, symbols are to representations as an outline is to a research paper. Hinton's conceptualization is very similar to Vygotsky's (1986) notion of the function of words. To Vygotsky, the rule-based operating system was conscious inner speech. As an aside, sometime, try to think by silencing your inner speech to test Vygotsky's premise. Hinton (1990) maintained that the mechanism for moving among representations and between levels of them, deciding which to unpack and drawing conclusions (rule-based inference) was different from the mechanism which unpacks, fills in information and satisfies multiple constraints (associative inference).

The final contingent to evaluate is the inheritors of the Skinnerian position or the "learning theorists." Interestingly, the largest number of papers on reasoning come from this group. In time-honored fashion, this group conducts scientifically controlled experiments, typically concerning causality, and empirically reports mathematically derived relationships involving conditioned and unconditioned stimuli. The most influential theory of associative learning (as conceptualized by this group) is the Rescorla and Wagner Model or RKM (Rescorla & Wagner, 1972, as cited by Buehner, Cheng, & Clifford, 2003). Originally proposed to describe Pavlovian conditioning, researchers adopted it to explain human causal reasoning. The RWM involves a mechanism of error correction by the subject over repeated conditioning trials. The model works as follows. "Learning" occurs by changing the associative strength between a conditioned stimulus, CS (like a flash of light) and an unconditioned stimulus, US (like an electric shock). A term ΔVcs is calculated after each trial, which quantifies the change in the association between a CS and a US. The term is a fraction. Another term, λus, represents the outcome of the trial and is set to 1 when the US is present and 0 when it is not. ΣV is the sum of all the associative strengths of all the conditioned stimuli present and is therefore the expected outcome. Two multiplicative parameters $\acute{\alpha}$ and β represent the salience (strength) of the conditioned stimulus and the unconditioned stimulus respectively. They are called learning rate parameters. Learning is defined as the reduction of the discrepancy between the expected and actual outcome. When $(\lambda us - \Sigma V)$ approaches 0, the outcome or unconditioned stimulus is fully explained by the conditioned stimulus.

Explaining causal reasoning with the RWM reduces it to associative learning. With only one candidate cause, ΔVs asymptotically approaches ΔP, or the probability of the US given the CS, minus the probability of the US in the absence of the CS. The complete formulas are given below:

$$\Delta Vs = \acute{\alpha}\beta (\lambda us - \Sigma V)$$ RWM equation

$$\Delta P = P(US|CS) - P(US|`CS)$$

In human causal reasoning experiments, the assumption is that the greater the strength of the association between two variables, the greater the causal strength between them (Beuhner, Cheng, & Clifford, 2003). Typically, in causality experiments, multiple unconditioned and conditioned stimuli are employed. In each case, unconditioned stimuli and conditioned stimuli are alternatively varied or controlled. Contrasting these cases provides the insight which bears upon the investigated hypotheses.

For example, the experiment described below used the RWM method to uncover an effect known as blocking. In an experiment described by Mitchell, Kildear, and Lovibond (2005), students were to act as allergists. Mr. X consumes different foods. He sometimes suffers an allergic reaction. Students were required to assess which foods Mr. X is allergic to. Associative theory suggests that the extent to which a food is judged to be causal is a function of the strength of the association between the food (CS) and the allergic reaction (US). Application of the RWM to this experiment revealed the cue- competition effect known as blocking. To illustrate, participants first observed that Mr. X develops a rash after eating beef. If, in a subsequent meal, Mr. X eats beef and radishes, and again develops a rash, the causal rating of the radishes, as a source of the rash, is very low. The presence of the first conditioned stimulus, the beef, has blocked any learning about the radishes.

The major limitation of the RWM method is the fact that co-variation and causality are not the same. Obviously, two things can co-vary and not have a cause and effect relationship. To account for this distinction between co-variation and causality, Cheng (1997) developed the Power PC theory. This more mathematically sophisticated approach allows for the decoupling of co-variation and causal strength.

Gopnik, Glymour, Sobel, Schultz, Kushnir and Danks (2004) report that a mathematical modeling process known as directed Causal Bayes Nets predicted causal learning in 2-to- 4-year-olds, in a series of experiments. In past work, Gopnik has documented the ability to provide causal explanations and causal predictions in children as young as 2 years old (Gopnik & Sobel, as cited by Gopnik et al., 2004). In the current paper, Gopnik et al. (2004) theorize that causal knowledge and learning involves a representation they term causal mapping. These maps are inferred from patterns of correlation among events or from observations of the effects of actions that manipulate objects in the world. They theorize that young children use unconscious inductive procedures that allow them to infer causal representations from the aforementioned observed patterns or interventional actions. Further, they contend that these kinds of representations and learning mechanisms can be understood in terms of a mathematically sophisticated formalization known as directed causal models or Bayes Nets. These tools have been used in domains like science to make predictive causal judgments. Cognitive maps perform in a metaphorically similar way to traditional maps, allowing a multidimensional view of relationships and facilitating prediction and planning prior to taking action. Gopnik et al. (2004) propose similar more sophisticated structures for adults.

Gopnik, et al. (2004) credit Cheng (1997) as having the most far-reaching account of how causal learning can be mathematically characterized, using her Power PC theory. They point out, however, that the theory has implicit within it, if we assume that it is in some measure isomorphic to the actual process, the requirement for knowledge of statistical causal inference. As they note, even college undergraduates rarely have such knowledge. Children certainly have none. As such, they chose not to model with this theory. In addition, children's causal inference capabilities exceed behaviors that can be modeled with the RWM method, according to Gopnik et al. They found the Bayes Net approach most appropriate.

Language Origins

Many scholars (Kagan, Calvin, and Manier) consider the book *The Symbolic Species* by Terence Deacon, professor of biological anthropology at the Harvard Medical School (Deacon, 1997) as the seminal work concerning the anthropology of language. Deacon begins his treatment of the subject by pointing out that most believe language is not a widespread phenomenon in the animal world because of its enormous complexity and incredible demands on learning and memory. Depending on which aspect of language is deemed most complex, different researchers and scholars have invoked different evolutionary adaptations to explain how language became possible: a generalized increase in intelligence, a streamlining of oral and auditory ability, a separation of functions in the two hemispheres of the brain, or the evolution of an a-priori built-in grammar. Deacon categorizes prior work on language origins into four categories or paradigms. These categories also align with the age-old nature versus nurture debate and point to a specific adaptation as the source of language ability. The first paradigm expresses the view that both word meaning and knowledge are learned by internalizing patterns of association, linking words to one another and words to objects. This view, championed by B. F. Skinner and recently reprised by cognitive researchers studying parallel distributed learning processes, would imply larger intelligence (capacity) as the enabling adaptation for language acquisition.

The second paradigm, first explicated by noted linguist Noam Chomsky, is the existence of an a-priori built-in universal grammar (syntax), which exists like firmware on a computer, and allows language experience to take on meaning and usefulness (Deacon,1997). This view is born out of the accurate observation that small children learn to correctly use the incredibly complex rules of English grammar without any formal training, and the observation that the basic rules of grammar are universal, in all languages. I have read of the shock and bewilderment of the first British researchers in Australia who noted that the Aborigines and the Queen shared the same grammatical constructions. Since one interpretation of this phenomena was that the Queen and the Aborigines shared a common ancestor, this information was regrettably withheld from their official reports.

An extreme form of innatism, originally championed by psychologist and linguist Stephen Pinker, is the view that language is an external reflection of an "internal lingua franca" of the brain, which Pinker terms "mentalese" (Deacon, 1997). Learning language under this visualization consists of translating this language of the brain into the socially negotiated strings of words used in the world to communicate. Pinker's view is derived from the need of a processor for children experiencing language in the world. Without such a processor, how could simply hearing sounds or English words take on meaning and reference? Language is more than parroting what one hears. The innatist position of Chomsky and Pinker requires an evolutionary adaptation resulting in specialized mental hardware in the brain specific to language acquisition and processing.

The final paradigm is the idea that word meaning is created when the perception of the sound of a spoken word is associated with an object, both as perceived and as stored in the mind in the form of a mental image. This model represents a kind of audiovisual associationism. It would require no specialized hardware, just a larger brain to store the vast inventory of associations.

Each of these paradigms has components that attract one's intuitions, as well as aspects that appear to me to be intuitively problematic. The problem with the associationist's models is the one resolved by innatist models. We require a mechanism for creating meaning, context, relevance and specific reference. In addition, these paradigms fail to explain the productivity, plasticity and generativity of language. Using 26 letters, and, on average, 50,000 words (Pinker, 2007), humans can express a virtually unlimited number of ideas. Even a brain with 10 billion neurons could not store all of the associations necessary to accomplish this task. With an associationist's model, if you had not seen or heard something, you could not know it. Yet, the mind, through language, can create unlimited scenarios.

The problem with the innatist view, for a biologist and anthropologist like Deacon, is the evolutionary quantum jump required to create the unique one-of-a-kind neural circuitry that an innate mentalese or universal grammar would imply. Surely, he argues, such a step would "leave a trail of evidence attesting to its discontinuity" (Deacon, 1997, p. 36).This view would imply a very large biological discontinuity: that language is separate from the rest of our biology. He states, "It is as though we are apes plus language - as though one handed a language computer to a chimpanzee" (Deacon, 1997, p. 35). For Deacon, an evolutionary biologist, this is too much incongruent change happening too quickly. Deacon (1997) believes that prior researchers have asked the wrong question. While they have been worried about where language comes from (an epistemological question), they have avoided a more basic question: what sort of thing is knowledge of language (a metaphysical question).

In my view, the previously described paradigms describe a classic circumstance. Often, when highly trained and intelligent investigators arrive at dialectically opposed views, it means that they have attached to the differentiated specifics of a more general and encompassing principle. The resolution of a dualism, nature versus nurture for example, requires that we consider both aspects of the dualism as part of a more complex relationship. In the case of the quadrilateralism above, the answer we will find is that elements of all four paradigms play a role in mental processes relating to language. Language acquisition and use has elements of association and imagery, as well as a requirement for a-priori mental structures. These a-priori structures are, however, different from those originally envisioned by Chomsky and Pinker. This will become clearer when we investigate the latest linguistic research.

To flesh out the question regarding the nature of language, Deacon (1997) asks us to consider the essential characteristics of language, compare human and nonhuman communication and conduct a thought experiment. If we were to analyze a signal from outer space for language characteristics, what would we look for? We would expect a combinatorial form in which distinguishable elements are able to recur in different combinations. It would exhibit creative productivity of diverse outputs using these distinguishable elements without large-scale redundancy. Although there would be a high degree of variety in the combination of elements, the majority of the combinatorial possibilities would be excluded. If we could view the objects or events being described by the signals, we would also find that the signals and objects do not form a one-to-one correspondence from one occasion of description to another. These characteristics, when taken in aggregate, describe a syntax or grammar. They occur not only in all languages but also in human games, mathematics and cultural customs. To me, this provides a big clue, indicating that mental structures generate these characteristics.

Animal communication, in contrast, occurs as isolated signals, in fixed sequences or in unorganized combinations that are better described in cumulative aggregates than through relational rules. Correspondence between signals in advance and behaviors are one-to-one in nonhuman communication. Deacon (1997) cites (without specific reference) a study that was published in the mid-1980s which reported that Vervet monkeys produce alarm calls that appear to act like names for distinct predators. Distinctly different calls appear to be produced to warn other monkeys of the presence of either eagles, leopards, or snakes. When hearing these calls, monkeys either climb down out of trees (eagle), rise up to check the bushes around them (snake), or proceed to climb up trees (leopard). The calls seem to indicate distinct classes of predators, not simply the state of the calling monkey. This finding led some to argue that the system of calls was like a simple language. This analogy, of course, depends on call reference being equivalent to word reference. Reference, however, is not the difference between alarm calls and words. Both can refer to things in the world and both can refer to internal states. The critical difference is the kind reference the two represent.

The philosopher Gottlob Frege (Deacon, 1997) provides a distinction between two aspects of a word. A word has a sense and a reference. The sense is the idea one has in mind when considering the word and the reference is something in the world that corresponds with the word. Said another way, the sense is something created in the head, while the reference is something indicated in the world. Frege offers the example of the "morning star" and the "evening star". Both terms refer to the same physical object but have different senses. These different senses trace back to history, when it was not recognized that the terms represent one and the same object. The crucial difference between the animal call and human words is that the animal call simply points to or refers to something in the world, while the human word accomplishes this external reference and symbolically represents an idea or meaning (Deacon, 1997). **The uniquely human ability is the capacity for symbolic representation.**

To develop an understanding of the nature and origin of symbolic representation, Deacon (1997) utilizes the classification of representational relationships provided by the American philosopher Charles Sanders Pierce. As part of a larger scheme of symbiotic relationships, Pierce determined three categories of referential associations: icon, index and symbol. Pierce confined the use of these terms to the description of the nature of the relationship between the characteristics of a sign token and those of the physical object (Deledalle, 2000). Pierce took the position that all forms of thought are in fact internal communication organized by an underlying logic that is not fundamentally different for communication processes inside or outside of the brain. It should therefore be possible, he thought, to investigate the logic of thought by studying sign production and interpretation processes in overt external human communication. His position was that once recognized as communication, there are logically necessary consequences that result (Deledalle, 2000). As previously stated, Pierce differentiated three forms of representation: icons, indexes and symbols. An icon represents the similarity we perceive between a sign and an object. An index represents some physical or temporal connection or correlation between a sign and an object. As the word implies, the sign indicates or points to an object. A **symbol represents some formal or socially agreed upon semantic link** (meaning) that establishes a relationship among things. A wedding ring for example would be a sign that symbolizes a marital agreement (Deacon, 1997). Another example would be the words in a sentence when taken together, they symbolize an idea.

According to Deacon (1997), Pierce's fundamental and original insight was that these three modes of reference are related in hierarchic fashion. In other words, the more complex forms are constructed from the simpler forms. An iconic relationship based on similarity and difference is built first. Next, an indexical relationship is created between icons, in which one icon indicates or points to another. This relationship is based on physical or temporal contiguity/co-occurrence or part/ whole relationship between the icons. Finally, indexes are related by formally or socially agreed upon links that create a symbolic representation.

Iconism derives from that aspect of the interpretive process that does not differ between the object and the representation. For example, that facet or stage of my interpretive recognition process that is the same for a caricature sketch and the face it portrays is what makes the sketch an icon. Although the net result is how things are similar in terms of perceptual processing, iconicity is in fact determined by differences. This results from the fact that the perceptual system works on the basis of contrast or difference. Iconicity is therefore the default or what is the same after all differences have been stripped away.

In the photograph below, the insect will not be recognized until it moves and is different from the branch in some fashion. Once this difference is determined the remaining features can be iconized with the branch.

Indexical representations represent physical and/or temporal (time) contiguity. They are an expression of nearness or connectedness in space-time or can express a part/whole relationship. It is important to point out that these relationships are not causal but simply the result of one icon co-occurring with another**. Indexical representation is the interpretive process where by one icon seems to point to or indicate the other**. In a certain sense, it is iconization, where the similarity or invariant is space-time or part-whole co-occurrence.

It is useful to consider an example. Suppose we receive a sensory stimulus, for example, the smell of smoke. This smell will bring to mind past events (episodic memories). These events come to mind because of their similarity to each other and to the present event. When experiencing these past events, the mind represented perceptual characteristics such as the sight and smell of smoke, the sight of flames, and the sight of an object burning or changing state. These icons represent the similarities present in all of these separate events. The repeated correlation (indexing) between the smelling of smoke and the presence of flames, or some other icon (feature) derived from these events permits a higher level of iconicity - the co-occurrence in time-space or part-whole relationship of these icons. Due to this, there is recognition of a more general similarity of the entire present situation with past ones, we make an association and thereby create an indexical relationship.

What psychologists call "learning theory" relates for the most part to the dynamics of indexical reference. Associative learning and conditioned responses are indexical references. The responses we develop as a result of day-to-day associations form the basis for all indexical interpretations. Indexes do, in fact, impart inferential and predictive power, as noted previously. The indexical statement "where there is smoke there is fire" is an example of such an inference or prediction.

In my estimation, indices or associative learning impart part of the mind's probabilistic character. For example, in experiencing a current event, such as a fire, we might first hear a crackling sound, then see smoke, then smell smoke and then see flames. With each recognized icon, the probability of the event being a fire increases. The more icons we perceive the greater the probability of the event being inferred to be a fire. It is the indexical relationship between the icons that facilitates the inference of the event. It is important to note that each of these indexical relationships are one-to-one and separated from each other at this stage of representation. For example, if one's knowledge of a fire consisted solely of icons connected through indexes, then one could only respond to the query "What is a fire" with single word icons like flame or smoke. To go beyond this requires the next stage of sign building: symbolic representation.

The transition from indexical representation to symbolic representation happens so quickly and fluidly in small children that it is extremely difficult to see. Let us try to view the process in slow motion. Words, for a very short period of time, consist of independent unlinked indexical associations. This accounts for the referential instability sometimes seen in young children's speech. As Vygotsky (1986) points out, a young child may use a word for multiple objects possessing a similar singular feature which is perceived by the child as iconic of these multiple objects. Building words as symbolic representations requires combining indexical relationships. The way that this is accomplished is through the relationships that words have to each other. If we view the child's first unstable words as pre-words, what is involved is a simultaneous solution that results in the stabilization or equilibration of these pre-words into symbolically representative words. As the meaning and sense of a word is developed through word-to-word relationships, the pairing between a symbol and an object or event in the world is solidified and differentiated from indexical relationships involved in other words. This is my rendition of the process.

Deacon (1997) states that what determines the pairing between a symbol (like a word) and some object or event in the world is not their probability of co-occurrence but the relationship the symbol has to other symbols that bear some relationship to the object and the symbol. Words also represent other words and are incorporated into quite specific individual relationships to these words. It is through these relationships that a word derives meaning and develops its representational power. It is the relationship with other words that defines the word. **Words point to objects (reference) and words point to other words (sense), but the sense defines the reference and not vice versa**. It is by virtue of this dual reference that a word conveys the information necessary to pick out objects of reference. The referential relationship between words indicating other words forms a system of higher-order relationships that allows words to be about indexical relationships not simply indexes themselves. Words need to be in context with other words, in phrases and sentences in order to develop determinate reference. Symbolic reference comes from combinatorial possibilities and impossibilities, or the invariance of indexical relationships between words. We depend on these combinations to both discover a words reference (learn its meaning) and to make use of it (communicate with the word). In a sense, what is occurring is the iconization of an indexical relationship between words. According to Deacon (1997), because of the systematic relational basis of symbolic reference**, no collection of signs can function symbolically unless the entire collection conforms to certain overall principles of organization**. "Symbolic reference emerges from a ground of non-symbolic referential processes (icons and indexes) only because the indexical relationships between symbols are organized so as to form a logically closed group of mappings from symbol to symbol" (Deacon, 1997, p. 99). The rules of combination implicit in the structure are discovered as different combinations are probed. New rules may be discovered as emerging requirements of novel combination problems, in much the same way as new mathematical laws are discovered as a result of manipulating known mathematical operations.

To make this a bit more concrete, what Deacon is referring to is the fact that we never see a tree swim or fly, we see a tree grow and spread roots through the ground. There are certain relationships that the word tree enters into with other words. It is through this relationship that the referential power of the word tree develops. The tree is something that grows and has spreading roots and a large number of other attributes and characteristics that are defined through the relationship of the word tree to other words. The logical closure that he speaks of is the fact that there is a closed set of relationships between the word tree and other words in the language. These words give meaning through their relationship to the word tree. Certain combinations never occur, for example: "the tree swam across the lake". We could say the tree floated across the lake, which would inform us of another characteristic property of the tree which we could include in our symbolic representation constituting the word tree, thereby expanding it by virtue of the relationship expressed in the sentence. In similar fashion, our symbolic representation of a fire has to be more than the previously expressed indexical associations. It has to be evolved through relationships that express something like the following:

1) A fire has flames that envelop an object.

2) The flames associated with a fire change the enveloped object into smoke and ash.

3) The smoke associated with a fire has a distinctive smell.

4) Near a fire, we often hear a crackling sound coming from the object enveloped in flames.

The symbolic representation of the word fire is relationally derived and determined by sentences like those above. As can be seen, what were initially icons of fire events and subsequently indexes that associated these icons as co-occurring across the events, are transformed via the above relationships into a symbolic representation which gives meaning to and defines the symbol fire. The symbolic representation or word fire is now something that: includes the aforementioned icons as elements, associates them (indexes), and relates them in a way that gives meaning to the word and gives it representational power. The definitional relationships also give the symbol the power of being a **category**. Items which share the characteristics and relationships that define the symbol are candidates to be included within the category represented by the symbol. St. Elmo's fire, for example, shared a sufficient number of these characteristics and relationships with fire for someone in history to have denoted the phenomenon as a fire. Abstraction and generalization of the relationships and icons associated with fire enables metaphorical use of the word, as in: "he was fired" or "she was fired up."

There are several pedagogical points we can touch on in connection with the above. In concept formation, the first step is iconization. As noted above, critical to this process is a clear demarcation of similarity and difference. To know what something is we also need to know what it is not. What makes it distinct and unique and allows us to draw a boundary around it as differentiated from the rest of the world. This, however, is only the beginning. We must show how these icons point to or index the concept. The most important step in the process of concept formation is enabling the student to understanding the concept by seeing the relationships that the concept enters into that define its meaning. The more the student understands the logic and pattern of these relationships, and the more experience they have defining the concept through these relationships, the firmer will be their understanding of the concept.

There is another aspect to this process that merits further consideration. What are the features that a child in a learning situation will consider to be iconic or defining of an object or event? Are these features determined by the way the mind naturally divides objects or events into features or are they socio-culturally determined through language, as per Vygotsky (1986). This appears to be a nature-nurture dialectic. The answer is then, undoubtedly, both. Depending on the specific objective or goal of the learning situation, there could be scaffolding requirements for the teacher at this stage of the knowledge construction or organization process. Needless to say, if the teacher can anticipate the student's likely basis for the differentiation of objects and events and choice of characterizing features or icons, the teacher can either modify the learning experience or intervene (scaffold) in such a way as to increase the efficiency and effectiveness of the learning process.

Learning difficulties associated with conceptual learning generally seem to fall into two categories. Students may not have a good understanding of the elements or differentiating iconic features involved. In other words, the elements may not be clearly defined or differentiated in the student's mind, or the element may represent a feature that the student is not familiar with. This is often the case with relationships that are built from elements that are themselves abstractions. If for example, a mathematics teacher is creating a relationship involving eigenvalues, the student will be lost if they are unfamiliar with the nature and characteristics of eigenvalues. The other problem students encounter is a lack of understanding as to why elements should necessarily have the form of relationship being proposed or they are unfamiliar with the specific type of relationship being proposed. In either case, the relationships within the concept do not make sense to them. One meaning of "doesn't make sense" is that the pattern of relationship is incongruent with relationships from their past experience. They do not have a relational pattern or set of logical connections which match those involved in the concept. Another way to say this is that they do not have an analogy or metaphor with the same relational structure as the concept. Another meaning of the phrase "doesn't make sense" is that the student does not understand why the proposed relationship is <u>necessarily</u> the relationship between the elements and not some alternative relationship. In other words, why do the elements necessarily relate in the fashion proposed by the teacher. What is occurring in this case, is that the student is deducting from his current inventory of rules, concepts and theories and concluding that the form of relationship proposed does not necessarily follow as a deduction from his prior understandings. The problem arises because the student himself did not construct the relationship or detect the pattern of relationship from his own experience and understanding. It came to him in the form of received wisdom. The pedagogical requirement here is to help the student gain sufficient experience such that he himself can see that the elements can be combined or related in a way that an invariant results or an equilibration with the context of his experience. In other words, that there is an invariant relationship that summarizes experience. Students often say to themselves: "I don't understand the logical necessity of the relationships in this concept, but I know it's going to be on the test, so I'll just assume that it's right and memorize it." This sentiment is a formula for non-retention or subsequent utilization of instruction. As previously stated, words constitute a matrix or web of relationships which are mutually defining in a logically closed group. The pedagogical challenge for a teacher is hitting on the right combination that creates meaning for the student and facilitates understanding.

Another aspect of symbolic representation is that once the symbolic power of a word is established through symbol-to-symbol relationship, it is stabilized and no longer relies on indexical association. A good example of this is embodied in the story about the boy "crying wolf" (Deacon, 1997). In the story, the boy cries wolf whether there is a wolf present or not. He thereby destroys the indexical power of the word because it is no longer associated with the presence of a real wolf. In spite of this, all those around him still retain the symbolic conception of a wolf and its attributes. This power of survivability results from the dynamics of how symbolic representation comes about. Previously learned associations are reorganized with respect to one another. We learn meaning by recognizing or discovering the implicit pattern in the relationship between indexical relationships, as previously described. Once this occurs, we have established the **semantic features** of the representation. The symbolic representations now allow the offloading of redundant details from memory by recognizing higher order regularity through symbol-to-symbol associations. It is no longer necessary to remember a huge number of symbol-to-object associations because we can keep track of them through symbol-to-symbol rules. As discussed previously, once we establish semantic features through word relationships, we have made the word categorical. We can then easily add new items that qualify with respect to this relationship and meaning. It is no longer necessary to add new indexical correlations because the word has been stabilized through word-to-word relationship. If we view iconization, indexing and relation of indexical associations as general processes, we can build a stage-like process of ever-increasing complexity. These processes become rules that define a **fractal** which can create forms of increasing complexity when operating in a changing environment. In this way, words ultimately are combined into complex systems of relationships and bodies of knowledge.

Psycholinguistics

Language syntax, commonly known as grammar consists of the rules of protocol, or laws of relationship, for word combinations in a language. Mechanisms specified include putting words in proper sequence or order, subject- verb agreement and a whole raft of other specifications. Taken together, these specifications are not only voluminous, but quite complex. A big mystery has always been how a 4-year-old generally exhibits mastery of these rules. There have been numerous theories, among them Noam Chomsky's (1968) postulation of an a-priori language processor or built-in cognitive hardware that humans are born with.

In his most recent book, *The Stuff of Thought*, noted psychologist and linguist Steven Pinker (2007) presents an insightful and well constructed hypothesis for how grammatical constructions come about. In summary, his thesis is that grammatical constructions are derived from the meaning of words and the meaning of the sentence, as created by the relationship of the words in a sentence; or said more accurately, how we **construe** these meanings. Under Chomsky's influence linguists tended to think of rules and syntax mathematically, as operations that manipulated parts of speech (Pinker, 2007). The goal of syntactic interpretation was to understand the mathematical regularity implicit in grammar. With this mindset, one would not predict that grammatical constructions would bear any relationship to the specific meaning of words. This, however, seems to be precisely what is occurring - the syntax derives from the semantic.

Pinker (2007) attributes the breakthrough in understanding to the work of Beth Levin and Malka Hovav (Levin, 1985). The key to resolving the paradox was in the semantic interpretation of sentences: the meaning of the construction and the meaning of the words within the construction. Pinker (2007) summarizes: "So in trying to crack the puzzle of how children inferred the syntax of their mother tongue, we were forced to re-conceptualize what they had to learn: from an operation for cutting and pasting phrases to a mental gestalt shift in how a situation is construed" (p. 51).

An even more valuable insight, perhaps, in Pinker's (2007) book is his illustration that a semantic interpretation of the rules of syntax reveals the fundamental categorizations by which the mind organizes received information. Language, in this sense, becomes a window into the organizational structure of the mind. Since this is completely congruent with the posture and conclusions reached so far in this Dissertation, I happily receive and incorporate his ideas into my work.

Pinker (2007) asks us to consider the following sentences:

1) Hal is loading hay into the wagon.
2) Amy poured water into the glass.
3) Jim fills water into the glass.

Linguists refer to these three sentences as <u>content locative</u> constructions. The term locative refers to the direct object or what is being acted upon (above: hay, water). In the above sentences, it is the content that is being acted upon, hence the term content locative. Conversely, in a <u>container locative</u> construction, we exchange the direct and indirect objects, making the container the entity being acted upon.

4) Hal loaded the wagon with hay.
5) Amy poured the glass with water.
6) Jim fills the glass with water.

Sentences three and five above are grammatically incorrect. The verb **pour** can be used in a content locative construction but not a container locative construction. Conversely, the verb **fill** can be used in a container locative construction but not a content locative construction. Why, would this be the case?

What syntactic rule is involved here? When is it grammatically permissible to exchange the direct and indirect object associated with the verb and when is it not permissible? Why do we know instinctively that these two sentences are not grammatically correct?

First, let us look at the semantic implication of the content locative construction. The meaning of the content locative construction is: A causes B to **go** to C. The meaning of the container locative construction is: A causes C to **change state** by moving B to it. There are two concepts involved here: a change of state and motion (go). Second, we can utilize a semantically discovered rule of syntax: the affected entity is always expressed as the direct object. Let us now examine the meaning of the verbs. The verb pour implies that we let a liquid move (with gravity as intermediary force). Nothing predictable happens to the destination of the liquid, in terms of change of state. The glass could be partially full or completely full; the verb is silent with respect to change of state. As such, the verb can participate in a content locative construction that semantically implies movement or motion, but not in a container locative construction which implies a change in state of the affected entity (direct object). That is why we can pour a glass of water, but not pour the glass with water. Conversely, the verb fill connotes a change in state of the affected entity, but is silent with regard to manner of motion. The verb fill, therefore, can participate in the container locative construction, but not the content locative construction. This is why we can fill the glass with water, but not fill water into the glass. The verb load simultaneously expresses how a content has moved and how a container has changed state (loaded implies it is full). This verb can therefore participate in both the content locative and container locative constructions. We can load the wagon with hay and load hay into the wagon. Applying the same semantic rules, we can understand the syntax associated with the verb throw, which implies motion without a change in state. We can understand why we can throw a cat into a room but not throw the room with a cat (Pinker, 2007).

Of course the acid test for this theory would be to test it out on 4-year-olds. This Pinker (2007) and colleagues did in a series of tests. Pinker (2007) does a lot of these tests, leading me to think that perhaps Harvard University has an employee nursery with a ready supply of 4-year-olds. Perhaps this nursery is free to employees, if they agree to allow the children to be submitted to fun tests developed by members of the faculty. In any case, Pinker (2007) set up two experiments. In one, the researcher executed a zigzag motion with a sponge, set it next to a purple cloth and told the child that the activity was called "mooping". In another experiment, the researcher executed a random motion with a sponge and touched the purple cloth, causing it to turn green (caused by chemical reaction). Again, the child was told that the activity was called "mooping". In each case, the children used the word "mooping" in a way consistent with a semantic interpretation of its meaning. In the first case, the children said that the researchers were mooping the **sponge**. In the second case, the children said the researchers were mooping the **cloth. The children used the correct locative construction, consistent with a semantic interpretation of the verb.**

Pinker (2007) analyzes a series of constructions, based on the work of Beth Levin (1985). These constructions involve simple transitive action verbs. The first construction is termed conative. The word conative derives from the Latin word for "to try". The conative construction conveys the idea that something is impinging on something else but not quite succeeding. The following sentences are allowed under this construction:

1) Jim <u>pushed</u> on the door.
2) Sal <u>hacked</u> at the tree.

The following sentences are disallowed under this construction:

3) Joseph <u>split</u> at the wood.
4) Ronda <u>broke</u> at the window.

Here again, the syntax derives from the semantic. Verbs such as split and broke convey an effect or outcome. As such, all words that convey an ultimate effect or outcome resulting from the action represented by the word are disallowed in this construction and sensed by the reader to be grammatically incorrect.

Another type of direct object alternation that transitive verbs participate in is called a possessor raising construction. This alternation is exemplified in the following sentences:

1) Sam <u>cut</u> Brian's arm.
2) Sam <u>cut</u> Brian on the arm. [possessor raised to direct object]
3) Jim <u>broke</u> the library window.
4) Jim <u>broke</u> the library on the window. [disallowed]

An analysis of verbs that can participate in the possessor raising construction reveals that they are verbs that connote contact without specifying the effect of the contact or a change in the state of the object contacted. We see again that the semantic content of the verb determines the grammatical constructions that are permitted.

Another alternation that is similar to the previously discussed locative alternation is shown below:

1) I <u>hit</u> the bat against the wall.
2) I <u>hit</u> the wall with the bat.
3) They <u>broke</u> the glass with a hammer.
4) They <u>broke</u> the hammer against the glass. [disallowed]

Sentence four above is disallowed. A semantic analysis of verbs which can and cannot participate in the above alternation reveals that verbs which communicate motion and contact, but not effect, are allowed to participate.

A construction called the middle voice relates to the ease with which an action can be performed. The examples below illustrate this construction:

1) This glass breaks easily.
2) The steak cuts like butter.
3) This dog slaps easily. [disallowed]

Sentence three above is disallowed. The semantic rule involved in this construction is that the verbs must signify a specific effect of some cause.

The construction called an anti-causative alternation converts a transitive verb to an intransitive verb by eliminating the causal agent. Examples of this construction are:

4) Jim broke a glass.
5) Glass was broken.
6) May hit a car.
7) Car was hit. [disallowed]

The semantic rule at play here is that a verb must express an effect without expressing motion or contact. The chart below summarizes the discussion above. It shows the construction, the underlying semantic which controls the construction and examples of allowed and disallowed verbs.

Construction	Semantic Concept	Allowed Verbs	Disallowed Verbs
Conative	Motion, Contact	Hit, cut, push, hack	Break, split, touch
Possessor raising	Contact	Hit, cut, touch	Break
Contact locative	Motion, Contact, No Effect	Hit	Cut, break, touch
Middle voice	Effect	Cut, break, split	Hit, slapped, touch
Anti-causative	Effect, No Contact No Motion	Break	Hit, cut, touch

Pinker (2007) shows how the underlying structure is better illustrated with a comparative sorting by verb rather than by alternation:

- **hit**: motion, contact
- **cut**: motion, contact, effect
- **break**: effect
- **touch**: contact
- **hack:** motion, contact
- **split**: effect

Pinker (2007) provides numerous other examples of how word meanings dictate the specific construction of what we deem to be grammatically correct sentences. The above results, I believe, not only demonstrate that syntactic structures emanate from the semantic content of words; they also strongly support the hypothesis that **human reasoning is fundamentally predicated upon the semantic structure of representations. The meaning in the semantic structure is derived from equilibrated invariant relationships among elements in the representations**. For individuals beyond a certain level of development, a significant percentage of these organized representations are words and their associated conceptual structures. While not inclusive of all forms of reasoning and representation, as discussed previously, words still direct most conscious thought, as concluded by Vygotsky (1986). In addition, **the relational structure of the concepts represented by words, constitutes the logic connectives of thought.**

The most important conclusion in Pinker's (2007) work is that when analyzing language semantically, as in the manner previously illustrated, word meanings seem to line up or fall under specific fundamental conceptual categories. For example, in our previous analysis, participation in certain sentence structures was contingent upon whether a component of the verb's meaning included or excluded concepts of motion, contact and cause and effect. Participation was based on which specific concept, or combination of concepts, were included within the word. The implication is that the mind organizes in accordance to a specific set of fundamental concepts. The conclusion that Pinker (2007) has reached, based on the semantic analysis of syntactic structures, is that the world's **languages (and by implication thought) appear to be roughly organized by the categories originally proposed by philosopher Immanuel Kant** (1724 – 1804):

- **Space**
- **Time**
- **Causality**
- **Substance**
- **Logic**

Pinker (2007) notes that a considerable portion of the vocabulary of the world's languages consists of words that address the basic questions of "what" and "where". These questions correspond to the categories of substance and space. The English language has over 10,000 words for shapes, but a smaller class of words specifying paths and places. For example, there are only 80 or so spatial prepositions (above, across, behind, below, etc.). This disparity is driven by the requirements of the task of specification. Specifying a shape can require as many pieces of information as the shape has facets. Specifying the disposition of one object relative to another, technically, requires only six pieces of information.

Pinker (2007) undertakes an extensive discussion of how language reveals the way that the mind construes space and spatial relationships. For example, rather than always conceiving physical objects as having three dimensions, the mind emphasizes the most prominent dimension or dimensions it requires for its reasoning process. A river is principally conceived of as an unbounded line (focus on its length dimension), together with a secondary dimension of width. Unless one is a geologist or hydrologist, it is unlikely that one's basic conceptualization of a river would be that of a three dimensional stream tube. This reflects the fact that our typical reasoning about rivers most often concerns length and secondarily width. Our language reflects these conceptualizations. For example, we use the term underground or underwater even though we are surrounded by earth or water and not beneath it. These expressions illustrate that the mind conceives of water and ground as two-dimensional surfaces reflecting the individual’s primary perceptual experience of ground and bodies of water.

Neuroscientist David Marr (Pinker, 2007) hypothesizes that humans represent shapes in their minds with shape feature-axis models rather than raw images. Humans easily recognize stick figures made of pipe cleaners and animals made of twisted balloons. A feature and axis model remains stable as an object moves relative to the viewer. A direct image representation, for example, one constructed of pixels, quickly becomes unstable with motion. One can see this effect by moving a video camera too quickly. Human vision does not suffer from this effect. This schematic representation of space finds its expression language. It appears from the above that our language is impacted by the manner in which the mind represents objects in space.

The precise way that the mind constructs spatial relationships and how these ultimately get reflected in language is a complex subject which will require additional research to work through. For purposes of this Dissertation, I believe we can conclude that an **important category of conceptual structures expressed in language involves either direct or metaphorical spatial relationships as the basis for organization.**

Lakoff and Johnson (1980) proposed that language expresses a time orientation metaphor, a moving time metaphor and a moving observer metaphor. In the time orientation metaphor, an individual is located at the present, with the past behind him and the future in front of him. This metaphor is expressed in phrases like (Pinker, 2007):

- that's all behind us now
- we are looking forward to the event
- they have a challenge in front of them

In the moving time metaphor, time moves by a stationary observer. This is seen in expressions like:

- the deadline is approaching
- the semester is flying by
- my day will come

The moving observer metaphor, as the name implies, has the observer moving through time.

- we are coming up on the holidays
- we passed the deadline

As Pinker (2007) notes, the above illustrates that the mind, like Einstein, equates time and space. I believe this has a neurological basis. I would hypothesize that the way the mind handles time relationships in memory is through a sequenced spatial relationship analogous to a graphical timeline. Again, language reveals that the mind uses both physical and metaphorical time relationships as a basis for organization.

Time is encoded in grammar in two ways (Pinker, 2007). The one familiar to everyone is the tense of verbs (ran, run, will run). The other encoding is termed aspect and can be thought of as the shape of an event in time. Aspect, for example, differentiates between an instantaneous event (hit the ball), an event that is open ended in time (running around in circles), and an event that has a finite beginning and end (draw a graph). Aspect can also express the viewpoint of an event: whether the individual is part of the event or an outside observer.

Linguist Len Talmy (1988) has examined the conception of causal force found in language. Pinker (2007) points out that there are verbs of pure causation, like: cause, get, force; verbs that include the nature of the effect, like: melt, paint, scratch; and verbs that express preventing or enabling, like: hold, block, permit, enable. Talmy (1988) demonstrates that these verbs are part of a mental model of force dynamics. In his model, there is an entity referred to as an agonist: an entity having a tendency toward motion or rest. There is a second entity in the model called an antagonist: an entity that exerts a force on the agonist in opposition to its tendency. If the antagonist's force is greater than the agonist's tendency, the agonist will change from rest to motion or vice versa. If it is less, the agonist will continue in its tendency.

Let us say that the agonist has a tendency to remain at rest. The action of the antagonist can be sufficient to initiate motion or it can be insufficient. The first case is expressed in a sentence like: the ball kept rolling because of the steep hill. In this sentence, the action of the antagonist (the steep hill) is sufficient to maintain motion and overcome the ball's natural tendency to stop. The second case is expressed in a sentence like: the tree kept standing despite hurricane winds. In this case, the action of the antagonist (the hurricane) is insufficient to overcome the agonist's (the tree) natural tendency.

Language illustrates that the mind also construes forces as acting for limited periods of time. In the above examples, the forces are construed as continuous. In cases where the agonist has a tendency to remain at rest, limited time application of force by the antagonist is expressed in sentences like: *he hit the ball over the fence* or the *wind stopped and let the dust settle.* In the first case, the action of the antagonist is sufficient to overcome the natural tendency of the agonist, while in the second sentence the cessation of the antagonist's action permits the agonist to return to its natural tendency. Cases where the agonist has a tendency to move and the action of the antagonist is insufficient to overcome this natural tendency are expressed in sentences like: *the golf ball kept rolling despite the thick grass* or *the plug failed and let the water rush in*. The opposite circumstance, where the agonist has a tendency to move and the antagonist is successful in overcoming this tendency is expressed in sentences like: *he would've failed without the tutors help* or *the rain put the fire out*.

Pinker (2007) contends the following:

> The basic script of an agonist tending, an antagonist acting, and the agonist reacting, played out in different combinations and outcomes, underlies the meaning of the causal constructions in most, perhaps all, of the world's languages. And in language after language, the prototypical force-dynamic scenario - an antagonist directly and intentionally causing a passive agonist to change from its intrinsic state - gets pride of place in the language's most concise causative construction (p. 222).

Pinker (2007) points out problems related to competitive theories of human causal reasoning. The philosopher Hume's (1982) idea of constant conjunction: if one event immediately follows another, an individual interprets the first event to be the cause of the second, fails to adequately describe human causal reasoning. What Hume (1982) describes is simple association, such as occurs in classical conditioning. Pinker (2007) points out that most people know the difference between correlation and causation, even if they don't always acknowledge it in their reasoning. People understand epiphenomena (by products of the real cause), like the fact that thunder does not cause lightning.

An enhancement over the constant conjunction theory is the counterfactual theory of causation or: A caused B means that B would not have happened if not for A. The counterfactual theory is a fundamental construct in Causal Bayes Network formulations of causal reasoning. This theory also has difficulties. For example, it does not handle the case of preemption. The example that Pinker (2007) gives is of two snipers who conspire to assassinate a dictator at a public rally. They agree that whoever gets the first clear shot will fire while the other drifts into the crowd. Assassin one kills the dictator with his first shot and clearly he is the cause of the dictator's death. Yet it is not true that if assassin one had not fired, the dictator would still be alive, because in this case, assassin two would have done the deed. The counterfactual theory would predict that neither assassin was responsible for the death. In experiments of human causal reasoning, subjects have no difficulty resolving preemption and identifying the appropriate cause (Pinker, 2007). This certainly casts doubt that the counterfactual theory represents a fundamental construct of human reasoning. The counterfactual theory also has difficulty with causal transitivity and over-determined circumstances (where any number of causes, individually, can be sufficient to create an effect).

Experiments by researcher Philip Wolff support Talmy's theory that human causal reasoning is predicated upon perceptions of force dynamics (Pinker, 2007). Wolff not only tested causal reasoning concerning physical situations, but also the causal dynamics of social situations. He found that people use the same calculus for both circumstances. The language used to describe social circumstances was simply a metaphorical rendering of the language used in physical situations (Pinker, 2007).

This brings us to another important conclusion of Pinker's (2007) text: **abstract reasoning is directed by conceptions that are metaphorical expressions of physical relationships**. Linguist Ray Jackendoff (1983) noted that verbs preserved a part of their meaning across physical and nonphysical uses, but not all parts. The preserved parts of the skeleton are roughly the fundamental organizing conceptions proposed by Pinker (2007), or Kant's (1982) categories. The skeleton is then labeled with a symbol for a semantic field, such as location, state, or time. Pinker (2007) cites as an example, the word keep used in two different sentences: *he kept the money* and *she kept the book on the shelf*. In both sentences, the skeleton behind the word keep is the same: an antagonist opposing an agonist's tendency to go away (a physically originated causal relationship). The concept behind keep in the first sentence additionally carries the label "possession". In the second sentence, the concept behind keep includes the label "location". Please note that the relational structure expressed in the skeleton remains the same in both senses of the word keep. Pinker (2007) summarizes:

> The metaphorical flavor of language comes from the fact that skeletal concepts like go, place and agonist maintain connections to physical reasoning. They are most easily triggered by the experience of seeing things move around; they are used by children in spatial senses before they are used in abstract senses: and they might have evolved from circuitry for physical reasoning in our primate ancestors. Yet, as they take part in moment to moment thinking, they are abstract symbols, and need not drag with them images of hunks of matter rolling around (p. 252).

Pinker's (2007) quote has an inference that I find appealing. In that the human is a biological organization, and that biological organizations adapt and build upon pre-existing structures. The idea that abstract thinking is metaphorical of physical thinking, at least in terms of its relational characteristics or its skeleton, is consistent with an adaptational and organic context for development.

In summary, the ideas expressed in Pinker's (2007) book, and in the works of his cited references, are congruent with other findings of this Dissertation:

- **language directs abstract thought;**
- **it is the semantic articulated within the relational structures of representations, such as words, that facilitates and enables rule-based reasoning (like deduction);**
- **development expresses the changing nature of representations and the form of relationship embedded within those representations.**

Science and Mathematics

The Scientific Method

The modern paradigm embraces rationality as its primary basis of authority and reductionism as its methodology. Much of the spirit of modernism is captured in the traditional definition of the Scientific Method. The Scientific Method begins with hypotheses. Hypotheses are derived from careful reflection on past experience. They typically result from inductive generalization of a presumed or hypothecated invariant pattern of relationship between the elements under consideration. Importantly, the fundamental ideology is that the world can be understood in terms of **invariant, deterministic** relationships between **fundamental** elements.

The next step is to devise an experiment which tests the validity of the hypothesis. It is important to the scientific process that certain elements can be defined as independent variables; that is, they do not depend on the other elements (variables) for their attributes, characteristics or states. This introduces another ideological presumption. Let us assume for the moment, however, that there is a domain of validity, or range of values of element attributes, characteristics or states for which this presumption is valid. The hypothesis is then typically expressed as a functional relationship between the dependent element(s) or variables and those elements or variables deemed independent. In other words, the characteristic, attribute or state of the dependent variable is **determined** by, or a **function** of, the characteristic, attribute or state of the independent variables. For example, we might hypothesize that the circumference of a circle was a function of its diameter, $C = F(d)$. Once a value is selected for diameter, the circumference of the circle is invariantly determined by the specified relationship. In many scientific investigations, the goal is to articulate the relationship between elements in mathematical terms.

The next step of the process is experimental design. If multiple independent variables are hypothesized as determinant of the state of the dependent variable (s), the experiment is typically designed in a way that controls or holds constant all of the independent variables, save one. This one element is then varied through a range of values or states, and its impact on the dependent variable (s) is recorded. This process is repeated for each of the independent variables in order to ascertain the impact of each independent variable on the dependent variable(s). The above procedure introduces yet another presumption: that the combined impact of the independent variables can be determined by a linear combination of the individual impacts. Linear combination is enabled by the presumed independence of the variables.

The potentially problematic nature of this assumption can be easily illustrated by considering the assumptions implicit in many quantitative educational research studies. Studies that intend to predict student performance in college based on personal historical factors provide a good example. Often, variables such as high school grade point, SAT scores, family socioeconomic status, use of meta-cognitive strategies, and study habits are chosen as independent variables or elements. The researcher typically comes to the not-so-amazing conclusion that a high grade point average in high school, upper middle class family background, good SAT score, strong study skills and the use of meta-cognitive strategies do, in fact, predict better student performance in college. After a regression analysis of the data, the researcher usually reports weight factors that indicate the relative impact or importance of each of these independent variables on performance. The difficulty with this analysis is the presumption that these elements or variables are, in fact, independent. Socioeconomic status, for example, has bearing on each of the other variables. These variables exist in the context of a highly nonlinear relationship. The relative importance of each of the elements is therefore additionally determined by the nature of this covariant or nonlinear relationship. The impacts, therefore, cannot be linearly added as independently acting factors with any accuracy. Some more sophisticated studies do examine covariance or address nonlinearity in their regression analysis, however, the nature of the nonlinear relationship is not explicitly demonstrated, nor are the more appropriate mathematical methods of non-linear dynamics employed. It is therefore imperative that one consider the paradigmatic presumptions inherent in this type of research, such as the true independence of selected elements or variables.

This specific example also illustrates why a qualitative research approach can provide insight beyond what can be achieved quantitatively. For example, socio-economic status has an impact on self confidence, self esteem and the resources available to a student should he encounter difficulty. It is most difficult to reduce these factors to a quantitative construct that has meaning and validity. These impacts are best addressed by qualitative methods. Calculating that socio-economic status accounts for 20.25 percent of student performance in college provides little policy guidance for college administrators. They are not in a position to raise the income level of parents. Knowing how this variable manifests itself in a student's academic life would, however, provide guidance. A qualitative study would better inform administrators in regard to what actions could be undertaken, for example, to create confidence-building experiences and to provide supplemental resources for low-income students.

After gathering and processing the data generated by an experimental investigation, the next step in the scientific method is the crafting of a relationship between the elements or variables under investigation. As stated previously, the goal is often a mathematical expression of this relationship. The reasoning process employed to determine this relationship is of necessity inductive. For example, if our hypothesis is that all swans are white, and we have gathered all available data pertaining to the color of swans, and this data confirms our initial hypothesis, we would inductively generalize that all swans are white. We have employed here what philosophers call enumerative induction; from the characteristics of our gathered data sample, we have arrived at a conclusion regarding the whole population.

This process imparts properties characteristic of induction. First, the scope of the conclusion transcends the scope of the evidence. The conclusion contains new information not explicit in the data. The evidence does not provide conclusive grounds for the conclusion. Since the conclusion expands our knowledge beyond the scope of the data, inductive reasoning does not preserve truth, as would a deductive argument. It is possible for the conclusion to be false even if the evidence is true (Boyd, 2003). In the example above, if we had failed to gather evidence about Australian swans (which happen to be black), we would have concluded falsely. Nonetheless, for those who live outside of Australia, we have generated a useful rule that will allow them to predict the color of the next swan they see with a high degree of probability. This illuminates the second aspect of inductive generalizations. They represent probabilistic judgments. They cannot, given the manner in which they are constructed, attain the status of logical necessity. If knowledge is arrived at inductively, we can never state that it is logically necessary that our conclusion is true. Logical necessity is an attribute of deductive reasoning. In a deductive argument, we can apply the rules of logic and state that a conclusion is a logically necessary consequence of the premises. This is enabled by the fact that the scope of the conclusion does not exceed the scope of the evidence or premises utilized (Boyd, 2003). A necessary consequence of this fact is that the evidence indeed provides conclusive grounds for the conclusion and the conclusion must be true if the evidence is true (Boyd, 2003). The difficulty with deductive arguments is: their validity depends completely on the validity of the initial premises. These initial premises are not usually provable through deductive process. They typically take the form of definitions, beginning postulates assumed to be true, or an appeal to what seems intuitively obvious, or they are themselves the result of prior inductive generalizations. The beginning definitions and postulates required for the development of Euclidean geometry or algebra are an example. The results of these disciplines are the logically necessary consequences of the beginning definitions and postulates. Is the fact that four plus four equals eight a fundamental truth of the universe? Many would assert that it is, including some philosophers of times past. Technically, it is simply the logically necessary consequence of the specific definitions we have constructed for numeracy, integer and the operation of addition.

Relativity

Next we consider how Einstein's Theory of Relativity alters Isaac Newton's conception of the universe and presents a major challenge to the assumptions implicit in the modern scientific paradigm. Newton's Laws were thought to deterministically and accurately describe the relationship between force and motion for all objects. The importance of these relationships to the solidification of the Enlightenment paradigm cannot be overstated. It was regarded, by 17th century thinkers, as proof positive that reason applied to the results of experiment and observation would lead to the discovery of the deterministic laws by which the universe operates. This reduced the problem of understanding and ultimately taking control of the physical world to one of finding elemental units and the deterministic laws of relationship that bind them together. The modern paradigm was set and the epistemological path to understanding the physical world through scientific inquiry was paved. Descartes ingeniously resolved the 17th century "political" problem of science through his bifurcation of the body and the mind into separate and distinct entities. The mind and soul thereby remained the province of the Church, while the realm of the physical became the province of the scientist.

Today, since most individuals are firmly entrenched in the modern paradigm, very few doubt that science reveals the objective reality of the physical universe. The problem with this viewpoint lies in the assumptions inherent in science, as discussed above. In 1880, the American physicist Albert Michelson and his assistant Edward Morley devised an instrument capable of measuring differences in the speed of light, corrected for the speed of the Earth's rotation. In accordance with the physics of Galileo and Newton, there should be a variation in the measured speed of light, when moving in different directions with respect to the source of light: $c + V$ when moving toward the source of light and $c – V$ when moving away from the source of light, where V is the Earth's orbital speed. These adjustments in relative velocity are very intuitive. If you have ever walked on a moving sidewalk at an airport, you have experienced the effect of adding the speed of the sidewalk to your normal walking speed. Much to Michelson and Morley's shock and dismay, they found no such variation. Their experiments, as well as other experiments with the same objective, have been repeated many times. There has never been any evidence of variation in the speed of light relative to the Earth (Taylor, 2005). As with every discovery that violates the prevailing paradigms of the time, these results were derided and ignored by the scientific community for over 20 years. It was not until the publication of Albert Einstein's Theory of Special Relativity in 1905, that an explanation for this experimental observation was provided. Einstein's theories of relativity suffered much the same fate as the Mickelson and Morley's experimental results. He first submitted his theory of Special Relativity as a doctoral dissertation, written to fulfill the requirements for a Ph.D. at the University of Zürich. It was rejected by his panel of professors, who viewed it as bizarre speculation (Moring, 2000). Einstein, instead, fulfilled the requirements of his degree by writing a conservative paper dealing with the determination of the size of molecules in liquids. Einstein never received the Nobel Prize for his Theories of Special or General Relativity; he received it for his discovery of the photoelectric effect. As late as 1922, when he received this Nobel, his Relativity Theories were viewed by the mainstream scientific community as speculation rather than science (Moring, 2000).

As with any deductive argument, Einstein's Theory of Special Relativity begins with a definition and postulates. An **inertial reference frame** is defined as any reference frame (system of spatial coordinates x, y, z and time t) in which all the laws of physics hold in their usual form (Taylor, 2005). The **First Postulate of Special Relativity** is:

If S is an inertial frame, and if a second frame S' moves with constant velocity relative to S, then S' is also an inertial frame.

This postulate basically states that the laws of physics hold in each reference frame; they are not impacted by the fact that the frames of reference move away from each other at a constant velocity.

The **Second Postulate of Relativity** is:

The speed of light (in a vacuum) has the same value c in every direction and in all inertial frames.

This postulate is, in essence, a formal description of the Michelson and Morley result; the speed of light is independent of the motion of the observer. Einstein (2002) did not cite Michelson and Morley, although he does allude to their result in his original paper. The first postulate is consistent with Newtonian mechanics, while the second is not. In a Newtonian universe, space dimensions and time are invariant and independent. In Einstein's universe, the speed of light is invariant. Let us now look at what this new postulate logically necessitates of the universe.

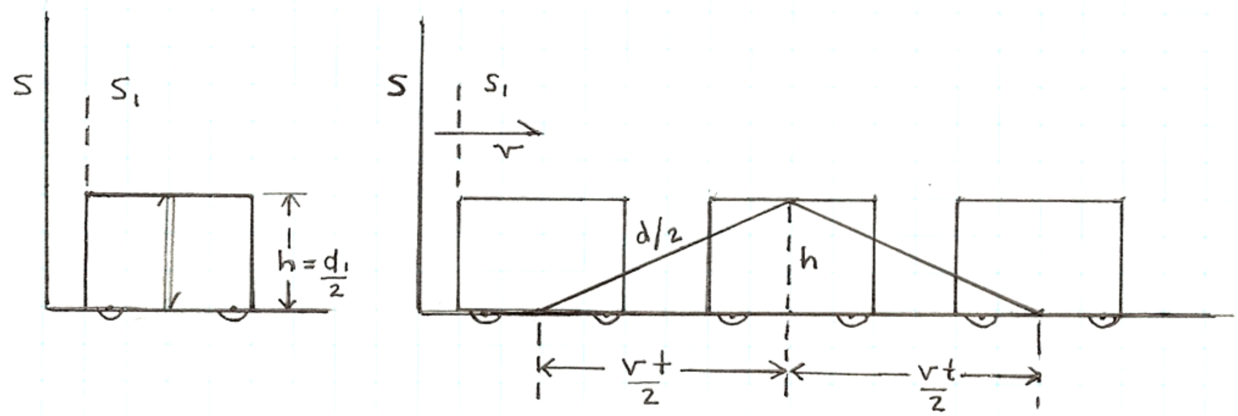
The relationship between time and space measurements in two inertial systems moving away from each other with velocity v, consistent with the postulates of Special Relativity, is given by the Lorentz transformations. Einstein (1961) provides a fairly tractable derivation of these transformations, but one that is not particularly pedagogical. Using simple algebra and deductive logic, we can heuristically, rather than formally, derive the results of these transformations, as logical necessities of the postulates, in a way that is a bit more instructive.

In the tradition of Einstein, let us conduct a thought experiment or "gedanken experiment." Suppose that we have a train capable of fantastic speeds traveling down a track. In one of the rail cars, we have an observer conducting an experiment. The observer sets off a burst of light, which travels straight up to the ceiling of the train, reflects off a mirror affixed to the ceiling, comes straight down and sets off a light detector on the floor of the railcar. The observer in the rail car records the amount of time it takes for the light beam to travel to the ceiling of the railcar and back. Similarly, there are observers standing on the ground beside the railroad track who also record the time required for the light beam to go to the ceiling of the railcar and back.

The observers on the ground see a different trajectory for the light beam than the observer on the train. The observer on the railcar sees the beam go straight up and down. Since the railcar is moving away from the stationary observers (beside the track), with constant velocity v (the speed of the train), these observers see the light beam traveling in a triangular path, as shown in the figure below. Obviously, the stationary observers see the light beam traverse a greater distance; that greater distance being a consequence of the rail car moving down the track, away from the observers, during the time interval required for the beam to travel to the ceiling of the rail car and back to the detector on the floor of the rail car.

Our intuitive sense, from episodic experience, is that all observers will record the same time for the event of the light beam arriving at the detector. After all, it arrives when it arrives, doesn't it? In Newtonian mechanics the space dimensions and the time dimension are independent, unrelated entities. The greater distance traveled by the light beam, as experienced by the stationary observers, in an amount of time presumed to be the same for both the stationary and the moving observer, is accounted for in Newtonian mechanics, by the fact that the speed of light is greater for the stationary observers. It is the speed of light (c) plus the velocity of the train (v). The addition of velocities in this manner is also intuitive and coincides with considerable episodic experience. However, according to the second postulate of the Theory of Special Relativity, the speed of light must be the same for both observers. Let us now use deductive logic and algebra to see what this postulate necessitates for space-time relationships.

While the specific derivations below are mine, a variation of them can be found in any standard textbook on Relativity, for example, Taylor (2005). For convenience we will designate the reference frame of the stationary observers S and the moving observer as S_1.



By Postulate 1, in each reference frame, the laws of physics hold in their normal form. Therefore, velocity multiplied by time equals distance in each reference frame. From the perspective of the observers in the stationary reference frame S, the light beam traverses the triangle illustrated on the right side of the above figure. The distance traversed by the beam is therefore the sum of the hypotenuses ($\frac{d}{2}$) of the two right triangles shown above. The other sides of each of the right triangles are: h, the height of the rail car, and $\frac{vt}{2}$, where $\frac{vt}{2}$ is the total distance the rail car moves in time t, the amount of time required for the beam to traverse the path shown and return to the detector, as measured by the stationary observers. Using the Pythagorean Theorem, we may write the total distance traveled by the light beam, as viewed in the stationary reference frame, as:

$$d = ct = 2\sqrt{h^2 + \left(\frac{vt}{2}\right)^2}$$

In the moving reference frame, the distance traveled by the light beam is simply twice the height of the railcar, since it goes straight up to the ceiling and back down again:

$$d_1 = ct_1 = 2h$$

By Postulate 2, the speed of light is the same in both reference frames, so we can equate c, the speed of light, in the above two equations.

$$c = \frac{2h}{t_1} = \frac{2}{t}\sqrt{h^2 + \left(\frac{vt}{2}\right)^2}$$

After some algebraic manipulation, the ratio of the time measured in the stationary reference frame to time measured in the moving reference frame is:

$$\frac{t}{t_1} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \qquad \text{(Eq.1)}$$

As we can see from equation 1 above, time is relative, given the two postulates of Special Relativity; the observer on the train measures a different time for the event (the arrival of the light beam at the detector) than the stationary observers along the track. Since the term on the right side of the equation 1 is always greater than one, the time measured by the stationary observers is always greater than the time measured by the observer in the railcar. In the language of Relativity, we say that time has dilated for the stationary observers when contrasted to the time measured by the observer in the rail car (moving reference frame). An alternative way to state this is that a moving clock is observed to run slow. How much time difference is there? The table below shows the time difference for different velocities of the train, as calculated using equation 1.

$V\ (m/s)$	V/C	α	$\gamma = t/t_1$
150000	.0005	.9999999	1.0000001
3000000	0.01	.99995	1.00005
15000000	0.05	.99875	1.00125
30000000	0.1	.99499	1.00504
60000000	0.2	.97980	1.02062
90000000	0.3	.95394	1.04828
120000000	0.4	.91652	1.09109
150000000	0.5	.86603	1.15470
180000000	0.6	.80000	1.25000
210000000	0.7	.71414	1.40028
225000000	0.75	.66144	1.51186
231750000	.7725	.63501	1.57477
240000000	0.8	.60000	1.66667
255000000	0.85	.52678	1.89832
262500000	0.875	.48412	2.06559
270000000	0.9	.43588	2.29415
277500000	0.925	.37996	2.63180
285000000	0.95	.31224	3.20256
292500000	0.975	.22220	4.50035
297000000	0.99	.14106	7.08881

Our train is imaginary and capable of fantastic speeds. If it were moving at 87 1/2 percent of the speed of light (v/c=.875), the table above indicates that there would be a factor of two difference in the measured time between events. That is, the stationary observers would record twice the amount of time for the light beam to reach the detector as the observer on the train. Although the above time relationship was heuristically derived from a physical example, it turns out to be completely general and describes the relationship of time intervals experienced by different observers in reference frames moving with constant velocity with respect to each other.

The treatment so far seems to imply that there is a preferred frame of reference. The implication of Relativity is, in fact, the opposite. The effects of Relativity are created by the relative motion of reference frames, without any regard to absolute motion, or to any idea of an absolutely fixed frame of reference. In the thought experiment which we set up, we could just as easily have conducted the light travel experiment on the ground beside the railroad track instead of on the moving rail car. In this case, we would have found the opposite effect: that time measured by the observer on the moving train was greater than the time measured by the observer on the ground.

Since the term on the right side of the equation 1 occurs so frequently in Relativity, it is usually given its own designation, γ.

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

In our moving train experiment, the time measured by the stationary observers was γ multiplied by the time measured by the observer on the train. If the light travel experiment had been conducted on the ground, the time measured by the observers on the ground would have been the time measured by the observer on the train divided by γ, or, as stated above, the inverse of the prior effect. The key to using the relative time relationship correctly is to understand that the shorter time interval occurs in the reference frame in which the two events in question occur at the same place, that is, the time clock is not in motion. This time is called, in physics, the **proper time** between the two events. The corresponding time interval measured in any other reference frame which is in motion relative to the reference frame in which proper time is measured, is always greater than or equal to the proper time. This is the reason that the effect is called **time dilation** and that the statement is made that a moving clock is observed to run slowly.

As illustrated above, a logically necessary consequence of the postulates of Special Relativity is that time is relative: the time between two events is different, when measured in different reference frames in motion with respect to each other. Another gedanken experiment will lead us to yet another major consequence of these postulates.

Using the same train we used to derive time relationships between reference frames moving at constant velocity with respect to each other, we can derive a relationship between distance measurements in the direction of motion of the reference frames made by observers in each reference frame. The observer on the ground (assumed stationary reference frame) can measure the length of the rail car by simply recording the time interval between the front of the rail car and the back of the rail car passing him. If he knows the velocity of the train, the simple relationship that rate times time equals distance yields the length of the rail car as measured in his reference frame (S).

$$l = v\Delta t$$

The length of the rail car in reference frame S_1 can be measured by placing observers at each end of the rail car and having them record the time difference between the observer at the front of the train passing the stationary observer on the ground outside of the train and the observer at the back of the rail car passing the observer outside of the train. In like manner as before:

$$l_1 = v\Delta t_1$$

If we now look at the ratio of the lengths measured by the different observers we get:

$$\frac{l}{l_1} = \frac{v\Delta t}{v\Delta t_1} \qquad (2)$$

We know from our prior work that the respective time measurements in the two reference frames are different. The equation above then implies that the length measurements are also different. We must now use caution in order to get our time relationships correct. Since the events, front of the rail car arriving at the stationary observer and back of the rail car arriving at the stationary observer, occur at the same place in reference frame S (the stationary reference frame), Δt, or the time interval measured in the stationary reference frame is the proper time. Therefore, we multiply the proper time (Δt) by γ and get: $\Delta t_1 = \Delta t(\gamma)$. Replacing this result in equation 2 above, we get:

$$l = \frac{l_1}{\gamma} \qquad (3)$$

Since γ is greater than one, the length of the rail car as measured in the stationary reference frame S is less than that measured in the moving reference frame S_1. The length measured in the reference frame in which the object is at rest is called the object's **proper length**. The length measured in reference frames in which the object is in motion relative to the reference frame is always less than the proper length and hence the effect is called **length contraction**. This result is also summarized by the phrase that a moving body is observed to be contracted. Please note that contraction occurs only in the direction of the relative velocity between reference frames, lengths in other directions are not impacted. This is the genesis of the term Special Relativity. Einstein addresses more complex relative motion between bodies and reference frames in his Theory of General Relativity.

Our previously derived relationships for relativistic time dilation and length contraction were expressed in terms of incremental time between two events and incremental distances. If we wish to express the relationships in terms of absolute times and positions in each reference frame, we can conduct yet another thought experiment with our previously utilized train and again apply a little algebra. The process is very straightforward and can be found in any standard text on Relativity (Taylor, 2005). The results are summarized below:

$$x' = \gamma(x - vt) \qquad (1)$$

$$y' = y \qquad (2)$$

$$z' = z \qquad (3)$$

$$t' = \gamma(t - vx/c^2) \qquad (4)$$

These four equations are known as the Lorentz transformations, named after H. A. Lorentz, the physicist who first proposed them. It is Einstein who first correctly interpreted them (Taylor, 2005). They express the time and position relationships between two coordinate systems: S (x, y, z, and t) and S' (x', y', z', t') moving with respect to each other at velocity v.

The inverse Lorentz transformations are derived by simply replacing v by $-v$ and exchanging prime and unprimed variables:

$$x = \gamma(x' + vt) \qquad (5)$$

$$y = y' \qquad (6)$$

$$z = z' \qquad (7)$$

$$t = \gamma(t' + vx'/c^2) \quad (8)$$

Note that $c = 3 \times 10^8$ meters per second. Time intervals measured in a military jet traveling at approximately 670 mph, or 300 meters per second, would differ from time intervals measured by an observer on the ground by less than 2 ns (2×10^{-9} Seconds), according to the equations above. It is easy to see why scientists throughout history failed to detect relativistic effects. Although Einstein predicted time dilation in 1905, it wasn't until 1941 that technology had evolved to the point that time dilation could be experimentally verified (Moring, 2000). Today, particles in nuclear accelerators routinely reach speeds approaching the speed of light. All measurements made to date on such particles are 100% in agreement with Einstein’s theories. It is an interesting comment on human nature that Einstein’s work, after a hundred years of existence and 100% experimental confirmation, is still referred to as theory, but Newton's outdated work is referred to as law.

Another thing to note is that, at speeds which are typically experienced by humans in their everyday lives, γ is for all practical purposes equal to one, v/c^2 is close to zero, and the Lorentz transformations reduce to the Galilean transformations of classical mechanics, in conformance with our episodic life experience.

$$x' = x + vt$$

$$t' = t$$

Taylor (2005) provides an interesting example of the counterintuitive nature of relativistic relationships. Assume that we have a snake 100 cm long moving along a tabletop at .6 times the speed of light ($v/c = .6$). A precocious physics student wants to give the snake a scare, but not kill it. He plans to simultaneously slam two meat cleavers, located at a distance of 100 cm apart, down on the table when the tail of the snake is adjacent to the second cleaver. He reasons that since the snake is moving at .6 times the speed of light, with respect to his reference frame, the snake will be shortened by $1/\gamma$, where $\gamma = 1.25\ for\ \ v/c = .6$ (see previous chart). The length of the snake will therefore contract to only 80 cm long, in his reference frame, and the cleavers will easily miss the snake. The snake, however, reasons that from his perspective, or in his reference frame, the meat cleavers are approaching at $v/c = .6$ and will only be 80 cm apart. He will thus be chopped to pieces. Since both circumstances cannot occur, how do we resolve this paradox? The paradox occurs because our intuition misleads us. We automatically assume that the cleavers fall simultaneously in both frames of reference. They fall simultaneously in the student's reference frame, but not in the snake's. We can use the Lorentz transformations to resolve this paradox.

Since the student plans to drop the cleavers simultaneously when the tail of the snake is at the position of the second or left cleaver, let us call this time $t = 0$ in the student's reference frame. The position of the left cleaver we will call $x = 0$. The position of the right cleaver is then at $x = 100$, in the student's reference frame. Note also that the position of the snake's tale is at $x' = 0$ in the snake's reference frame, a fact we can confirm using equation 1. We can calculate, using equation 1, the position of the snake's head in the student's reference frame at the time the cleavers hit the table. In the snake's reference frame, the position of the snake's head is at $x' = 100$. This is the snake's proper length, since the snake is at rest with respect to his reference frame. By equation 1:

$$x' = 100 = \gamma(x - vt) = 1.25\big(x - .6c(0)\big)$$

$$x' = 100 = 1.25x$$

$$x = 80$$

The student has reasoned correctly. The snake's length has contracted to 80 cm in the student's reference frame and the cleavers safely miss the snake.

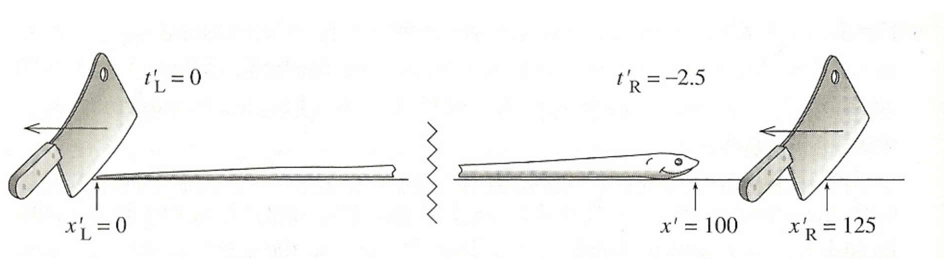
Now let's look at the situation from the snake's perspective. The time when the right cleaver falls, in the snake's reference frame, is given by equation 4:

$$t' = \gamma(t - vx/c^2) = 1.25(0 - .6(3)(10^8)(100)/((3)(10^8))^2) = -2.5 \times 10^{-9} \text{ Seconds}$$

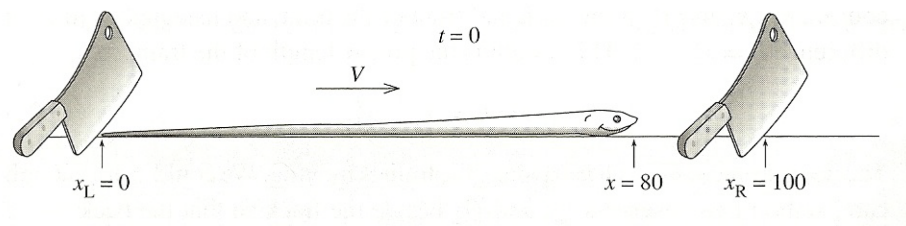
The right cleaver falls before the left cleaver, in the snake's reference frame, in fact, 2.5 nanoseconds before. The position, at which the right cleaver falls, in the snake's frame of reference, is given by equation 1:

$$x' = \gamma(x - vt) = 1.25\big(100 - .6c(0)\big) = 125$$

The snake's reasoning was partially correct; if the cleavers had fallen simultaneously, in the snake's frame of reference, they would be only 80 cm apart. The fact that the right cleaver fell 2.5 ns before the left cleaver lets them land 125 cm apart. The snake is safe from injury. The perspective from the two different frames of reference is summarized in the figures below from Taylor (2005):



Perspective from snake's reference frame



Perspective from student's reference frame

At this juncture, the reader is undoubtedly wondering why, in a tome that portends to say something about instruction and educational administration, so much time has been spent covering the rudiments of Special Relativity. First, Relativity is a beautiful illustration of Thomas Kuhn's (1996) premise, in *The Structure of Scientific Revolutions*, that science is a process that is paradigm driven. As a consequence of this, contrary to the popular modernist notion that science is a process that renders objective reality, science becomes in essence a theory within a theory.

Galileo, Descartes and Newton began their investigations with a goal; that goal was to understand the relationship between the motion of objects and the forces that act upon them. As with any thought process, such an undertaking requires a **context** within which to interpret actions and the results of those actions. Galileo supplied the methodology: a process that has come to be known as the Scientific Method. Descartes supplied the framework; a space reference frame that has come to be known as Cartesian coordinates. Newton supplied the theory with his three laws that summarize the relationship between force and motion for all objects exhibiting extension (physical dimensions). The combined efforts of these men represent one of the greatest achievements in intellectual history of mankind.

Unbeknownst to all three investigators, their efforts were predicated upon an implicit theory: that space and time were independent and absolute. To any human confined to planet Earth and to the speeds typically encountered in the course of ordinary life, these seem like very reasonable assumptions. Our perceptions, derived from our senses, tell us that the world, and presumably the universe, consists of three physical dimensions. Descartes system of specifying position by locating objects within a three dimensional grid consisting of three mutually orthogonal axes seems like a completely reasonable way to specify and quantify position. It is an approach that is consistent with our experience, again, derived from our sense perception of the way the world/universe is. That time, as we experience it, is independent of space seems intuitively obvious also. We have no experience to tell us otherwise.

The important point in the above discussion is that our sensory derived perceptions and intuitive notions of space and time are in fact assumptions derived from a summarization of experience. In this sense, they are a theory about the way the universe is. It is within the context of this theory, or set of initial postulates, if you will, that our subsequent inductions and deductions proceed. As Kuhn (1996) points out: "normal science is predicated on the assumption that the scientific community knows what the world is like"(p. 5). Once a scientific community commits to a set of shared or received beliefs:

> Effective research scarcely begins before a scientific community thinks it has acquired firm answers to questions like the following: What are the fundamental entities of which the Universe is composed? How do these interact with each other and with the senses? What questions may legitimately be asked about such entities and what techniques employed in seeking solutions (Kuhn, 1996, p.4)?

Kuhn (1996) chose to point this out about science. It can be generalized, however, to all human thought. All reasoning activity proceeds within the context of a paradigm. In its most fundamental form, this paradigm is derived through a categorization, organization and summarization of prior experience.

The Mickelson in Morley experiment provided an experience that could not be **accommodated** within the context of the existing paradigm. As our prior derivations showed, if we alter our beginning postulates so as to **accommodate** this new experience, we arrive at a set of completely different ideas concerning the nature of space- time relationships in the universe. Our newly derived "reality" is that time and space are connected via a nonlinear relationship, as expressed by the Lorentz transformations.

The Mickelson and Morley result and Einstein's explanation of it, represent an example of what Kuhn (1996) summarizes as:

> When the profession can no longer evade anomalies that subvert the existing tradition of scientific practice - then begin the extraordinary investigations that lead the profession to a new set of commitments, a new basis for the practice of science. The extraordinary episodes in which that shift of the professional commitment occurs, are the ones known as scientific revolutions. They are the tradition shattering complements to the tradition bound activity of normal science (p.6).

In the 20th century, three such tradition-shattering revolutions occurred in science: Relativity, Quantum Mechanics, and the Science and Mathematics of Nonlinear Systems. Not only did these innovations change the face of science, they changed the fundamental paradigm of thought itself, contributing a fundamental predicate and part of the basis of Post-Modern thought. In the same manner that Newton's work facilitated the emergence of Modern thought, these innovations drive Postmodernism.

My second goal in covering Relativity was to exemplify for the reader the role that prior experience plays in the learning process. As the reader will see, as we progress through this Dissertation, the entirety of my research justifies the premise that knowledge is constructed, not passively received, and that it is constructed on the platform of prior experience. As the readers of this Dissertation are highly sophisticated and possess considerable experience in abstract representation and the creation of meaning in systems that are of a purely abstract nature, I wanted to place those readers without a background in physics or Relativity in a world in which their prior experience, either concrete or abstract, was of limited help in creating meaning: Einstein's relativistic universe. I am attempting to simulate the circumstance in which students often find themselves, and in which the reader, as a professional in his field of endeavor, seldom finds himself.

During my doctoral studies, I did extensive observation of teachers and students at the middle school level, including a year-long internship at the Fort Worth Independent School District's Applied Learning Academy. My observations included watching teacher's mostly unsuccessful attempts to teach the fundamentals of Newtonian mechanics to middle school children. Teachers undertook an instructional regime that was roughly analogous to what we have just gone through with Special Relativity. In the teachers' minds, the lessons were logical, straightforward and utilized background knowledge that the students should have been familiar with. By analogy, in my prior treatment of Special Relativity, I presumed that the reader was familiar with the fundamentals of deductive logic and algebra.

The problem of understanding for the middle school student, or, analogously, for the reader without experience in Relativity, is that the results of the lesson are completely counterintuitive. They are not a summarization of any prior episodic life experience that the student has had; they are incongruent with past concrete relationships or schemas the student has constructed; and, for those students who are developmentally able to construct abstract representational relationships, they are not to be found in their inventory of prior sense-making constructions. In Newton's world, an object stays in motion at a constant velocity unless acted upon by a force (Newton's first Law). In the students' world, in which friction and gravity are always present, an object with some initial velocity always eventually comes to rest. When they roll a ball on the ground, it eventually stops. If they throw a ball into the air, it comes back down and remains at rest. They do not yet understand that gravity and friction impart forces that decelerate the ball, causing it to come to rest; this state of rest is a state of the equilibrium with surrounding forces that act in accordance with Newton's second Law. In addition, living in a world with friction and gravity, they have difficulty comprehending that Newton's second Law states that a given fixed force will cause an object to continually gain speed until acted upon by contravening force. In the students' world, increasing speed requires increasing force. In fact, because of the effects of friction, students' natural intuition is to presume that force creates speed not acceleration.

Because, in the students' world, gravity is always present, their natural inclination is to equate mass with weight. In spite of formal instruction, many students have great difficulty making this distinction. Weight is a force generated by the acceleration of gravity and distinctly different from mass. Depending on the gravitational acceleration, the weight of a given mass will vary. An object, for example, weighs less on the moon than on Earth because of the difference in gravitational acceleration.

Last, but not least, a student's life experience is that force is intrinsic to an object, a property possessed by the object. There is ample life experience to justify this belief. They see strong people who are capable of generating a lot of force. They know that oceans possess a lot of force, as do weather systems that are capable of producing tornadoes or hurricanes. The baseball pitcher they encounter in Little League gives a lot of force to a ball when he throws it. The idea that force arises from a change in motion, or that the impact of a force is a change in motion (Newton's second Law), is a difficult abstraction for students to comprehend. Dawson-Tunik and Stein (2005) have documented students' tendencies to confuse energy with both motion and force. Students also tend to think that potential energy is the potential to have energy and generally demonstrate little understanding of the principle of conservation of energy (Dawson-Tunik & Stein, 2005). So powerful are the ideas formed from students' empirical life experiences that even college physics students who have had formal instruction often return to their canonical, empirically derived, understandings when confronted with real-world problems (Reisberg, 2006).

Keith Devlin (2000) constructs an analogy for what it feels like to be a professional mathematician thinking about mathematics. When faced with a new piece of mathematics to understand or a new problem to solve, his first task is to bring alive the mathematical **concepts** involved. He states that this is analogous to creating plans and blueprints to build and furnish a house. By studying the instructions of the task, he can locate and acquire the necessary materials, furnishings and so forth. Then, step-by-step, he constructs the house. Devlin (2000) states: this is a "house built of abstract mathematical objects, fastened together by logical and structural relationships; to me, then, learning new mathematics is like constructing a mental house in my mind" (p. 125).

What Devlin describes is characteristic of expert performance. This is precisely the mechanism described by cognitive psychologists studying experts in a variety of fields. For example, Chi, Feltovich, & Glaser (1981) reported that expert physicists ignored the details of physics problems and, instead, sorted problems according to the physical principles and concepts relevant to the problem solution. Attention was paid to deep structure rather than superficial detail (Chi, Glaser, & Feltovich, 1981).

It is instructive to examine Devlin's analogy in the context of Vygotsky's (1986) theory of concept formation and the role that concepts play in directing thinking. One of Vygotsky's (1986) central themes is that concepts direct the higher-level psychological processes that the mind undertakes. Since concepts primarily arise through socio-cultural interaction, in settings like schools, the workplace, or social settings, the psychological functions that the mind undertakes, like solving a problem, are a reflection of the history of these socio-cultural interactions and their role in forming the concepts that direct thought.

For Vygotsky (1986), the teleos of development is the fully formed adult concept. Such a concept has a hierarchical structure with increasing levels of abstraction, summarization, and generality at the top of the hierarchy and decreasing levels of abstraction, but increasing levels of detail, moving down the hierarchy. At the bottom of the hierarchy, we have direct association with the objects of episodic experience. All elements of this hierarchy have a pattern of connection. They are like Devlin (2000) states for his house of math, "fastened together by logical and structural relationships." The structure reflects the individual’s prior relationship building or prior sense and meaning-making activities.

The process of building the house of math, as described by Devlin (2000), is revealing from many perspectives. What Devlin (2000) describes is an on-demand process. All of my research to date confirms that the invocation of a conceptual framework is indeed an on-demand process and is dictated by what we perceive to be the requirements of the task at hand. It would be rare and, in fact, inefficient, to invoke the full breadth and depth of our conceptual frameworks for each task we undertake. I think all of us have had the experience of saying to ourselves "I know better than that" after having initially failed to achieve an intended goal. This is our way of reminding ourselves that we failed to engage the full breadth and depth of our conceptual frameworks on our initial attempt at solving the problem.

Devlin's (2000) description also reveals that professional mathematicians, like the professional physicists referenced previously, have the building materials necessary to construct the house, as well as the plans (blueprints) to guide them in putting these materials together in order to affect the construction. Said more abstractly, they know the elements of the abstract conceptualizations and what the structure and logical connection of these elements are, in order to build the type of conceptual framework described by Vygotsky (1986) around the problem.

Devlin (2000) goes on to describe the problem solving process:

The house is there, I am living in it, and I know my way around. My next job is to move the furniture around so that it best suits my lifestyle. Because I am familiar with the house and its contents, I do not have to think about each piece of furniture individually, I can concentrate on the arrangement of the furniture, what items go with what other items. … understanding mathematics is like building the house and thereafter knowing my way around it…. working on the mathematics problem is like arranging the furniture. Thinking mathematics is like living in the house. As a mathematician, I create a symbolic world in my mind and then enter the world (p. 25-127).

Allow me to interpret this passage in the language of concept development. Devlin (2000) has constructed the conceptualization and knows his way around it, its hierarchical configuration and its connective structures. In the case of the house of math, this is, indeed, a very tall structure, reaching the highest level of abstraction described by Fisher and Rose (1998) as abstract systems thinking. Because Devlin (2000) built the house and is familiar with it, he does not have to think about each item within it individually, he can concentrate on the arrangement. What Devlin (2000) describes here is a central feature of abstract representation. Once something has been abstractly represented, it is no longer necessary to think about the myriad individual details of the numerous exemplars from which the abstraction was formed. That is the beauty of abstraction. These details have been categorized, organized and summarized into the abstraction. For example, when we use the term circle we know that it has attributes such as diameter, circumference and area. We also know that there is a relationship between these attributes, such as the circumference being equal to the diameter times π. These attributes and relationships hold true for all things which we term circles. In this way we are freed from the particulars of each individual circle that we may have encountered or that we may have used in deriving these relationships and attributes which are common to and summarize all things represented by the abstraction circle. When Devlin (2000) states that he concentrates on the arrangement of the furniture rather than on individual pieces, I metaphorically interpret this to mean that he is free to create an organization or set of relationships at the higher logical level of the abstract representations. In fact, as we saw when we discussed Piaget, it is precisely this organizational process that gives rise to the next higher logical level of abstraction. For example, it is the process whereby we would go from the consideration of systems exemplifying adaptation to the generalized conception or super-ordinate concept of adaptation as a summary articulation of the common features of the individual systems.

Devlin (2000) describes working on a problem as arranging furniture so that it suits his lifestyle. I metaphorically interpret this, in the language of concept formation, to mean that the problem is placed in the context of the organizational structure of his mathematical conceptualizations (house of math) in such a way that it is stable and congruent with that structure. The final result is a stable configuration that meets the constraints, requirement, goals, and needs of both the problem and the problem solver. This is a process that Piaget (1985) calls the equilibration of cognitive structures. In the work of Maturana and Varela (1998), it is called affecting a structural coupling that satisfies the requirement for autopoiesis. Depending on the problem and the existing conceptual structure, the process can be either **assimilation**, like adding an extra chair at the dinner table; or, the conceptual structure might require modification to **accommodate** the particulars or idiosyncrasies of the problem, like building or creating an exercise room in the house to accommodate a new treadmill. In either case, the goal is the creation of stable, congruent and equilibrated conceptual structures (arrangements that suit one's lifestyle, in Devlin's terms).

Let us get back to the poor middle school students struggling to understand Newtonian mechanics and the cognitive researcher's novice physicists who focused on the surface features of problems rather than on core physical principles. These struggling young physicists do not yet live in a house of physics. They stand amidst bricks, bags of mortar, and stacks of pipes. As of yet, they are not in possession of a plan or blue print with which to build this house. Faced with a problem, is it any wonder that they simply rummage around the building materials (focus on the surface features of problems) and employ the most primitive of problem solving strategies: trial and error? More accurately, what we see them do is search for a previously presented formula that relates the variables given and the variables unknown, as they are presented in the statement of the problem. This is a problem-solving heuristic known to everyone who has been a student for awhile. It is a procedure (procedural learning articulation) in which most students are extremely well-versed. Put eggs in a bowl, mix vigorously, place in a pan, heat, and voila, we have scrambled eggs. If students can memorize the recipe (formula), all the better for them, when it comes time to take a test.

Part of the problem is our obsession with content coverage. Students have barely begun to build the foundation of the house when the next group of trucks arrive full of brand-new building materials. We need instructional programs that teach students how to construct houses of math and houses of science. These will not be the grand edifices that can be constructed by professionals in these fields. But, we can give them sufficient experience, cognitive strategies and conceptual structures to build houses that will keep them out of the rain and allow them to solve real, practical problems they may encounter in the course of their lives.

Let us return to our relativistic snake. I ask the readers unfamiliar with physics and relativity to introspectively ask themselves whether they could have resolved the snake paradox before they saw the solution to the problem presented. Could they solve the problem if we now restate it such that the student drops the cleavers when the head of the snake is opposite the cleaver on the right side of the diagram? Is the snake still safe? We used equations one and four in the solution of the original problem. Would we still use the same equations in the restated problem, or would we instead use equations five and eight?

These are difficult questions to answer at this stage of the learning process. College physics students, learning this material for the first time, would simply have to try to solve the problem in a manner analogous to how the original problem was solved. Their professor, however, could answer these questions without writing down a single equation. The difference here is depth of experience and the fact that the professor has developed a strong qualitative understanding of the conceptual framework of relativity, a house of relativity, if you will. I have every confidence, given the intellectual level of the reader is that if they solved several relativity problems and went back iteratively between the conceptual framework and their concrete expression in the problems several times, in the effort to give meaning to the theory, they would gain the qualitative understanding and conceptual framework to answer these questions as easily as the physics professor could. The readers however, are at the highest levels of intellectual ability and have attained the highest of academic credentials. As such they have considerable experience undertaking this type of process. The middle school students I observed received neither sufficient time to build experience nor guidance in the process of creating meaning for the abstraction by understanding its articulation in concrete terms, nor were they given guidance and experience in creating the abstraction from relationships manifest in concrete objects and interactions. They simply made an attempt to memorize relationships that held little meaning for them and were counterintuitive in the context of their real episodic experiences.

With the Theory of Relativity, Einstein completely eliminates the physical objectivity of space and time. In arguing for his position, he asks us to reconsider the assumptions, ideas and frameworks that underlie our current conceptions of space and time (Einstein, 1961). His arguments constitute a deconstruction in the sense of this term, as interpreted from the work of modern philosopher Derrida (1976), or curriculum theorists Pinar (2004) and Slattery (2006). We will discuss deconstruction as pedagogy, more specifically, later in the Dissertation.

Einstein (1961) begins his deconstruction of space-time by re-examining the assumptions of Euclidian geometry. Euclidian geometry begins with defining conceptions, such as point, line and plane, which we can associate more or less with definite ideas. In addition, Euclid states five simple beginning axioms or postulates. We are inclined to accept these postulates as "true" by virtue of the plausibility of the defining conceptions and their congruence with our general episodic experience. For example, Postulate one is: given two points, there is one straight line that passes through them. There is nothing in this axiom that our episodic experience would compel us to argue against. In fact, this statement seems rather obvious. We can get a piece of string and use it to convince ourselves that this axiom must be "true."

The theorems of geometry are what follow as logically necessary, given these beginning definitions and postulates. A theorem is "true" if it has been faithfully derived in accordance with the formal rules of deductive logic. As discussed previously, the caveat of deduction is that the ultimate "truth" of the theorem is contingent upon the truth of the beginning axioms.

How are we to ascertain the truth of these axioms? Einstein (1961) points out that the methods of geometry cannot answer this question, and, in fact, the question itself has no meaning.

We cannot ask whether it is "true" that only one straight line goes through two points. We can only say that Euclidean geometry deals with things called straight lines, to each of which is ascribed the property of being uniquely determined by two points situated on it. The concept of "true" does not tally with the assertions of pure geometry because by the word "true" we are eventually in the habit of designating always the correspondence with a "real" object; geometry, however, is not concerned with the relation of the ideas involved in it to objects of experience, but only with the logical connection of these ideas among themselves (p. 4).

In the quoted paragraph, Einstein (1961) stakes out a considerable amount of epistemological turf. First, he implicitly offers us a definition of "truth". Truth is, ultimately, correspondence of concept and theory with "real" physical experience. While this definition is less than satisfying philosophically, it is certainly consistent with the scientific conception of truth and does pragmatically describe how humans tacitly understand "truth". I believe that Einstein understands that an abstraction is a summarized and abbreviated representation of reality, or in the words of Korzybski (Bateson, 2002), that the map is not the territory and the name is not the thing named. As such, ideas of “truth” within abstract systems, or relationships among abstract representations, can be judged only with respect to their internal consistency and conformance to the formal rules of logic. The truth of these relationships, as he defines truth, is ascertainable only by judging, ultimately, their conformance to observable, measurable physical reality. In other words, any derivation consisting of a relationship between abstract representations, must ultimately be subjected to experimental confirmation before we can judge its "truth".

Einstein (1961) also provides, in this paragraph, a partial definition of "meaning". Einstein (1961) implies that meaning is derived through relationship. It is solely through the context of a relationship that we can appraise whether something has meaning. Since geometry is the logical connection of ideas among themselves and not concerned with the relation of these ideas to objects, there is no "meaning" to the question of whether the axioms of geometry are "true". We can only ask whether the internal relationships among the ideas are “true" (logically consistent). This position coincides with that of Gregory Bateson (2000; 2002) whose work persistently and emphatically makes the point that meaning is derived through an understanding of the "pattern that connects", or in other words, through relationship.

Einstein (1961) creates a relationship between geometry and real physical objects which will permit a question with meaning to be asked. He picks two points on an extended rigid body and places a line between them, as per Euclid. According to geometry, the distance between these two points, along the line, should always be the same; independent of the change in positions we subject the body to. In this way, Einstein (1961) moves geometry into the realm of physics (by introducing motion), creates a relationship between the abstract and the physical, and facilitates a method for the determination of "truth". This facilitation is the physical experience that is consequent to an experiment. Shortly, we will review a “gedanken” experiment from Einstein's original paper on General Relativity. We will examine how geometrical constructions, such as the one previously described, hold up when objects are viewed from reference frames in relative motion with respect to each other. We will find that the "truth" of Euclidean geometry is indeed limited and that our experience is rather incomplete. Before moving on to this, there are two additional topics that are worthy of elaboration.

Einstein's previous description of geometry is formal. Certainly, Euclid had in mind that his geometrical ideas corresponded more or less to real objects in nature. His intention, no doubt, was to derive laws of relationship which exist in actual objects which exhibit extension in the physical world.

The process employed in geometry can be abstracted because it manifests an immanent pattern that exists in every form of abstract mental reasoning. A complete description of real physical objects, utilizing all possible sensory data and encompassing the specific and idiosyncratic uniqueness of each object, would render them ineffable; it would constitute an impossibly lengthy, unwieldy, and cumbersome description. We speak instead of classes of objects which share specific chosen attributes or characteristics we have judged to be common in and distinguishing of the class. The class is **similar** with respect to the characteristic and, if we have chosen wisely, differentiated from other classes by virtue of the defining or distinguishing nature of the characteristic(s) chosen. It is in this way that **similarity** (and difference) and **classification** is fundamental to thought**.**

It is important to note that our classes are approximations or **representations** of the real objects (the map is not the territory). They are distillations or summarization in accordance to characteristics deemed similar and seminal to the class. How do we go about selecting appropriate characteristics or attributes? At this stage of human history, they are largely socio-culturally transmitted, and, in great measure, transmitted through formal education. It is important to remember Bateson's (2002) admonition concerning this process: "The division of the perceived universe into parts and wholes is convenient and may be necessary, but no necessity dictates how it shall be done" (p. 35). Bateson's (2002) point here is that our selections of similar and distinguishing characteristics that go into the determination of our classifications are arbitrary and likely to be goal and context driven. These choices do not possess the property of being logically necessary; other individuals or societies could, with complete legitimacy, parse the universe in a completely different fashion.

In the natural world, it would be hard to find precise points, straight lines, planes, triangles, parallel lines and circles, or their three-dimensional extensions: cubes, right circular cylinders, spheres and pyramids. We can, however, find objects that are more or less similar and for which Euclidean geometric definitions usefully summarize attributes which we may deem salient in defining and characterizing the object's extension. The abstract, synthesized representations which we construct generally become paradigmatic if they are found to be consistently useful. If the readers doubts that we live in a Euclidean paradigm, they need only peer out of their windows at the many man-made objects juxtaposed against various natural objects. They will see cubical buildings with roofs consisting of planes intersecting to form triangular shapes. They will see linear walls intersecting at right angles. They will, in fact, likely be looking through a rectangular frame holding a plane of glass. Juxtaposed against this Euclidean world are the curved, infinitely varying and asymmetrical forms of the natural world (trees, plants).

The power afforded by the heuristic of abstract representation goes beyond simplifying the natural world into units sufficiently tractable for thought. The real power of abstract representation is that it frees us from thinking only in terms of the actual individual physical objects of our experience. It allows us to summarize our experiences in meaningful ways. Each subsequent encounter with the object is not a unique experience to be relived as if the prior encounter never occurred. Once generalized and abstractly represented, we can think about these objects whenever we wish and without the necessity of an encounter. We can develop theories, theorems and other relationships that speak to entire classes of objects: relationships that are "true" for the classes that possess the similar and defining attributes/characteristics that were utilized to form the class.

If we view, for example, a tree trunk in a Euclidean context, as approximately a right circular cylinder, and we measure its circumference and height, we can determine, using the deductively derived theorems of Euclid, the diameter of the tree, surface area of the tree, the area of the base of the trunk and the volume of the tree. These would be useful pieces of information for anyone in the lumber business. It would permit determinations like: a) how many tree trunks could be stacked in a building or transported on a truck that had specific dimensions, b) the total amount of material derivable from a tree trunk or c) how many boards of a certain dimension(e.g. 2'x4') could be cut from a specific tree trunk. For the individual in the lumber business each encounter with a tree is not a unique experience in which all is unknown and problems must be solved in trial and error fashion. Once she accepts Euclid's construct of a right circular cylinder as sufficiently representative of the salient properties of extension for a tree trunk, she is freed from considering individual trees and can surmise things concerning the whole class. If she knows, additionally, the abstract system of statistics, life gets even easier. She can dispatch someone to measure the heights and circumferences of a representative sample of trees and make appropriate plans to harvest, transport, store and process an entire grove of farm planted trees. It is important to note that the abstract systems of geometry and statistics allow the individual to plan, project and design without cutting, transporting, or storing a single actual tree. It is this facilitation of prediction, planning and development of strategy that is the most powerful attribute of abstract representation.

There is another epistemic that we can derive from our consideration of Euclid, or, in general, any abstract knowledge system that evolves rules of relationship. As stated previously, the contingency of such a system arises from the starting definitions and axioms. These beginning definitions and axioms are, in turn, derived within a context. As previously discussed, meaning derives from relationship, or, in other words, it is through relationship that meaning arises. For the creation of meaning, we also require that something be seen in a specific context. As an example, consider the following sentences:

1) She caught the ball.
2) She put on a gown for the ball.
3) She had a ball at the party.

The relationship between the words gives meaning to the sentence. We understand what the sentence means by relating the words. The meaning of the word ball in each of the above sentences is also dependent on an implicit context. In the first two sentences, the context is suggested by the relationship of the words in the sentence. Our mind invokes the context that allows the relationship of the words in the sentence to have meaning. The verb catching suggests the context and infers the specific definition of ball as a portable spherical object. Likewise, the second sentence suggests the meaning of the word is a formal dance since it is unlikely that the lady in question would put on a gown for the benefit of a portable, spherical object. In each case, the invoked context assists in parsing the sentence in a meaningful way. The third sentence, however, is ambiguous. It is interpretable only if we had been provided a context before reading the sentence or if a subsequent sentence allowed us to build a context. The relationship of the words is insufficient for understanding. The lady could either have had a spherical object at the party (beach party) or she could have had fun at the party.

The specific context employed also controls the type and depth of meaning derivable from relationships. Bateson (2002) supplies a couple of good examples. He cites Goethe's revision of the gross comparative anatomy of flowering plants. Goethe was unsatisfied with characterizing a leaf as a flat green thing or a stem as a cylindrical thing. Goethe, noting that buds formed in the angle of leaves, built definitions based on relationships between leaf, stem, bud and so forth.

In Bateson's (2002) opinion, the way we teach children language is nonsense. A child is taught that a noun is a person, place or thing and that a verb is an action word. They are taught that the way to define something is by what the thing is, not by what relationship it bears to other things. He advocates defining parts of speech in terms of their relationship to other parts of speech. For example, a noun would be defined by the relationship it bears to a verb. I couldn't agree more. Not only would this facilitate greater retention, it would also impart a greater depth of understanding regarding the elements of language and their use in effectively articulating thought and creating meaning.

We will now examine, through Einstein (2002), how Galileo, Newton, and Descartes created a context for physics which ends up being limiting in the sense previously discussed. To give meaning to the extension of physical objects and to their change in position with time, or motion, we require a frame of reference or context. The frame of reference that made sense to Descartes and Newton was the articulation of space in terms of three mutually orthogonal axes emanating from an origin. The origin we can place at a point convenient for our subsequent analysis of extension and motion. Once placed, however, it is presumed to be fixed. In addition, to quantify time, we require concurrence on some handy metric. Any mechanism by which we can divide time into equal increments or "units" will do. As Einstein (2002) points out, our physical experience of "events" amounts to coincidences in space - time of the event and our chosen frame of reference. Einstein (2002) states:

The introduction of a system of reference serves no other purpose than to facilitate the description of the totality of such coincidences. We allot to the universe four space-time variables $x_1,\ x_{2,},\ x_3$, and x_4 [x, y, z, and t in Cartesian coordinates]. … to two coincident point-events there corresponds one system of values of the variables $x_1,\ x_2,\ x_3$ and x_4, that is, coincidence is characterized by the identity of the coordinates. If in place of $x_1 \ldots x_4,$ we introduce functions of them, $x_1',\ x_2',\ x_3',$ and x_4' as a new system of coordinates so that the system of values are made to correspond to one another without ambiguity, the equality of all four coordinates in the system will also serve as an expression of the space-time coincidence of the two-point events. As all our physical experience can be ultimately reduced to such coincidences, there is no immediate reason for preferring certain systems of coordinates to others, that is, we arrive at the **requirement of covariance** (p. 39-40).

What Einstein feels he has done with this argument is to show the logical necessity of General Relativity: that the laws of physics need be invariant (what Einstein's term covariance means in common language) with respect to the choice of reference frame. In other words, our arbitrary choice of reference frame or context does not change the reality of the relational structure which exists (i.e. the laws of physics). Said in philosophical terms, we do not change the "thing in and of itself" by how we look at it or the metrics by which we choose to evaluate it.

We now review a thought experiment from Einstein's (2002) treatise on General Relativity that illustrates the limitations of Euclidean geometry and Newtonian formulations of mechanics. First, the coordinates of space-time in Newtonian mechanics have a direct physical meaning. When we say that a point event has x coordinate x_1, we mean that the projection of the point on the x-axis, as determined by the rules of Euclidean geometry, is x_1 times some unit length from the origin of the coordinate system. The unit length is defined as some distance on a fixed linear rod such as a ruler. When we say that a point event occurs at time, t_1, we mean that a standard clock, made to measure time in definite unit increments (for example, seconds), and which is stationary relative to our system of coordinates and coincident in space with our point event, has measured off t_1 units of time at the occurrence of our point event. Einstein (2002) points out that this view of space-time has always been in the mind of physicists, even if it has been subconscious.

Now consider two Galilean/Cartesian systems of reference, S (x, y, z, t) and S' (x', y', x', t') , with the S' reference system in uniform rotation with respect to S. Let the origins and the vertical, or z axes, of the two systems coincide. In this way, S' rotates around this mutual z-axis. We now place a circle in reference frame S. By reason of symmetry, a circle in reference frame S will also be a circle in reference frame S'. We rotate reference frame S' at a speed which is an appreciable fraction of the speed of light. If we measure the circumference of the circle and its diameter in the fixed reference frame S, in which the circle is at rest, and we divide the two measurements, we find that the quotient is π, a result familiar to us from Euclidean geometry. Consequent to the theory of Special Relativity, if we measure the distance along the periphery, or the circumference of the circle, in reference frame S', which is moving at some fixed velocity v with respect to the fixed reference frame in which the circle lies, the distance will be contracted in accordance with the previously discussed Lorentz transformation. The diameter, which is normal to the direction of motion, is not impacted and measures the same in both reference frames. Therefore, if we divide the circumference by the diameter, we will get a quotient that is greater than π, in reference frame S'. In fact, the ratio of circumference to diameter is a function of the relative velocity between the two frames of reference or, said another way, the relative speed of rotation of S' with respect to S. Euclidean geometry, hence, does not apply to reference frame S'. The concept of coordinates, as defined above, which is contingent on Euclidean geometry, breaks down with respect to S'.

The problem is exacerbated when we consider time. If we place identical clocks at the coincident origin of both systems of reference and on the periphery of the circle in both systems of reference, and we view the situation from the stationary reference frame, we get different times for events than would an observer on the periphery of the moving reference frame. By Special Relativity, the clock at the circumference in the moving reference frame moves more slowly than the clock at the origin. An observer at the coincident origin of both reference frames "will be obliged to define time in such a way that the rate of a clock depends upon where the clock may be" (Einstein, 2002, p.39). Such a circumstance plays havoc with a Newtonian formulation of mechanics.

The thought experiment above also creates, for Einstein, an epistemological problem: one that was first called to his attention by Ernst Mach (Einstein, 2002). Relations in mechanics are relations of time, space, momentum and so forth. It appears, from the above, that our choice of reference frame **causes** a change in those relationships. But, as Einstein (2002) points out:

> … a merely factitious cause and not a thing that can be observed. No answers can be admitted as epistemologically satisfactory, unless the reason given is an observable fact of experience. The law of causality has not the significance of a statement as to the world of experience, except when observable facts ultimately appear as causes and effects (p. 36).

Since reference frames are mental constructs implemented to facilitate relational meaning and not real physical objects of the universe, they cannot **cause** physical phenomena. Said more directly, the way we choose to view, describe, evaluate or understand something cannot change the "thing in and of itself". For example, the Red River and the trees along its banks are completely indifferent to the fact that we have designated this river as the boundary between Texas and Oklahoma. This is a mental construct we have imposed to define the physical boundary of political entities. The trees will grow and the river will change course without any impact from this arbitrarily imposed border. This boundary has meaning only to those who have imposed this context and who recognize and assign significance to it. In similar fashion, the universe is completely indifferent to the fact that we have chosen to describe it with a Cartesian coordinate system, unit lengths on a fixed linear rod and standard clocks. In summary, these metrics are arbitrary constructs which we have fabricated in order to impose a context and describe relationships that permit the creation of meaning for observed (sensed and perceived) phenomena.

How did Einstein extract himself from the dilemma posed by the prior thought experiment? First Einstein conceived of the equivalence of gravity and acceleration. Einstein called the day that he had this thought, the happiest day of his life (Moring, 2000). This conception can be understood with the benefit of yet another thought experiment. If we have a traveler in a spaceship with no windows, completely isolated from the outside of the spacecraft, traveling at constant velocity, that traveler will not have a sensation of motion. Since the traveler is in space, he will also be weightless. The traveler may, in fact, be floating around the spacecraft. If the spacecraft begins to accelerate, let us say in the direction that his head is currently pointing, the traveler will feel a force; his feet will likely become planted on the floor of the spacecraft opposite his head, and he will feel as though he were under the influence of gravity. Being completely isolated from the outside of the spacecraft, he cannot distinguish whether the force he feels is caused by coming under the influence of the earth's or another celestial body 's gravity or is a force imparted by the acceleration of the spacecraft. Einstein's happiest thought was that it is impossible to tell the difference between the force of acceleration and the force of gravity without a frame of reference. This has become known as the principle of equivalence of gravity and acceleration (Moring, 2000). Please note that this abstracts into the general principle that **the creation or interpretation of meaning requires a context**.

Einstein (2002) expresses this in terms of two reference frames, one of which is uniformly accelerated with respect to the other. In the first reference frame, call it S, a mass is moving with uniform motion in a straight line. Relative to the accelerated reference frame, call it S’, this mass would have an accelerated motion such that its acceleration is independent of the material composition and physical state of the mass. Can an observer at rest relative to S’ infer that he is actually on an accelerated system of reference? No, it can be equally interpreted that S’ is not accelerated, but that the mass is under the influence of a gravitational field which generates the accelerated motion relative to S’.

In our treatment of Special Relativity, where coordinate systems moved with constant velocity with respect to each other, logically necessary consequences of our beginning postulates were transformations that related one coordinate system to another: the Lorentz transformations. When reference frames accelerate with respect to each other or move complexly with respect to each other in order to conform to the postulate that the laws of physics cannot be altered by our choice of reference frame, as discussed at length above, the transformations become much more complex. It is necessary to abandon Cartesian coordinates and express space-time in the curvilinear geometries of Gauss and Reiman. The mathematics involved is very complex. But, it is precisely these transformations of coordinate systems, which preserve the invariance of the laws of physics that "produce" the effect that we know as gravity. Gravity is not a mysterious force generated between objects with mass; it is the curvature of space-time in proximity to objects with mass. As Einstein (2002, p.37) states: "… in pursuing a general theory of relativity we shall be led to a theory of gravitation, since we're able to "produce" a gravitational field merely by changing the system of coordinates."

We can get an approximate feel for the effect of space-time curvature by considering a simple analogy. Let's say we have a trampoline and we place a bowling ball in the middle of it. If we roll a marble in a straight line on the edge of the trampoline, it will likely remain in a straight line. If we roll the marble a little closer to the bowling ball, it will move into the depression created by the bowling ball but, if it has enough velocity, it will come back out and continue across the trampoline. If we roll the marble closer yet to the bowling ball, it will move into the depression created by the bowling ball and come to rest next to the bowling ball. This is the situation that occurs near a black hole or super-dense mass. Although only a three dimensional example, this gives one a flavor for space-time curvature effects.

I now ask the reader to allow me to epistemologically abstract the implications of Einstein's work. The implication is that we can choose, at will, the context and consequent "metrics" (attributes or characteristics) by which we facilitate understanding and enable the creation of meaning. Our reference system:

a) must unambiguously describe the phenomena,
b) is a necessity for understanding and the creation of meaning,
c) cannot possess the quality of logical necessity or constitute "the" way of characterizing the phenomena, and
d) does not control the nature of the relationship existent in the "thing in and of itself."

In other words, there is no context or perspective that is unique, fundamental or logically necessary. This result is consistent with the idea in postmodernism that no single perspective or context constitutes "the" way of characterizing or understanding a phenomenon. There is, however, a substantive difference regarding the development of understanding implied by d) above and the traditional postmodern position that different contexts or perspectives cannot be reduced to one another, or that we cannot abstract a single result from multiple perspectives. The implication of d) above is that multiple contexts can be related, because they describe the same thing. And if related in a way so as to preserve an invariant relationship within the thing in and of itself, the relationship between contexts becomes a source of considerable insight. The traditional postmodern view is that understanding is developed by examining a phenomenon in multiple contexts, and in so doing, defining a morphology or structure of understanding (Guba, 1985). We can move through this morphology (landscape) and view our object of consideration from a multiplicity of perspectives and thereby achieve a greater overall understanding. A related and more subtle postmodern expression of evaluation from multiple perspectives is that an overall understanding emerges or morphs out of simultaneous or contemporaneous consideration of multiple perspectives. This idea is a bit more diffuse. As an example, what would be our concept of a person, say Betty? Our concept of Betty might include her physical features, her personality, her intellectual capabilities, her personal history and our experiences interacting with her. These are all different contexts within which we view Betty, come to understand her and form our concept of Betty. None of these contexts are reducible to another context. We cannot understand Betty's intellect in the context of her physical appearance. Taken together, however, these various contexts do morph into some composite understanding or idea of Betty as a person. Given the task of defining Betty, we would perhaps respond with an extensive definition and list a compendium of her characteristics or attributes within the various contexts. We might say that Betty is beautiful, intelligent, but rather aloof. We might say that it has been hard to get to know her. Item d) above would suggest that we could understand Betty better if we connected these seemingly unrelated contexts, since all describe the same thing, Betty. For example, Betty's aloof demeanor may have evolved as a protective mechanism in response to her understanding that some past relationships with others were the result of her appearance and not an appreciation of her as a multidimensional person with much to offer beyond physical beauty.

I am completely empathetic to the socio-cultural objectives of this postmodern viewpoint. Many of our knowledge systems have evolved within limited socio-cultural paradigms and from initial assumptions that reflect the bias of groups which held power over the development of systems of knowledge. Certainly, the pre- modern history of Western thought represents an example of such a circumstance or dynamic. The voices and perspectives of those with lesser political or economic power have indeed been silenced throughout history and must be heard if we are to have a full understanding of our world and its occupants. It is also absolutely invaluable to view things from multiple perspectives in order to create a tapestry or morphology of understanding. Statement d) above does not conflict with these ideas. It does imply, however, that a relationship between multiple contexts can be invaluable in revealing the nature of the relationships existent in the object of our consideration and in revealing phenomena not apparent within or derived from the individual unrelated perspectives. For example, when we conserved the laws of physics and related two different contexts (frames of reference) in Special Relativity, we found that time and space were nonlinearly connected, and we deduced consequent effects like time dilation and length contraction. When we conserved the laws of physics for contexts or reference frames that accelerated or moved complexly, with respect to each other, we deduced that gravity was in fact a change in the shape of a connected space-time continuum around objects with large mass.

The obvious caveat to the Relativistic epistemic above is whether there actually exists a unique relationship within the thing in and of itself. A Pacific ocean full of ink has been spent in the history of Philosophy arguing this point. It is an unsolvable metaphysical problem. To take a position that something possesses a unique invariant reality implies that there exists an absolute frame of reference or context. We have seen from the discussion above that no such context is determinable. The best we can hope for is that through a relational combination of multiple contexts, some invariant relationship in the thing in and of itself is emergent. What we will still never be sure of is whether that relationship is unique, absolute and independent of the specific contexts we employed and subsequently combined. Some philosophic camps have gone so far as to suggest that there is no reality and that the universe is devoid of intrinsic meaning (existentialism).

We need not stake out a position or come to a conclusion regarding whether there exists an invariant relationship or reality within the thing in and of itself. We can take the position that our epistemic is, for the time being, a powerful problem-solving strategy. As Einstein did with Relativity, we can probe the creation of relationships between multiple contexts in a way that preserves a consistent relationship within the object of our consideration and simply see what insights that provides.

When we deliberate the epistemic implications of Quantum Mechanics, we will see almost the inverse of the epistemic discussed above. In Quantum Mechanics, objects do not possess an invariant reality. They possess a probabilistic distribution of possible states of existence or potentialities. It is not until objects interact with each other that a physical reality manifests itself. Theoretical Physics has thus far been unable to combine or resolve Relativity with Quantum Mechanics. This still remains The Problem of Theoretical Physics. The first person or group of individuals who effect this reconciliation will ascend to the throne of Science and may even have a bagel shop next to the TCU campus named after them (inside joke).

In the introduction to this Dissertation, we talked about four different perspectives on child development, which were developed in four separate contexts. Can we relate these different contexts and further our understanding through this relation? What is the implied relationship within the child that remains invariant among these different contexts?

These questions bring up another possible caveat to the relativistic epistemic that we have been discussing. Note that all of Einstein's contexts or frames of reference exist at the same logical level: that of space and time dimensions. What we find when we compare Skinner to Piaget and Vygotsky is a difference in the logical levels of their contexts and consequent conceptions. Association and operant conditioning do exist within Piaget and Vygotsky's contexts. They exist, however, as mechanisms operating at a lower level of psychological functioning. Concept formations in Vygotsky' system and the evolution of operational schemas in Piaget system, involve higher psychological processes which incorporate association as a lower-level mechanism. The relationship between contexts here is hierarchical or vertical rather than lateral. The genetic perspective is at an even lower logical level than the three aforementioned contexts and can be incorporated in all of them as an agent or factor. Freud's subconscious is at a collateral level with the contexts of Piaget and Vygotsky. We have to go one logical level higher to accommodate all three of these systems within a more general theory or super-ordinate conception of development.

Having extensively used the term logical level without much elaboration, let's examine this crucial concept more closely. As with any concept, it is hard to ascribe its emergence to any one individual. One of the more famous articulations of logical level can be found in Oxford philosopher Gilbert Ryle’s (1949) successful refutation of Descartes’ bifurcation of mind and body. Ryle (1949) takes the position that Descartes’ argument contains a logical category or logical level mistake. He uses the example of a visitor who is shown the classrooms, colleges and libraries of a University and then asks, "yes, but where is the University?” The point here is that the term University is an abstraction at a higher logical level, which summarizes and includes within it the various elements the visitor observed. The term does not exist as a separate physical manifestation, but only as an abstraction summarizing the collective phenomenology of the lower level physical entities. Ryle's (1949) formal statement of this point is that it is permissible to construct conjunctive propositions (propositions connected by the word “and”) only when things belong to the same logical category. In the example above, it would not be permissible to say that there are classrooms, colleges, libraries <u>and</u> a University, as this implies that they are separate and distinct entities. He offers, also, an example of a pair of gloves. It is permissible to say that there is a left-hand glove and a right-hand glove. It is also permissible to say that there is a pair of gloves. It is not permissible to say there is a left-hand glove, a right-hand glove and a pair of gloves, because this implies that these are three different items. The term pair of gloves is at a higher logical level and includes within it the right-hand and left-hand gloves. Similarly, it is correct to say there is a mind, and it is also correct to say there is a body. Descartes' conclusion that there is a mind and a body is a mistake because mind and body belong to different logical categories. The mind no more exists separately from the body than the University exists separately from its classrooms, colleges and libraries. This thought is captured in the colloquialism: mind is what the brain does. One cannot open a skull and find the mind. The term mind is an abstraction that refers to a composite or aggregate, and the phenomenology produced by the relationship of the various elements that comprise the composite.

Artificial intelligence pioneer Marvin Minsky (1985) makes a similar point when he draws the distinction between agent and agency. If we look at any mechanism (mind or machine) that exists in systemic relationship, or as a system, we can inspect the individual agents or parts and see what each agent does. This will not inform us, however, as to what all these agents working together in cooperative relationship can do or accomplish. We must look at the system in aggregate to determine the phenomenology of the whole or the combinatorial consequences of the sum of the individual actions of the parts or agents. This Minsky (1985) refers to as the agency of the agents. As we will see, time and again, simple actions of individual agents, when placed in a cooperative relationship, or in a system, can produce complex phenomenology that dramatically exceeds the sum of the individual actions of the parts or agents. This is particularly true if the relationship between the agents is of a codependent nonlinear nature. The most profound example is how electrochemical interactions between neurons in the brain can combine to produce complex emotions. The fundamental predicate of systems theory is that all systems can be characterized by the same set of general principles of operation regardless of what they are composed of. For example, the emergence of new phenomena that must be articulated within a new and emergent context is a characteristic of all systems or things placed in systemic relationship. The goal of systems theory is the discovery of those principles common to systems of all types. An important point to note is that the aggregate phenomenologies do not exist at the level of the agent or individual part. They are an **emergent** consequence of the **relationship** of the parts. As we will see most emphatically when we cover nonlinear dynamics, emergent phenomenology at the higher logical level creates a different **context** characterized by a completely different set of parameters and metrics that express the combined systemic behavior of the parts. The table below illustrates an example succession of logical levels.

Logical Level	**Example Unit of Analysis**	**Example Element**	**Context or Discipline**
Society	Classroom	Student	Social Science
Human Mind	Concept	Association	Psychology
Human Brain	Sensation	Sight	Neuroscience
Organ	Systems of Cells	Hippocampus	Neurology
Cellular	Cell	Neuron	Biology
Molecular	Molecule	Protein	Organic Chemistry
Atomic	Atom	Carbon	Physics
Particle	Subatomic particle	Electron	Quantum Mechanics

There are several observations which are cogent with respect to the above table. First it represents a hierarchy of increasing complexity and higher logical level. A systemic relationship of elements, at each level, produces the elements and units of analysis at the succeeding level. As discussed previously, this systemic combination produces a phenomenology which transcends the actions of the individual elements which comprise the system. A new context is created when we shift levels and new parameters or metrics are required to describe the emergent relationships. For example, in describing a relationship between the hippocampus and other organs of the brain, it would be insufficient to characterize the system in terms of the quantum mechanical characteristics of the electrons contained within the system, such as spin or permissible energy levels. Such a description, while informative, would not capture or describe the phenomenology which results from the systemic combination of organs. Questions like, Will the universe ever be reduced to physics, or will psychology ever be reduced to neurology, actually, have no meaning. As Gilbert Ryle might point out, these disciplines deal with objects at different logical levels or in different logical categories. As Einstein might point out, physics is not concerned with human interactional dynamics. As such, the question as to whether physics can describe human interactions has no meaning. This is not to say that that the logical levels in our hierarchy must be viewed in separate and distinct fashion. As stated previously, they are intimately related by virtue of the fact that combinatorial relationships at one level lead to the succeeding level. The appropriate question to ask is whether, and how, a specific combinatorial relationship leads to a corresponding phenomenology at the higher logical level. Are the two isomorphic? For example, when someone is prescribed Prozac, interactions occur at every level of the previous chart. The goal of the prescription is to impact phenomenology at the level of the human mind and social interaction. It is, however, important to understand dynamics at the cellular or neuron level and evaluate isomorphism between relationships at this level and the behavioral level (mind/social). This comparison is vital in evaluating side effects or in knowing how to design the next generation of such psychoactive drugs. There is a difference in relating one level to another and reducing one level to another. We can relate, but we cannot reduce because of the emergent properties produced by relationships among elements within a given logical level.

Before we get carried away creating isomorphic relationships between logical levels, we need to look at philosophic arguments from the 1960s and 70s, in the sub-discipline of Philosophy of Mind. In the 1960s, a group of Australian philosophers brought to prominence a materialistic philosophy called "mind-brain identity theory." Major proponents included David Armstrong (1986) and J.J.C. Smart (1959). The basic idea of identity theory is that mental events, such as thoughts or sensations, are identical to specific physical events in the brain. When, for example, Smart (1959) states that there is a strict identity between the two, he means they are one and the same, not simply correlated. As an example, Smart says a flash of lightning is not correlated with a discharge of electricity in the atmosphere; it is a discharge of electricity in the atmosphere. In similar fashion, mind-brain identity theorists contend that each mental state or event is one and the same thing as some physical state of the brain. Philosophers distinguish two types of identity: qualitative and numerical. To say that two things are qualitatively identical means that the two things are similar to each other in every respect. To say they are numerically identical means they are one and the same thing (Morton, 1997) . Mind-brain identity theorists contend that neurological states and mental states are numerically identical. Another central tenant in mind-brain identity theory is that the identity of mental states and brain states is a contingent fact. A contingent fact is a fact that is a result of how the world happens to be. If the world had been different, it might not have been a fact. The fact that George Bush is president of the United States is a contingent fact. If he would have lost the election, this would not be a fact. A necessary fact possesses the quality that it is impossible for it not to be a fact. These facts are generally limited to those that are the logically necessary consequences of deductive logic. For example, once we define integers and the process of addition, it is a necessary fact that two plus two equals four. Necessary facts, then, result from logical consistencies between concepts, whereas contingent facts are discovered in the world. Identity theorists therefore argue that since mind-brain identity is a contingent fact, discovering the nature of the mind is a scientific endeavor to be determined by experiments and observations, not by examining concepts of mind and brain (metaphysics).

The identity theorist's position is reductionist. It implies that by understanding the electrochemical activity of the brain, we can understand why the mind acts as it does. Mental activities such as problem solving, under this theory, are explained as a specific firing pattern of neurons in the brain. As Morton (1997) points out, much of science proceeds in the same fashion. He cites, as an example, how the phenomenon of lightning was first explained as an electrical discharge, and electrical discharge was subsequently explained as the movement of electrons. In this way, lightning has been reduced to electron movement. Lightning is electron movement. They are numerically identical.

Since philosophers are loath to relinquish any turf to scientists, mind-brain identity theory evoked a torrent of criticism and alternative theory. Among those weighing in were Jerry Fodor, Ned Block, Hillary Putnam and Patricia Churchland. Fodor, Block, and Putnam promote a position called Functionalism. Functionalists agree with identity theorists that the mind-body problem is to be solved by observation and experiment rather than by metaphysical speculation or conceptual analysis (Morton, 1997). Functionalists, however, argue that understanding neurological actualizations of mental states will not help understand the real nature of the mind. Instead it is necessary to understand the functions and activities that these neurological states bring about. In other words, understanding must occur at the higher logical level of function.

Fodor (1986) deconstructs the identity theorists previously discussed position as follows. To follow his argument requires an explanation of what philosophers mean by types and tokens. A token is an actual physical exemplar, a specific object or thing. A type is a category to which the object or thing belongs (Morton, 1997). For example, Texas, Oklahoma and Kansas are tokens of the type state. Using this language, a mental type would be a kind of thought or sensation, whereas a mental token is the mental state of a particular person at a particular time. Identity theorists contend that mental states are identical to physical states of the brain. Fodor (1986) points out that this claim is ambiguous. It can mean each mental token is identical to a physical token or it can mean each mental type is identical to a physical type. The first of these possibilities is a soft claim and is simply the statement that a mental state has a physical implementation. With this position, Functionalists would concur. The second statement, which Fodor (1986) calls type physicalism, has much stronger implications. It states that any states of mind that are of the same mental type will necessarily be of the same physical type: thoughts and emotions of a certain type have a specific and unique neurological implementation. To use an example from Morton (1997) of the stringent requirements created by type physicalism, if we say that water is H_2O, and if we found a substance that had precisely the same physical attributes as water, but a different chemical composition, it could not be water. For a pool of liquid to be water depends entirely on whether it is H_2O.

Let's look at an example and see what this would imply. Let's say that we have a visitor from outer space whose neurological composition (material makeup and/or configuration) is different than ours. Let's also say that this visitor seems to be able to express beliefs, desires, thoughts and sensations similar to ours. The second statement, or type physicalism, states that this could not be the case because of the required identity between types of mental states and types of physical states. We are also precluded by type physicalism from building a robot or computer or any other device that can take on the type of mental states that humans take on, or that perform human mental activities.

Fodor (1986) argues that these implications show that identity theory is not a plausible solution to the mind-body problem. If type physicalism is false, the implication is then that mental states can be implemented in different ways or can have the attribute of "**multiple realizability.**" If different configurations of physical states can produce the same or similar mental states, what is it that they have in common? What they have in common is that they address the same goal and attend to the same function. They have a functional similarity. This is the genesis of the Functionalist position. Morton (1997, p. 314) states that Functionalism consists of two doctrines:

1. Mental states are internal states that interact with one another and with external stimuli to produce observable behavior.
2. Each mental state type is defined not in terms of physical makeup, but in terms of its function in the operation of the system.

Fodor and Block (1972) make the point that functionalism also allows for the productivity seen in human mental states. Fodor and Block (1972) equate thoughts with mental states (a position that other philosophers have argued against). A productive system is one that consists of a limited set of initial elements and a set of rules by which these elements can be related or combined. While initially limited, the system can generate a virtually unlimited set of combinations. For example, 26 letters in our alphabet have generated around half a million English words. These words can be combined, using the **rules** of grammar, to express a virtually unlimited number of thoughts. Language is a productive system. Morton (1997) provides another example. Suppose you wanted to explain to someone what the set of positive integers is. You could provide an extensive definition and list them all. That however would require an infinite amount of time. Alternatively, you could give them one of the elements, the number one, and the following rule: if a given number is a member of the set, so is the sum of that number and the number one. The first application of the rule yields the number two; the second application yields the number three, and so forth. One of the attributes of a productive system is that you can identify all of its members only by means of a set of rules (if one of the rules defines the initial members of the set). As an aside, let me call the reader's attention to the fact that an abstract representation which also consists of elements connected through relationship and, by virtue of this relationship, articulates a rule, shares this same property of productivity. Tom, Dick, Kerry, John, ad infinitum are all contained within the abstract representation men, which has rules that determine inclusion in this class. Let me also point out that simple mathematical relationships or rules recursively applied in nonlinear systems produce complex behavior that includes the generation of fractals and self organization into qualitatively different structures. We have all undoubtedly seen the complex structures that can be built through the repetitive application of fractals. While not completely resolving the question of how freedom and determinism can coexist, productive systems illustrate a circumstance in which they do coexist. In spite of rules, possibilities are often virtually unlimited.

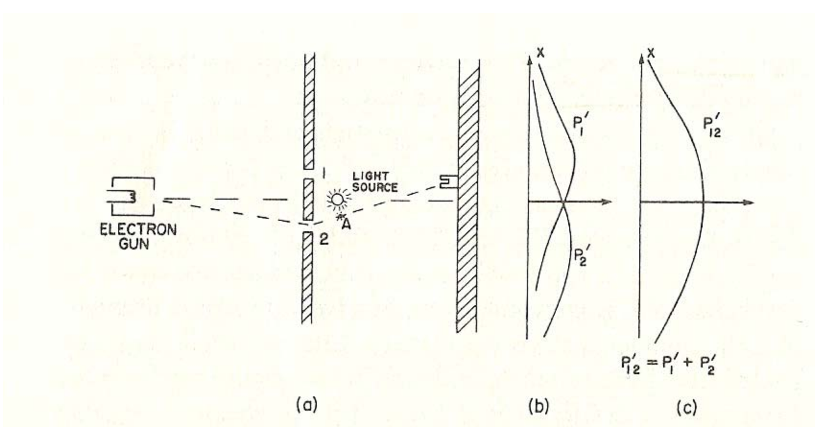
The reason for going through the previous discussion was to make the point that isomorphic relationships between logical levels need not be unique or singular. There can be multiple realizations or combinations of elements at one logical level that could produce the same phenomenology or characteristics observed at the higher logical level.

The Functionalist position is supported by research in Neuroscience. It is well known that while the brain has evolved in such a fashion that each part specializes in a specific function, the plasticity of the brain is such that it can often, however, overcome pathologies or injuries. Undamaged areas of the brain take on the functions, or organize themselves in a way to carry out the functions, of the damaged areas (LeDoux, Synaptic self, 2002). This is particularly true in young children.

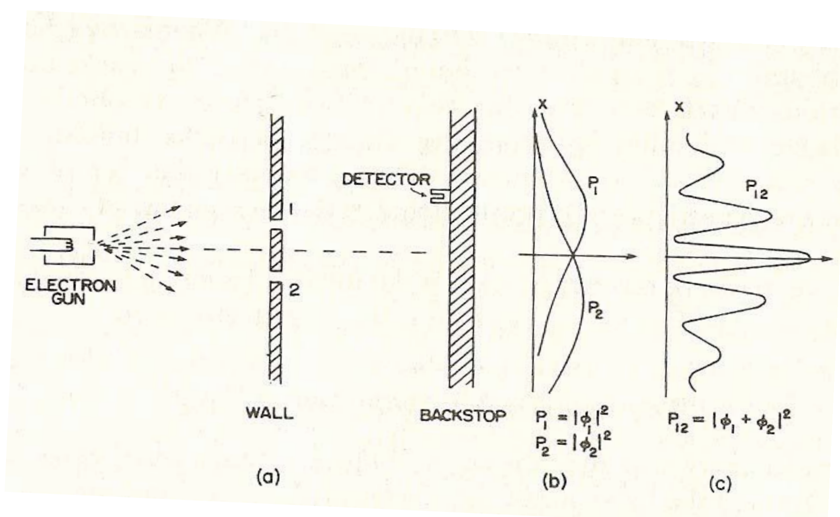
Quantum Mechanics

In the Relativity chapter, an implied conclusion was that a context could not change the relationship within the "thing in and of itself". This brought up the giant metaphysical question: "is there in fact an independently existent relationship within the "thing in and of itself"? The answer from quantum mechanics is that there may be such a relationship, but it is one we will never ascertain. Objects on the atomic scale, such as electrons, do not manifest a specific "reality" until they enter into a relationship with another object. They possess a potentiality articulated by a probability function. Prior to entering into a relationship with a particle at the atomic scale, such as in an experiment to measure one of its properties, the best we can do is to predict the odds that something will happen (probability). The fundamental epistemic of quantum mechanics is that **meaning emerges through relationship.**

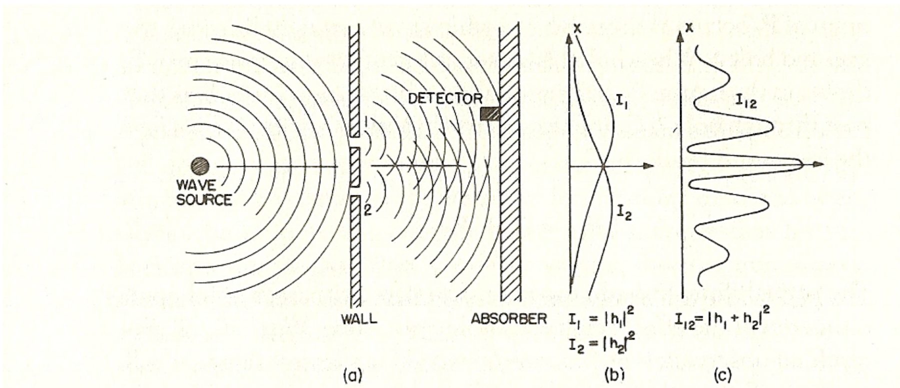
Noted physicist Richard Feynman (1995) states that the heart of quantum mechanics is expressed in the double slit experiment. In this experiment, illustrated below (Feynman, 1995), electrons are fired against a surface with two small slits that permit electrons arriving at the slits to pass through. Detectors on a second surface record the number of electron arrivals at each point on the second surface.



In the experimental setup shown above, we have inserted a light source which allows us to determine which slit the electrons pass through. Electrons scatter light, so every time an experimenter hears a click from the electron detector, they also see a flash of light, either near slit number one or slit number two. Note here that we are inferring that we can identify a specific location for the electron's position and are therefore treating the electron as a particle. Figure (c) above shows the composite tally of electron arrivals. Figure (b) above shows what the tally of arrivals would look like if we covered one or the other of the slits. We can see that the composite tally is simply the arithmetic total of the tallies that we would get from the individual slits. If we did this experiment with bullets fired from a gun instead of electrons, we would get the same result as shown above. Now let us remove the light source and conduct the experiment shown below.



The resulting tally of electron arrivals is surprisingly different. We can better understand this result by looking at what would happen in the experiment if our original source was a light wave instead of an electron gun. The result of such an experiment is shown below. What we see is that the electron arrival density in the second experiment is precisely the same as what we get when the source is a wave, such as an electromagnetic wave (light). The light intensity recorded on the second surface is the result of interference (positive and negative) between the two waves emanating from the two slits. If we correlate light intensity in the third experiment with the density of electron arrivals in the second experiment, we find that the electron arrival density can be expressed as a wave function. We can then interpret this wave function as expressing the probability that an electron will arrive at a given position.



Feynman (1995) summarizes: "The electrons arrive as individuals, like particles, and the probability of arrival of these individuals is distributed like the distribution of intensity of a wave. It is in this sense that the electron behaves "sometimes like a particle and sometimes like a wave"" (p.126). In the first experiment above in which we used a light source to determine the position of the electron, we would find that it is impossible to arrange the light in such a way that one can tell which hole the electron went through, and at the same time not disturb the electron's trajectory and the distribution pattern of electron arrivals. This result in an expression of the Heisenberg uncertainty principle.

Feynman (1995) states:

> We would like to emphasize a very important difference between classical and quantum mechanics. We have been talking about the probability that an electron will arrive in a given circumstance. We have implied that in our experimental arrangement it would be impossible to predict exactly what would happen to an individual electron. We can only predict the odds. This would mean, if it were true, that physics has given up on the

> problem of predicting exactly what will happen in a definite circumstance. We do not know how to predict what would happen in a given circumstance, and we believe now that it is impossible, that the only thing that can be predicted is the probability of different events (p. 135).

The interpretation of the physical "realities" manifest in the atomic and subatomic world was articulated by physicists Max Born, Werner Heisenberg, Niels Bohr, and Wolfgang Pauli. It has come to be known as the "Copenhagen Interpretation". The "Interpretation" rests on three premises. The first is the Complementarity Principal of Bohr. This principle states that it is not possible to describe physical observables simultaneously in terms of both particles and waves. The second premise is the Heisenberg Uncertainty Principle. This principle states that we cannot simultaneously know with absolute certainty, the momentum and the position of an object. The third premise is that solutions to the Schrödinger wave equation, the fundamental equation used in quantum mechanics to relate the energy state of an entity to its state in space and time, express probabilities that define the permissible range of states that an entity may take on.

Physicists conducting experiments with atomic and subatomic particles found an inability to replicate the results of identical experiments. What they found instead was a range of values for physical observables. For example, let us suppose that we conduct an identical experiment many times and in each of the experiments the position x of an electron is measured. If we average the measurements and obtain $\bar{x}$, we can calculate the standard deviation of our measurements, $\Delta x = \sqrt{\frac{\sum(x-\bar{x})^2}{n}}$. This standard deviation is the definition of uncertainty in the Heisenberg Principle. The Heisenberg Uncertainty Principal can be expressed mathematically as:

$$\Delta p \geq \frac{h}{2\pi\Delta x}$$

If our experiments are run in a way to minimize the uncertainty in position, that is, to have Δx approach zero, we can see from the above equation that the uncertainty in the momentum (Δp , or mass times velocity) approaches infinity. The electron in this type of experiment also behaves like a particle. If we were to design an experiment to measure the momentum with great accuracy, conversely, we would be unable to determine the position of the electron with any accuracy, and the wave character of the electron would manifest itself. The probable position of the electron propagates like a wave.

If there is one idea in quantum mechanics that postmodern thinkers have latched onto, it is the Heisenberg Uncertainty Principle. It has been generalized to mean that any observation, measurement, or interaction with an entity (human being or otherwise) alters the future course of that entity. It has also been generalized to mean that it is impossible to undertake a completely objective, detached, and non-impacting observation. To observe, measure, and interact creates a relationship. This relationship changes or modifies the future course of events. The ready adoption of this principle is due to the fact that it is confirmed by episodic experience. For example, sociologists who study groups of people invariably encounter this phenomenon. Their act of observation, measurement and interaction changes the behavior of the group being studied.

The mathematics of quantum mechanics becomes very complex very quickly. We can look at a simple example to develop a feel for how the process works. Let us consider a point mass m, constrained to move on an infinitely thin, frictionless wire that is strung tightly between two impenetrable walls at a distance a apart. For simplicity's sake, we will only consider the time invariant case. The time invariant Schrödinger equation for the above case is:

$$-\frac{h^2}{2m}\frac{\partial^2}{\partial x^2}\varphi = E\varphi$$

If we define a parameter $k^2 = \frac{2mE}{h^2}$, the Schrödinger equation reduces to:

$$\frac{\partial^2 \varphi}{\partial x^2} + k^2 \varphi = 0$$

This is an ordinary differential equation with solution:

$$A \sin kx + B \cos kx$$

If we now impose the boundary condition: that this function must be zero at the boundaries $\varphi(0) = \varphi(a) = 0$; this requires that B=0 and $A \sin ka$=0. The sin function is zero for integer multiples of pi or $k_n a = n\pi$. Therefore, $k_n = \frac{n\pi}{a}$ and the solution becomes:

$$\varphi_n = A \sin(n\pi x/a)$$

To find A, we recall that the wave function expresses a probability, and that the sum of the probability densities $|\varphi_n{}^2|$ must equal one:

$$1 = A^2 \int_0^a (\sin(n\pi x/a))^2$$

$$A = \sqrt{\frac{2}{a}}$$

The final wave function and probability densities are then:

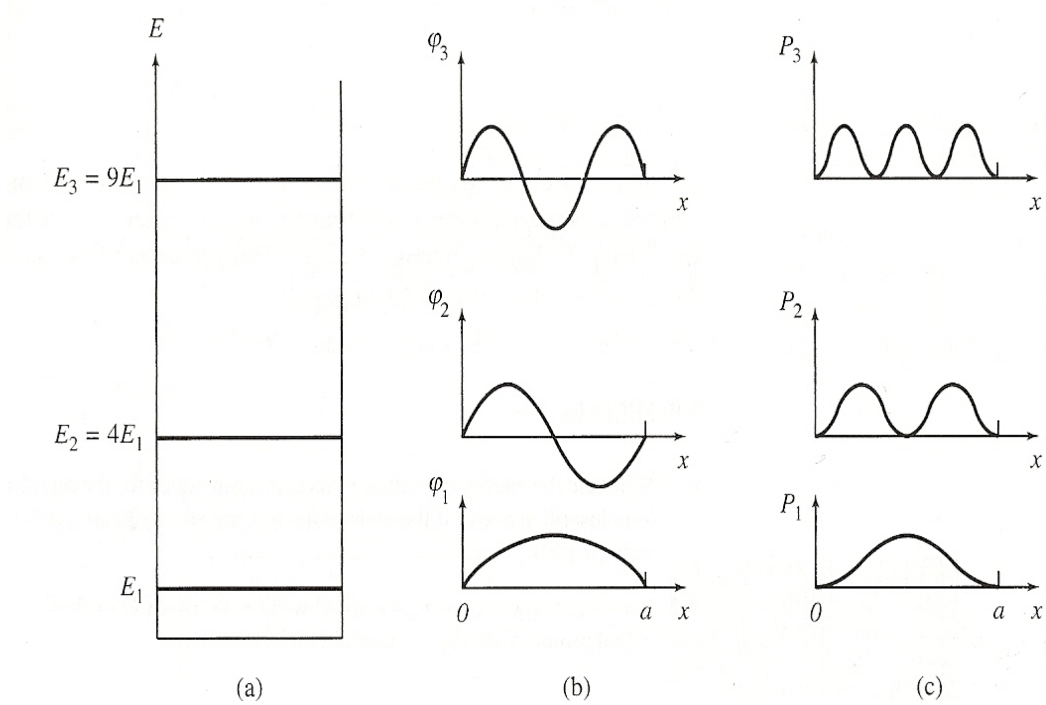
$$\varphi_n = \sqrt{\frac{2}{a}} \sin\left(\frac{n\pi x}{a}\right)$$

$$P_n = |\varphi_n|^2 = \frac{2}{a} sin^2(n\pi x/a)$$

Note that in the beginning, the parameter k was created from a combination of the energy level, mass, and Planck's constant h (h here is assumed to be divided by 2π). The solution to the problem required that k take on values that are integer multiples of π/a . Energy (E), which from our previous definition of k, can be expressed as:

$$E_n = \frac{{k_n}^2}{2m} h^2 = \frac{h^2 \pi^2 n^2}{2ma^2}$$

therefore, must also take on values as shown by the equation above that are the integer squared multiples of the base energy value: $E_n = n^2 E_1$. The permitted energy values are said to be **quantized** into these values. Note that this was a consequence of the requirement imposed by the boundary on the sine wave solution to Schrödinger's equation. **Note also that our result can abstractly be expressed as a state of equilibrium between driving force (Energy), relationship (Schrödinger's equation) and environmental contingency (boundary conditions).** Shown below are sketches from Liboff (2003) that show permitted energy levels, wave function, and probability density for the above "particle in a box problem".



As shown above, at the base energy level E_1, the most probable place that we would find the particle is in the center of the box. This result would also be predicted by classical mechanics. However, at the next permissible energy level ($4E_1$) there is no possibility of finding the particle in the center of the box. This is a very surprising result. I should point out that, for atomic and subatomic particles, experimental results confirm quantum mechanical predictions, not predictions from classical mechanics.

While not a specific objective of this Dissertation, I feel that quantum mechanics, when related to the other knowledge structures investigated in the Dissertation, expresses a fundamental epistemology that is worth discussing. First Schrödinger's wave equation is a deterministic relationship that expresses a structure of the universe. This relationship conserves a quantity, Planck's constant. In similar fashion, the Minkowski relationship expresses a deterministic relationship between space and time that conserves the speed of light. By analogy, we can think of an organism's DNA as a fundamental relational structure that conserves the organism's autopoiesis. Also, in a nonlinear system, we can think of the characterizing difference equation or differential equation as a relationship expressing the unity or organization of the system characterized. In a nonlinear system, constant parameters are conserved.

In each case above, what these deterministic relationships express is potentiality for a range of probable outcomes for the entity or system characterized. They do not define a specific outcome. For example, in the case of an atomic or subatomic particle, Schrödinger's wave equation yields a probability of potential outcomes. It is not until the atomic or subatomic particle enters into a relationship with an environment (boundary conditions) that meaning or a reality emerges for the particle. Meaning is created through relationship. In addition the specific meaning and reality represents an equilibration between the system energy (driving force), environmental contingency (boundary conditions) and the deterministic relationship that characterizes the system (Schrödinger's equation).

Precisely the same circumstance occurs in Relativity. Space and time do not take on a reality or meaning until two objects with mass are placed into relationship. In an organic organization, meaning and reality is an equilibration of driving force (goal), the intrinsic organization of the organism (expressed in its DNA) and environmental contingency. Similarly, a nonlinear system reaches a state of equilibrium determined by the confluence of driving force, systemic relationship, and environmental circumstance. In all situations above, a specific outcome or structure is not emergent until an equilibration occurs.

In nature, all of the aforementioned systems are open systems. These systems are therefore subject to perturbations that will change the nature of emergent structures, meanings and realities with time. In an organism, this is expressed as a phylogenetic and ontogenetic progression that expresses adaptation. In a nonlinear system, it is expressed as a qualitative change in the structure of the system consequent to an external change in parameters or the statistical accumulation of external perturbations from an environment. Whether we speak of electrons, organisms or other entities in systemic relationship, we will see an evolution with time that expresses a synthesis of determinism (original relational structure) and chance (environmental contingency and perturbation). We can therefore tentatively summarize as follows:

1) Natural systems exhibit preliminary relational structure conserving universal invariants.
2) These relational structures impart a potentiality for the system.
3) Meaning or reality emerge through external relationship.
4) This relationship (with meaning/ reality) is a state of dynamic equilibrium between driving force, environmental contingency (external relationship) and the intrinsic relationship expressing the unity of the system.
5) Natural systems are open, subject to perturbation, in a continuous state of change and express an ontogeny and phylogeny that is the confluence of determinism and chance.

Nonlinear Dynamics

All of us have undoubtedly had the experience of waiting in a large crowd of people to board a bus or to enter through a single doorway into a building. The initial dynamic that occurs in such a circumstance is that everyone acts individually in pursuit of his personal goal of entering the bus or building. They approach the narrow entryway at every conceivable angle or from every direction that the geometry of the situation permits. Invariably, several people arrive at the entrance simultaneously, the doorway gets blocked, no one is now entering and progress is temporarily halted. In the language of nonlinear dynamics, the system has reached an unstable fixed point. One way to characterize this is to say that the competing interest of the individuals has prevented the collective interests of the aggregate (entering the bus or building) from being realized. The system has reached a point of no change or a fixed point, but it is a highly unstable one. If the system energy is exceedingly high, for example, if the individuals were in a burning building and the narrow passageway was the only exit, then chaos would ensue and people would get hurt or killed. If system energy is lower, the possibility for organization or self organization exists.

If the bus, in the example above, was a bus used for transportation during military basic training, a drill sergeant would begin screaming at the soldiers to line themselves up in single file (one behind the other) in order that all could enter the bus in an orderly fashion. The drill sergeant in this way imposes an organization upon the system. This organization meets the collective needs of the group and also represents an adaptation to the conditions of the environment (narrow doorway).

The system can also self organize itself into the same morphology. How does this occur? Do all individuals come to the conclusion simultaneously that by cooperating rather than competing, they will accomplish their individual goal of boarding the bus or entering the building? Does this self organization even need to involve an act of intelligence?

Let us assume that we have three individuals who simultaneously arrive at the doorway entrance. As the doorway will accommodate only one individual at a time, entrance to the building is temporarily blocked and an unstable fixed point is created. Let us now say that, in the jostling at the entryway, one of the three individuals is shifted to a position slightly behind the other two. If a second individual in the trio is also pushed into a position behind one of the other two individuals, we have the beginning of a linear geometry or single file line, entry into the building is facilitated and the system starts moving again. Let us use the language of nonlinear dynamics and call the shifting of the three individuals a perturbation. The system continues to move if the process of one individual sliding behind another continues within the crowd. If the crowd is large and bodies are pressed against each other, this change in motion is communicated through physical contact and requires no act of intelligence. The continual sliding of one individual behind the other is the motion that keeps the system moving. The system self organizes into a linear morphology that enables resumption of a trajectory toward a point of stability (the state of being inside the building or bus). Note that this linear morphology is an equilibration of the relationships among the individuals, the conditions of the environment (narrow doorway), and the driving force of the individuals (desire to enter the bus or building). The process described above is directly analogous to the self organization that occurs among water molecules when water is forced to change its morphology in response to an obstruction or other environmental alteration in its channel of flow.

If the individuals in the crowd are physically separated, information regarding the process required to keep the system moving would be communicated through observation: the observation that progress is reinitiated and continued by individuals moving into a single file or linear geometry of one behind another. By cooperating rather than competing, the interest of each individual is better served. This realization comes about because of the observed correlation between behavior (trajectory) and goal (driving force). Of course, as everyone who has experienced traveling down a three lane freeway that narrows to one lane knows, there are still a few boneheads who will try to press to the front of the line and re-create the instability.

Let us examine the circumstance where there is not a crowd at the entryway and individuals arrive widely separated in space and time. Such a circumstance would have the following attributes:

1) everyone could act according to his interest alone
2) we could calculate when someone went through the door, if we knew his location (position in space) and his speed (velocity) of movement
3) everyone's actions would be independent of everyone else's (a linearly independent system) and,
4) we could deterministically calculate when the bus or store filled to capacity, if we knew people's intentions (driving force), locations and velocity of movement

In summary, it would be the kind of world envisioned by 18th century mathematician Laplace, who stated that the future of the world could be precisely determined by Newton's laws if we knew the current position and velocity of everything. Laplace, however, has suffered the same fate as every other thinker throughout history who metaphorically climbed to the front of the Titanic, stretched out his arms, and proclaimed himself "King of the world" and in possession of a theory of everything. We have come to find out that he has perhaps over- generalized his case a bit.

What foils Laplace and all other linear thinkers is, of course, nonlinearity. In our simple example above, when the crowd at the door got large, the system went from linear to nonlinear: everyone could no longer act independently and follow the trajectory first set in motion by the force of his will. What happened depended upon the collective action of all of the individuals. Everyone's future state was determined by codependent relationship among the individuals. In other words, nonlinear system dynamics replaced individual trajectories.

Even our simple example illustrates a number of the phenomena associated with nonlinearity and self organization. These include the codependent nature of the variables involved in a relationship, the existence of fixed points or points of non-change that can either be stable or unstable, bifurcations at unstable points that can result in qualitatively different morphologies or directions that future trajectories will take, and the determination of these morphologies by the combined impact of the relationships among system components, inputs into the system, driving forces, and the adaptations required by environmental circumstances.

We also see a number of the conditions required for self organization. First the system must be nonlinear or have codependent variables. Second the system must be sufficiently far from a point of stability (the large crowd created this circumstance in our example). Third, a morphology must be available that simultaneously satisfies the relationship among the elements or variables, the system inputs, and the imposed environmental constraints; there must be a state that represents a dynamic equilibrium among all of these factors.

We also see in our example a number of other characteristics of self organizing systems. The instabilities drive the system toward the stabilities. At points of instability, a perturbation or small change is all that is required to move the trajectory down one path or another. In the self organizing process, the number of possible states or the "state space" collapses or gets smaller. In our example, all of the multiple approaches to the doorway collapsed into a single line behind the door. Ilya Prigogine (1997) calls this a "dissipative structure". In the mathematics of nonlinear systems, dissipative structure is defined as trajectories that emerge when there is a continuous reduction in time of the number of available states that a system can occupy. It typically involves the dissipation of energy from a system and hence the term dissipative is used.

Also note that when an organized or self organized structure forms, the information and parameters of all of the individual trajectories become summarized by parameters and information pertaining to the organized structure itself and the system in total or in aggregate. In our example, to describe the system before the self organization or organization would have required us to specify information regarding each individual and his trajectory. After the self organization, we can characterize the entire system by a line. The individual trajectories are all now specified within the **context** of this line (position within it) and we can summarize the system and the individuals in terms of the parameters of the line. In this way, we have abstracted individual behavior into the attributes of an aggregate, as these attributes are articulated in the organized or self-organized structure. Please note that a self-organized nonlinear system, in this sense, **creates a context**. Context is created as the consequence of a dynamic equilibrium which simultaneously satisfies the relationship between system components, the driving force, inputs to the system and the constraints of the environment. Please note also, that the previous description also qualitatively describes how a word, as an abstract representation or a concept comes about. Although they do not articulate their work in the context of nonlinear dynamics, when Vygotsky (1986) describes the process of concept formation or Piaget (1985) describes the equilibration of cognitive structures, or Terrance Deacon (1997) describes the nature of language, their descriptions invoke in my mind the process of self organization in nonlinear systems. As a result, many of my interpretations of their work are in this context. As we will see when we cover Neuroscience, all human systems are nonlinear. They are all connected and codependent systems that act in service to the goal of allowing the human to not only adapt to the circumstances of his environment and survive, but to also alter that environment in a way that allows him to enhance his condition. In that biologic systems, such as human systems, are nonlinear nature, it is not a big stretch to presume that the processes they take on, such as concept formation and learning in general, are also nonlinear in nature. As such, it is in our interest to develop a qualitative understanding of the nature of nonlinear dynamics, or Complexity, as it is alternatively termed. This will provide us with another context and important complement in our effort to develop a morphology of understanding of the epistemology implicit in the learning process.

In order to more fully understand organization and self organization in nonlinear systems, it is beneficial to examine the idea of entropy. We begin with an example from Hermann Haken (1981), a German physicist most famous for developing the theoretical basis of the Laser.

Haken (1981) provides an example relating to an automobile traveling down a road. This automobile has kinetic energy or the energy of motion. The automobile also has only one degree of freedom, that being the direction in which it is traveling. Let us say that the driver puts on the brakes. There is friction between the tire and the road which causes the tire, the brakes, and the air inside and outside the tire, and to a degree, the road, to heat up. As we know, heat is the kinetic energy of motion of the atoms (and consequently the molecules) that comprises a substance. The molecules, particularly those in the air, have many degrees of freedom, meaning they can move in many directions. During the braking process, the kinetic energy of the car, with one degree of freedom, has been converted into the kinetic energy of molecules with many degrees of freedom. This situation is the inverse of the self organization we saw in our bus or building entrance example.

Can we reverse this process? This would involve putting the kinetic energy of a great many molecules, widely dispersed, in a variety of mediums, and with a great number of degrees of freedom, back into the kinetic energy of the car, which has a single degree of freedom. Note that this requires an act of organization. We would literally have to collect and reorganize all of the molecules, with their diverse distributions in a variety of places, back into the kinetic energy of the car with a single degree of freedom. Since part of the energy of the car was originally transferred to the Earth's atmosphere during the braking process, and the Earth's atmosphere is quite extensive, "good luck with that"! The answer to the original question is, obviously, no. Physicists would therefore characterize this breaking operation as an irreversible process.

Let us look at another irreversible process: the process that occurs within the engine of the car. In the engine of the car, the explosion of gasoline creates a heated gas consisting of molecules with high kinetic energy and many degrees of freedom. Part of the kinetic energy of the molecules is converted into the kinetic energy of the piston of the engine, which has one degree of freedom (it only moves up and down). Ultimately the kinetic energy of the piston is converted into the kinetic energy of the car. The majority of the heat or kinetic energy of the gas molecules is, however, lost and dissipated in the form of heat transfer to the radiator and the metal of the car engine, and in the heat of the exhaust gas. This process is also irreversible, for the same reasons stated above.

In the 19th century, when steam and internal combustion engines were invented, scientists noted this type of loss in energy and gave it a name: entropy. It wasn't until the late 19th century, however, that a theoretical explanation was provided by Ludwig Boltzmann, who showed that entropy was a measure of the state of order or disorder of the molecules comprising a system. Since virtually all then known energy transfers involved a measure of entropy, it wasn't long before another famous Hermann (one we have already met in this Dissertation), Hermann Helmholtz, jumped to the front of the Titanic and pronounced: “the universe is condemned to a state of eternal rest (Haken, 1981,p. 31)". In other words, the pronouncement was that the universe was going to die a thermal death as a consequence of entropy, in a state of complete disorganization. Helmholtz's view is still shared by most people today.

As a paradigm, the view that every process involves an increase in entropy has some difficulty providing an explanation for what former Vice President Al Gore might call a few "inconvenient truths" about the universe. A few questions remain unanswered. First, how did clouds of gas in the early universe organize into stars, planets and galaxies? In addition, how did the basic ingredients of primordial Earth organize into DNA? How do we explain evolution? I realize that there are varieties of theological answers to these questions and I do not wish to affront anyone's religious beliefs. I will, however, presume that the reader will acknowledge that the geologic record shows evidence of increasingly complex life forms with time, and in this sense, there is evidence of increasing levels of biologic organization with time. The source of this organization is, of course, up to the individual to interpret. The only possibility we need to allow for in the succeeding discussion is that every process in the universe need not be entropic or increase entropy.

At this point, a more expansive elaboration of order and disorder may be helpful. Let me use a personal example. I have two middle-school children and a first grader at home. Their bedrooms are generally in a state of disorder, meaning that items are not in their allotted places. Each day, their personal items can be in a different place in their rooms and the words: "where is my thing, I can't find my thing" are often heard in our house. The **disorder** in their rooms is related to the large **number of possible places** for things to be in their rooms. They have a large number of degrees of freedom in connection with where they might place their personal items. At the current time, any ordering of their rooms is as a direct result of an organizing force imparted by either my wife or myself. I am currently working on creating environmental conditions that will encourage the children to self organize their rooms.

Boltzmann's discovery, in the late 19th century, was that the entropy of a system was directly related to the number of possible states that molecules that comprise the system could take on. We can look at an example from Halliday, Resnick, and Walker (2005) to illustrate this. Suppose we have a box with six molecules in it that initially occupy one half of the box and are partitioned off from the other half of the box. We undertake an operation whereby we remove the partition, effectively doubling the volume of the space that the molecules could occupy. We ask two questions: what is the entropy associated with this process, and is the process reversible?

Let us first look at the possible distribution of molecules between the two boxes and tally up these possibilities. First, we look at the total number of ways we can arrange six molecules. When we pick the first molecule, we have six different choices, since there are six molecules. When we select the second molecule, there are five left, so we have five choices. So far, we have determined there are six times five or 30 ways to pick the first two molecules. Continuing with this process, there are four choices to pick the third molecule, three choices to pick the fourth, two choices to pick the fifth and one choice in picking the sixth. The total number of arrangements of the six molecules is therefore $6 \times 5 \times 4 \times 3 \times 2 \times 1$ or 720. This particular multiplication is designated in mathematics as $6!$, and called six factorial. If we generalize our operation above and designate the number of objects we are trying to arrange as N, the number of possible arrangements is $N!$.

Let us now number the molecules from one to six and start placing them from the original half of the box into the other. If we are going to place only one molecule into the right half of the box, we have a choice of six molecules, so there are six ways in which this can occur. If we are going to place two molecules in the right half of the box, we have six choices for the first molecule and five for the second or a total of 30 possibilities. Does it matter whether we pick molecule two and then molecule three, or molecule three and then two? No, because both result in the same two molecules in the other half of the box. Our tally of 30 possibilities includes these redundancies as separate and distinct arrangements, so we have to divide our number of possible arrangements by the number of ways we can arrange two objects. This number is" two factorial" or two. So, there are 15 (30/2) ways to have four molecules in the original half and two in the new half. Similarly there are $6 \times 5 \times 4$ or 120 ways to arrange three molecules in each half of the box. Again, picking molecules 1, 2, 3 or 1, 3, 2 or 3, 1, 2 to place in the right half of the box produces the same result, so we have to divide 120 by the number of ways three objects can be arranged or $3 \times 2 \times 1$. The number of unique arrangements is then 20 (120/6). There is a pattern to the operations that we have undertaken above, so let's go ahead and abstract this pattern. If we let N represent the number of objects we are arranging, then, as shown above, the total number of arrangements is given by N! . If we are rearranging only a portion of these objects, let's call this portion R, the above shows that we multiply only the first R number of terms of N! . We can arrive at this result by dividing N! by$(N-R)$! . For example, when we determined the number of ways we could pick two molecules from our group of six, we multiplied six times five. In this case, N is equal to six, R is equal to two, and N-R is equal to four. Putting these values into our formula we get: $\frac{6\times5\times4\times3\times2\times1}{4\times3\times2\times1} = 6 \times 5$. Since the order in which we picked these molecules didn't matter, we had to divide this answer by the number of ways two things could be arranged or the number two. As we know from above, the number of ways things can be arranged is the number of things multiplied in factorial fashion. Therefore, we have to divide our preliminary result by the number of ways our number of selections could be arranged or R! . Our final formula that gives the number of unique arrangements is then: $\frac{N!}{(N-R)!R!}$. This formula is the familiar formula for the number of combinations of N things taken R at a time. This is a formula we all learned and then quickly forgot (myself included), because we memorized it rather than learned how to derive it from the logic and relationships of physical situations, as above. This is an example of a circumstance we will see time and time again. To have knowledge that we can apply requires that we have a conceptual understanding. To develop a conceptual understanding we must construct the knowledge as a set of logical relationships between the elements or characteristics of the object of conceptualization. This relationship must ultimately represent a stable summarization that is congruent with our experience of the object of our conceptualization. A more effective way to teach this formula is to begin by having students actually sort four billiard balls numbered one through four. Have the students try to create all 24 possibilities in trial and error fashion. Next, take them through the logic of the factorial multiplication. For example, ask them how many choices they have for selecting the first billiard ball. The answer is four. Have them pick one of the four billiard balls. Then ask them the question: "how many choices do I now have left to pick the second billiard ball “? Then point out that each of their first choices can have three second choices, so they have to multiply four times three to get the total number of ways to pick the first two billiard balls. Then, ask them to create all 12 combinations. In this way multiplying four times three makes sense to them as a way of determining all of the ways to pick the first two billiard balls. They can also see how the multiplication is a summary of their actions or operations. Continue this process to create all 24 possibilities. Then show them the cute mathematical hieroglyphic that symbolizes or represents the operation they have just undertaken. Point out to them that when they see this hieroglyphic it simply tells them to undertake the operation they have just completed. In similar fashion, the concepts of combinations and permutations can be developed. I am not with this example simply making a pitch for the use of manipulatives in teaching mathematics. Manipulatives are worthless unless used contemporaneously in the concept development process as a means of creating the experience or undertaking the operations that will ultimately be abstracted into the concept and its symbolic representation. It is the role of the teacher to assist the students in making sense of the operations or experience by assisting them in the creation of relationships that summarize their operations and can ultimately be represented symbolically. In the example above, N! becomes the symbolic representation of the logical process or operation that the children undertook to create the total number of arrangements. In the absence of a concept formation process, N! simply becomes one more of a long string of symbols and procedures a student has to memorize in order to get through mathematics. Note in the above example that we are continually answering the question: why are we undertaking this specific operation to achieve our goal?

Getting back to our discussion of entropy, the table below from Halliday, Resnik, and Walker (2005, p. 551) shows the total number of arrangements for the six molecules in the two halves of the box, as well as the entropy of each arrangement. We will get to entropy shortly.

Configuration Label	n_1	n_2	Multiplicity W (number of microstates)	Calculation of W (Eq. 20-18)	Entropy 10^{-23} J/K (Eq. 20-19)
I	6	0	1	6!/(6! 0!) = 1	0
II	5	1	6	6!/(5! 1!) = 6	2.47
III	4	2	15	6!/(4! 2!) = 15	3.74
IV	3	3	20	6!/(3! 3!) = 20	4.13
V	2	4	15	6!/(2! 4!) = 15	3.74
VI	1	5	6	6!/(1! 5!) = 6	2.47
VII	0	6	1	6!/(0! 6!) = 1	0
			Total = 64		

First, we cover a subtle, but important, point. Each individual possible state of the six molecules is equally probable. That is, five on one side and one in the other has the same probability as three on one side and three on the other. There are, however, only six ways we can get to this state versus 20 ways to get to the state of three molecules on each side, so it is more likely or probable that we will find the molecules in the evenly distributed state of three on each side.

Let us now up the ante to a hundred molecules and calculate the number ways we can have a 50-50 or even distribution of molecules.

$$W = \frac{100!}{50!\,50!} = 1.01 \times 10^{29}$$

The number of ways we can get to 100 molecules on one side and none on the other is:

$$W = \frac{100!}{100!\,0!} = 1$$

It is therefore, 10^{29} more likely that we will have an even distribution of molecules in the box than to have the circumstance that all of the molecules will stay on the left side of the box. When we imagine the enormous number of molecules of air in a room, it is understandable why we never go to a spot in a room and find ourselves gasping for air (Halliday, Resnik, & Walker, 2005).

The tendency for molecules with kinetic energy and multiple degrees of freedom to distribute themselves evenly is manifest in a number of physical phenomena. If we put a drop of ink or food coloring in a glass of water, it will evenly distribute in time. Why does this occur? The ink molecules have kinetic energy and can move freely among the water molecules. In time we are likely to find them in their most frequently occupied state, the even distribution. All diffusion phenomena in physics, chemistry, and biology, such as heat conduction, concentration equalization and pressure distribution, operate according to this principle. Note that all of these processes involve the kinetic energy of molecules.

Boltzmann's discovery was that the entropy of a system (in a given state) was directly related to the multiplicity of the configuration that the molecules, constituting the system, took on in that state. The multiplicity of a state, or W, is the number of possible ways of achieving the configuration that constitutes a state. In our six molecule example, we had seven possible states. The multiplicity was the number of possible ways we could arrange or distribute the molecules to achieve those states. Boltzmann's formula for entropy is:

$$S = k \ln W$$

where k is a constant called Boltzmann's constant and $\ln W$ is the natural log of multiplicity (Halliday, Resnik & Walker, 2005). In our six molecule example, the entropy of the even distribution or three molecules on each side is:

$$S = 1.381 \times 10^{-23} J/K \ln 20 = 4.13 \times 10^{-23}\, J/K.$$

The term J/K represents the units Joules of energy per degree Kelvin. If we wanted to know how much energy was lost due to entropy when the system changed from six molecules on one side of the box to three molecules on each side of the box, we would multiply the term above by the temperature of the box in degrees Kelvin. This would give us the energy loss in units of Joules. Note that the starting state had entropy of zero, so the entropy change associated with the process is the entropy of the final state. The previously shown table gives the entropy for all of the possible configurations and multiplicities of the six molecules. As the table shows, the most likely state, which we call the equilibrium state, has the highest entropy. This is the basis of the idea that nature tends toward the state of highest entropy and that equilibrium represents a state of maximum disorder.

We can now answer the questions that we initially posed about our system consisting of six molecules. First, the process or redistribution of molecules incurred an energy loss associated with the increase in entropy of the system from zero to $4.13 \times 10^{-23}\,J/K$. Our system is closed and there is no mechanism whereby the molecules can be forced to return to the left side of the box and stay there. Therefore the process of opening the partition and allowing the molecules to redistribute themselves is an irreversible process.

The vaunted second law of thermodynamics, which our example system conforms to, states that if a process occurs in a closed system, the entropy of the system increases for irreversible processes and remains the same for reversible processes. Entropy never decreases. Mathematically the statement is:

$$\Delta S \geq 0$$

We can see from the above that a reversible process would not increase the multiplicity of the possible states that molecules could occupy.

Since virtually every energy transaction involves at least some loss and hence irreversibility, we can see where the idea comes from that the universe is doomed to a thermal death and a state of maximum disorder. The caveat in the second law of thermodynamics is the word closed. In the second half of the 20th century, open systems, where mass and energy were continuously exchanged with the environment were discovered that could achieve reductions in entropy and increased order. In fact under certain conditions they were seen to self organize. One of the first experimental observations of self organization was made in the early 1950s by Russian biochemist Boris Belousov. As is always the case with radical scientific innovation, his experimental results were ridiculed by the scientific establishment of the time and he was not permitted to publish his results. It was not until a graduate student named Zhabotinsky discussed these results at an international conference in Prague that the scientific community began to acknowledge this unique phenomenon. By the mid-1970s, these results became quite famous and came to be called the B-Z reaction (Strogatz, 1994).

The main reason to concern ourselves with nonlinearity and self organization is that this Dissertation is headed toward the conclusion that the learning process, as it is manifest in the mind of the individual or, in other words, how the mind creates meaning, is through a nonlinear self-organizing process.

In order to get a good qualitative understanding of organization and self organization, let us explore these ideas further with the assistance of Herman Haken (1983). We start by considering a string composed of a large number of molecules, say: 10^{30}, held together by intermolecular forces. We are going to pluck the string and give it some energy. Plucking the string also gives each molecule a starting position or initial condition, to state things mathematically. We want to know the position of each molecule at some time in the future. In other words, what trajectory will each molecule take in time? To make a model of this process so that we can express it mathematically and make computations, we assume that each molecule is connected to another molecule by means of a spring. The spring represents the intermolecular forces between the molecules.

With our spring and molecule model, we can write Newton's law for each molecule. This will give us 10^{30} linear differential equations. This is too many for even a super-computer, so let’s lump molecules into string segments and write a thousand differential equations instead. We can then simultaneously solve these equations, with the help of a computer, using the methods of numerical analysis, to give us our desired positions of the string segments with time, or the trajectories. The computer will give us our answer in the form of pages and pages of tables. Let's say we specify 10 positions and a thousand time intervals as the desired output. Our computer will output 10^7 pieces of data.

In the succeeding discussion, I will place the terminology of concept formation in parenthesis next to the physical language of the process, so that the reader can make an association between the two. In reflecting on what we have done, we find that our two shopping carts full of data are not terribly useful to us in their current form. If we examine the tables, we may, however, find certain typical features (similarity of attributes/characteristics between data items). In the example above, we would find certain correlations between the positions of adjacent molecules (spatio-temporal relationships). In addition, we would see that the motion of each molecule is periodic or that the molecules returned to a given position in regular intervals of time. Our examination would also reveal that there are consistent maximum and minimum positions of the molecules that can be characterized (abstracted) in terms of an amplitude or range. Our examination would never, however, yield the observation that the motion of a molecule between this maximum and minimum position is characterized by a sine wave, unless, of course, we already knew this answer and therefore knew what to look for. Haken (1983) describes this spatio-temporal pattern, or in our example, the sine wave, as a mode or organized structure. Once the microscopic level (level of molecules) assumed this mode (stable or equilibrated relationship), the microscopic motion of the individual molecules was summarized (abstracted) by two macroscopic (higher logical level) parameters, amplitude and wavelength, and the organization (relationship), which is the sine wave or sine function. Note that at the level of the molecule, these parameters are completely unknown. We see only the action of agents, the molecules, and not the agency of the whole, the sine wave.

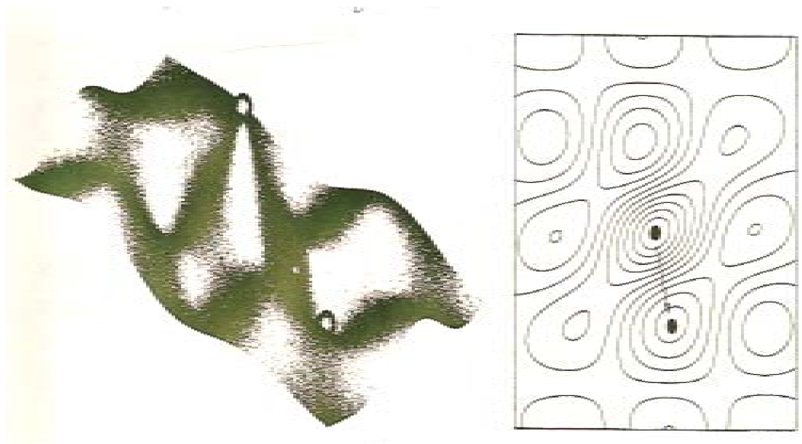
Haken (1983) makes a keen observation concerning this thought experiment. He asks the question: why didn't the computer calculation lead directly to the mode or sine wave. The answer is that the equations we fed into the computer were linear. It is a property of linear systems that any superposition of solutions is again a solution (Haken , 1983). How we discerned the sine wave was through the mental process of correlating the observed pattern of movement and associating it with our mental concept of a sine wave, which in turn is something we know from our prior experience. This process occurred at a higher logical level than the linear computations of the computer. In our minds, the summarizing parameters (amplitude and wavelength) and relationship (sine wave) were emergent and the consequence of our mental organizing process. The computer doesn't organize; it simply reports the agency (positions in time) of the parts. The computer is a linear machine. That's why, unless the task is raw computation, our minds can always outperform a computer. We arrived at our organization (concept) by selecting features (abstracting attributes/characteristics) and looking for correlations (making associations and creating relationships) that expressed constancy (invariance or equilibration), like, for example, the periodic behavior. The macroscopic summary parameters, like amplitude and wavelength, were consequent (emergent) and the result of our organizing process (concept formation). Note that our macroscopic summary represents a new idea (concept) compared to the microscopic descriptions of position and time. The ideas of amplitude and wavelength are different than those of molecular position. In this sense, we have created a new **context** in which to view our experience. Note also that this again conforms to Bateson's (2002) idea of context as an emergent pattern with time.

In more complicated systems, the task is to find out what modes (in physics, spatio- temporal patterns) the system can take on and what parameters characterize the system (like amplitude and frequency in our example). In each case, the mode or pattern is a simultaneous equilibration of the relationship between system elements, environmental conditions, starting conditions, and system inputs. In linear systems that receive organizing input the mode or organized structure that the system assumes is a reflection of the imposed organization. In nonlinear systems it can either be a reflection of the imposed organizing forces, or it can be a qualitatively different structure that results from the process of self organization. Another way to say this is that linear systems do as they're told. For example, this is how the computer I'm using to type this Dissertation works. I do sometimes wonder when my computer does something odd whether nonlinearities have crept in somehow. Bureaucracies, like school districts, are organized in linear fashion. The problem with predicting what will happen in a school district relates to the fact that the elements are highly nonlinear entities. They form all manner of nonlinear relationships in the form of heterarchies all through the basic hierarchy of the school district. In spite of the best efforts of school boards and superintendents, the organization of the system and the processes undertaken within it can become qualitatively and substantively different than the organization that was imposed from above.

Next we will explore how nonlinear systems create landscapes or morphologies through which system elements move. Elements that have a nonlinear relationship to each other can occupy a range of states that represent the satisfaction of the terms of the nonlinear relationship. We can metaphorically visualize these states as a multidimensional landscape or terrain. For example, we can think of visiting the various states that the system can occupy as a hike in a mountainous region. Our walk will lead us down valleys, over peaks and along ridges. There are a limited number of physical locations in three-dimensional space that we can occupy. We cannot be in the middle of a mountain or suspended above a valley.

A hypothetical landscape, from Haken (2006), of a nonlinear system is shown below.

Resolving Instability



In the depiction above, we can perhaps think of a marble being placed on a landscape constructed of papier-mâché. The peaks and valleys represent the fixed points in our nonlinear systems or places where the marble can come to rest and stop its motion. The valley bottoms can be thought of as stable fixed points. If the marble is in a valley, it will stay there unless we impart a force sufficient to push it to the top of a surrounding peak and perhaps, if the force is strong enough, into the next valley (fixed point) or beyond. If the marble is on any of the hillsides surrounding a valley, it will roll into the valley and come to rest there. This is called the basin of attraction of the fixed point (valley) in nonlinear dynamics. On any of these slopes, the marble is "attracted" to the valley bottom.

If our marble is resting at the top of the peak, we can think of this as representing an unstable fixed point. At a peak, or unstable fixed point, any small force or perturbation can send the marble on a trajectory toward any of the valleys surrounding the marble, depending on the direction of the perturbation or force. The marble will experience a qualitatively different trajectory depending on the direction of the force. From our metaphorical landscape, we can see why, in a nonlinear system, it is a creation of unstable fixed points that allows such systems to produce qualitatively different behavior. The future of the marble at the top of the peak (unstable fixed point) is ambiguous. Its future depends on the magnitude and direction of the next force or system impact. The ridges in our landscape are termed saddles in nonlinear dynamics. We will see later how these emerge and impact system dynamics.

The future course of a nonlinear system is determined not only by the relationship between the elements as discussed qualitatively above; it is also determined by starting or initial conditions, and system parameters that are expressed in the nonlinear relationship. These parameters are termed control parameters and can express both attributes intrinsic to system elements and the impact of changing external environments (environmental contingency). As we will see, the control parameters can change the nature of the landscape of permissible states, the location of fixed points and their stability, and can create qualitatively different behavior within the system.

Systems in the real world are subject to random fluctuations. In the case of a biological cell, we call this a mutation. In electronic systems or information systems, it is called noise. A fluctuation can move the system off of an unstable fixed point. If fluctuations (perturbations) can accumulate and become strong enough, they can move the trajectory of a system toward other basins of attraction and fixed points. When we consider the impact of fluctuations, particularly in systems at or close to instability, we can see how nonlinear dynamics can exhibit a dance between deterministic behavior (the fundamental nonlinear relationship) and chance (perturbations).

Let us consider first, a simple one dimensional nonlinear system characterized by the following nonlinear differential equation:

$$\frac{dx}{dt} = rx - x^3$$

This equation states that the rate of change of x with respect to time is equal to a control parameter r multiplied by x minus the cube of x. To find the fixed points of the system, or the points where the rate of change is zero, we set the left side of the above equation to zero and algebraically solve for the roots of the subsequent equation.

$$0 = rx - x^3 \quad (1)$$

$$0 = x(r - x^2)$$

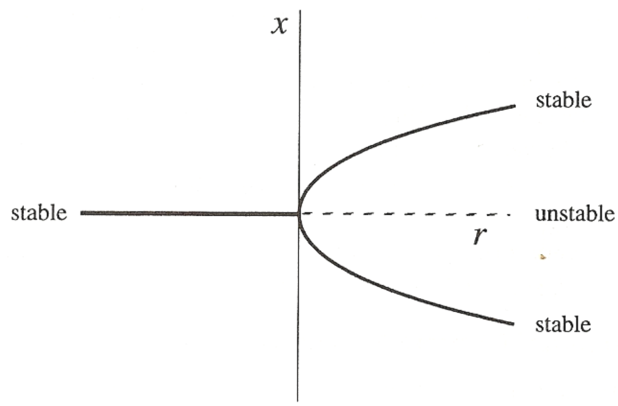
$$0 = x(\sqrt{r} + x)(\sqrt{r} - x)$$

We can see from the above, that the roots of the equation, or fixed points are: 0, $\sqrt{r}$, and - $\sqrt{r}$. To find the stability of these fixed points, we take the derivative of equation 1 above, with respect to x, and look at the value of this derivative at the fixed points. If this value is negative, the fixed point is a stable attractor. If this value is positive, it is an unstable repeller. If the value is zero, the stability is undetermined. Taking the derivative of equation 1 with respect to x we get:

$$\frac{d(rx)}{dx} + \frac{d(-x^3)}{dx}$$

$$r - 3x^2 \quad (2)$$

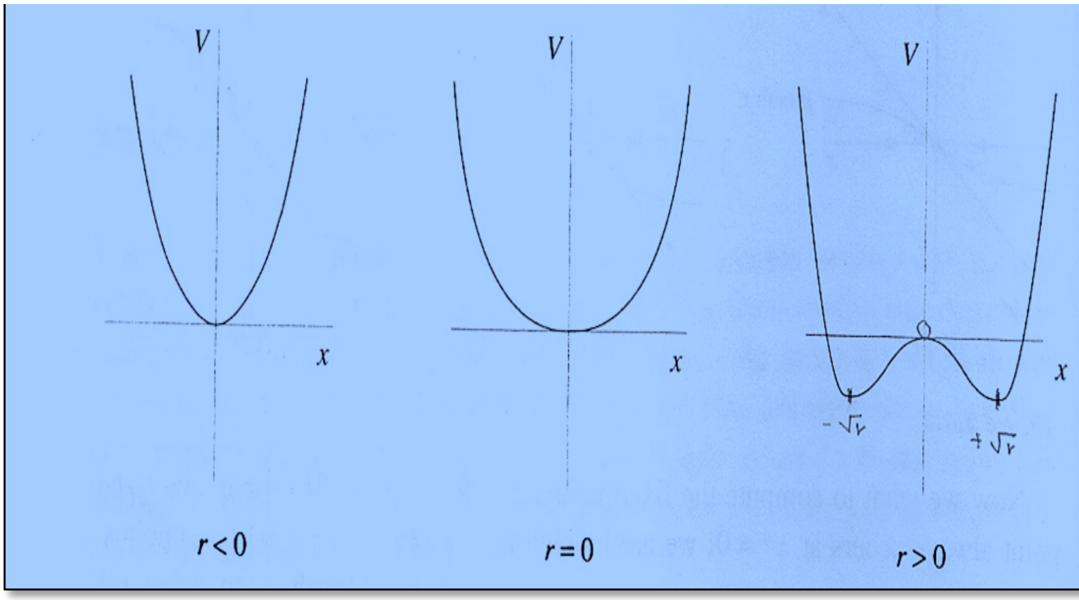
When we put the fixed point at the origin, or $x = 0$, into equation (2) above, we can see that the fixed point is stable for negative r and unstable for positive r. If we put $x = \pm\sqrt{r}$ into equation (2) above, we get the same result, because the term is squared: the fixed points are stable for positive r and do not exist for negative r. The figure below from Strogatz (1994) summarizes these results and shows the nature of the fixed points (x) as an r changes value.



As we can see from the graph above, the nonlinear system we are analyzing has a single stable fixed point at the origin for negative values of the control parameter r. As r goes positive, three fixed points emerge: an unstable repeller at the origin(x=0) and stable fixed points at $\pm\sqrt{r}$. In the terminology of nonlinear dynamics, there is said to be a **bifurcation** at the origin. The specific form of bifurcation that results here is called a pitchfork bifurcation (based on its appearance when graphed). Depending on the nature of the system, other types of bifurcations can result. In the system we have been considering, the parameter r is considered as something that can change, such as an environmental condition. We can see that changing this parameter produces a qualitative change in the nature of the trajectory that a nonlinear system can undertake. This type of change in qualitative behavior, as a result of a parameter change, does not occur in linear systems. Changing parameters in a linear system produces quantitative rather than qualitative change.

To produce the metaphor that we discussed earlier, we can integrate equation 1. Since the rate of change of x with respect to time can be considered as a velocity, the physics metaphor that an integration of equation 1 produces is the potential energy of the system. Integrating equation 1 yields:

$$\int rx - \int x^3 = \frac{1}{2}r\,x^2 - \frac{1}{4}x^4 = -V(x)$$



The figure above (modified from Strogatz, 1994), which is a plot of the equation above for different r values, can be interpreted as follows: If the environment is such that r is less than or equal to zero, given any initial potential energy, the system will gravitate to zero potential energy and a state of rest. If, however, the environment is such that r is greater than zero, the system can end up in any one of three states. If the initial state is represented by negative x, then the system will end up in the state represented by $-\sqrt{r}$. If the initial state of the system is represented by positive x, then it will end up in a state represented by $+\sqrt{r}$. If the system is initially in a position represented by x equals zero and zero potential energy, it will remain there. This position is, however, unstable. Any perturbation will move the system into either of the two stable states, depending on its direction. Please note that an initial position in either of the two stable valleys ($\pm\sqrt{r}$) is a state of negative potential energy. To move from one stable valley to the other would require positive energy input.

In the neuroscience chapter of this Dissertation, it is discussed how long-term memory consolidation could be the result of the stabilization of protein kinase concentrations that maintain the phosphorylation of NMDA receptors in the synapse of a sufficiently activated neuron. Griffith (1971) has proposed a generic model for a genetic control system that illustrates how such a process could work.

In a system where the activity of a gene is directly induced by copies of the protein for which it codes, Griffith (1971) proposed the following equations to describe the autocatalytic process.

$$\frac{dx}{dt} = -ax + y$$

$$\frac{dy}{dt} = \frac{x^2}{1 + x^2} - by$$

In the equations above, x represents the concentration of the protein and y represents the concentration of the messenger RNA from which the protein is translated. The terms a and b are constant parameters that govern the rate of degradation of x and y respectively. The first equation above states that the rate of change of the protein concentration with time is equal to the concentration of messenger RNA minus a term which expresses the natural degradation of the protein with time ($-ax$). The second equation states that the rate of change of the messenger RNA concentration is equal to a term which expresses the positive feedback mechanism or autocatalytic behavior minus the natural degradation of messenger RNA with time ($-by$).

Our first task is to find the fixed points of the system. This we do by setting the rate of change of both concentrations to zero (in the above two equations). Performing this operation results in the following two equations:

$$y = ax$$

$$y = \frac{x^2}{b(1 + x^2)}$$

The above two equations express curves along which the rate of change is zero in x and y respectively. They are termed nullclines. To find the fixed points, we must solve these two equations simultaneously. Doing so, we get the following equation:

$$ax = \frac{x^2}{b(1 + x^2)} \quad (2)$$

The nullclines and their intersections (the fixed points and solutions to equation 2 above), are shown in the graph below from Strogatz (1994).

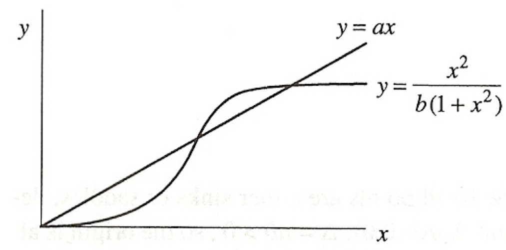


Figure 8.1.3

As we can see from the above figure, there are three intersection points or simultaneous solutions to the two equations. One is at the origin, or x and y equal zero. If we were to increase a, the slope of the straight line shown above, the two fixed points, not at the origin, would coalesce into a single fixed point tangent to the sigmoid shaped curve. For higher values of the slope a, there is only the one fixed point at the origin.

We can algebraically manipulate our simultaneous solution, equation 2 above, to produce the following equation:

$$abx^2 - x + ab = 0$$

This is a quadratic equation with the following solutions:

$$x = \frac{1 \pm \sqrt{1 - 4a^2b^2}}{2ab} \quad (3)$$

These solutions coalesce when the term in the radical is equal to zero or when $1 = 4a^2b^2$. This yields a value at the point of coalescence of $a_c = \frac{1}{2b}$. Replacing this into equation 3 above yields the value $x = 1$ and subsequently $y = a$ for this fixed point.

To evaluate the stability of fixed points in our previous one-dimensional example, we took the derivative of the rate of change function and evaluated it at the fixed points. For a two-dimensional system, the process is a bit more complicated. It involves evaluating a matrix of partial derivatives, called the Jacobian matrix, at the fixed points. The Jacobian is given by the following matrix:

$$\begin{bmatrix} \frac{\partial \dot{x}}{\partial x} & \frac{\partial \dot{x}}{\partial y} \\ \frac{\partial \dot{y}}{\partial x} & \frac{\partial \dot{y}}{\partial y} \end{bmatrix}$$

The terms $\dot{x}$ and $\dot{y}$ designate derivatives with respect to time, or the right-hand sides of the original dynamic equations. For the example we are considering, the Jacobian is:

$$\begin{bmatrix} -a & 1 \\ \frac{2x}{(1+x^2)^2} & -b \end{bmatrix}$$

An evaluation of the trace and the value of this determinant reveal the nature of the fixed points. The trace of the determinant above is $-(a + b)$. This number is always negative, therefore, all of the fixed points are either sinks (attractors) or saddle points. Evaluation of the determinant reveals that the fixed point at the origin is a stable sink, the middle point (at $x = 1$) is a saddle, and the remaining fixed point is a stable sink. I have left out the details of how these conclusions are reached, as they involve a considerable amount of background knowledge to follow. I ask the reader without a background in nonlinear dynamics to indulge this omission and accept these conclusions.

Knowing the nature of the fixed points, we can plot the nullclines and draw arrows that show the direction of change of the variables, or gradients near the fixed points and nullclines. At the nullcline represented by the straight line, which is the graph of points where the rate of change in x is zero, the arrows will be vertical. At the nullcline represented by the sigmoid curve, the arrows will be horizontal, denoting no change in y with time. A plot with nullclines and arrows (gradient vectors), from Strogatz (1994), is shown below.

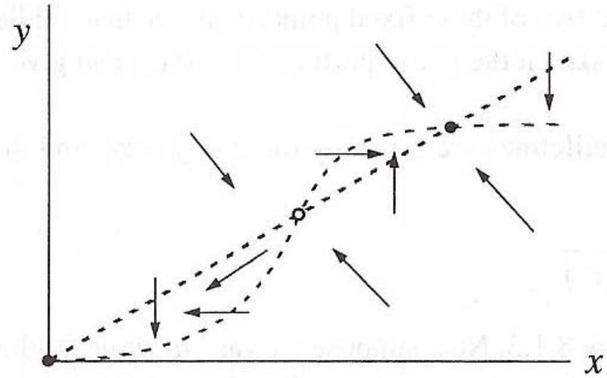


Figure 8.1.4

This figure above can be used to qualitatively sketch a final phase portrait, or the original equations can be solved numerically to yield the final phase portrait. The figure below (Strogatz, 1994) shows what this phase portrait looks like.

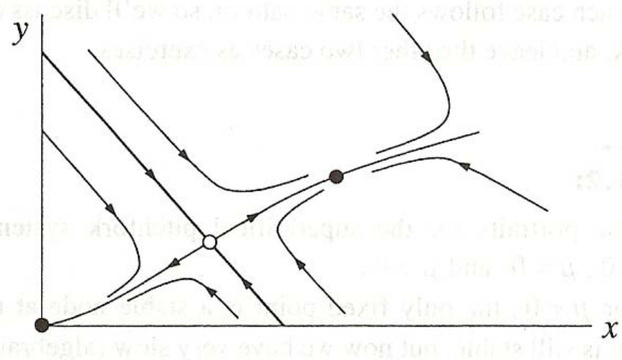


Figure 8.1.5

As shown above, the axis associated with the saddle point (stable manifold) separates the plane into two regions, each of which is a basin of attraction for a stable sink. The biological interpretation of the above is that the system acts like a biochemical switch. If the concentration of the protein reaches a sufficiently high threshold level, the system will equilibrate and a constant concentration of the protein (the second stable sink) will result. Below this threshold value, the concentration of the protein degrades back to zero. Autocatalytic reactions are commonplace in cell dynamics. We can see from the above, how a protein concentration necessary for long-term potentiation of a neuron could be maintained.

We began this chapter with a description of self organization. This concept is so crucial to the Dissertation that it is of value to expand upon this initial introduction. We will consider two physical examples which are often discussed in the literature as being exemplary of self organizing systems: fluid convection and laser dynamics. As discussed previously, self organization is a phenomenon exhibited by elements that exist in systemic nonlinear relationship. In such a relationship, all of the elements are codependent. As a consequence of this codependent systemic relationship, the elements of the system occupy states that represent a dynamic equilibrium between the intrinsic relationship between system elements, external driving forces/system inputs, and the contingencies of the element's environment. If the system is to conserve itself as a unity, the mutual satisfaction described above becomes a logical necessity. As shown above, the landscape of possible states the system can assume include stabilities and instabilities. Also, changes in system input, characterized by control parameters, can qualitatively change the trajectory of states that the system can assume.

The mathematical discipline of nonlinear dynamics, for all practical purposes, began in the early 1970s. As such, it is a discipline still in its early stages of development. A full rendering and complete mathematical articulation of the miracle of self organization is yet to come. The work of Prigogine (1997) and Haken (1983) represent strong, although incomplete (and somewhat controversial) beginnings. The mathematical renderings from these two authors are beyond the scope and needs of this Dissertation. We can, however, gain a good qualitative understanding of the elements and behaviors of self-organizing systems. The first characteristic of self organization is that the process begins **far from static equilibrium** at an **instability**. An instability represents a fixed point, or said alternatively, a point at which further progress (within the current structure) is impeded. In terms of real systems, this could be expressed as Piaget's (1985) disequilibrium, the blockage at the entrance of the theater in our example in the beginning of the chapter, or any circumstance in which the current structure or organization of a system prevents progress. As the colloquial expression goes, "necessity is the mother of invention." So it is with nonlinear systems. Beyond this instability, as we saw above, there are qualitatively different trajectories that the system can undertake. Depending on the specifics of circumstance, movement toward these trajectories often requires only small fluctuations from the environment and can result from chance inputs . System behavior can then be said to be the result of a confluence of **determinism and chance**. When the system moves beyond the instability into one of the qualitatively different paths, this is expressed as a **symmetry breaking** event, in the literature. Given the same set of parameter values, the system can adjust to the environment in different ways. Haken (1981) describes system activity as the instability in terms of fluctuations testing the possibilities of orderly alternative states in a trial and error fashion. For example, in our movie theater example, these fluctuations would be the jostling around of individuals in the crowd in an attempt to find a structure which enabled them to gain entry into the movie theater. In the fluid convection example, it would be small elements of fluid executing various vertical motions in an effort to resolve the instability. In Haken's (1981) description of laser dynamics, he speaks of various light waves, in effect, competing to get amplification from electrons. Those waves whose frequency most closely resembles the natural frequency of the electron end up being the ones amplified and reinforced. He states that this wave grows like an avalanche and ends up dominating and controlling the others. What Haken (1981) seems to be describing is an equilibration between the electron (its intrinsic structure) and the wave (outside force). Haken (1983) generally characterizes the stage right before the onset of self organization as a competition of modes or possible states in which one mode wins out and becomes dominant. The other modes begin to cooperate with this dominant mode. Haken (1983) regrettably calls this the slaving principal, since the other modes in effect become slaved to the dominant mode. In his mathematical characterization, the dominant mode is typically the one that produces the largest increase in velocity or rate of change in the system. In this sense, it is the most unstable mode that begins the process of driving the system ultimately toward a state of dynamic stability or equilibrium. The instabilities drive the system toward stability. The unstable modes, in this way, order the stable modes. Please note that there is a difference between an unstable mode and an unstable fixed point. An unstable mode is one in which the system has a continual exponential increase in rate of change.

If we consider a characterization described by Kelso (1995), we can get another insight into the process. A parameter that characterizes the convection process is the Rayleigh number. The Rayleigh number is the ratio of the driving force (which tends to push the system apart) to the forces that tend to hold the system together (dissipative forces). In the convection system, it is the ratio of the temperature gradient between the plates and the viscosity and thermal conductivity of the fluid. The convection system reaches an instability when the Rayleigh number is greater than one, indicating that the driving force is exceeding the ability of the liquid to remain as a motionless mass. The system is about to move in response to the driving force. As Haken (1983) describes, it is at this point that competing fluctuations emerge in an attempt to resolve this instability. Kelso's (1995) insight is that the convection rolls represent a dynamic structure that accommodates the driving force and at the same time meets the need of the retentive force to keep the system together. This specific geometry of motion maximizes the cooling of the highly heated liquid at the bottom of the system, thus allowing the system to stay together and not turn into a gas (completely disorganized system). The self organizing process then, represents a structural change which effects a cooperation or equilibration between competing forces in a way that maintains system unity. When coupled with Haken's (1983) qualitative description of laser action, it appears that self organization can be described as mutual satisfaction of the requirements imposed by competing forces and environmental contingency in the effort to maintain or conserve system unity and integrity (congruence with the relational structure intrinsic to the system).

Haken's (1983) points are well taken. At the instability, there is no prescription regarding which mode or path will be taken to resolve the instability. Different modes that are variously successful will emerge as fluctuations. The one that prevails will undoubtedly be the one that produces the greatest velocity or rate of change and releases the bottleneck or instability the quickest. As this is an unstable mode which cannot persist and since the elements are in systemic relationship, the ultimate structure that appears is a stable equilibration of system and external input (driving force and environment). As per Haken (1983), the instabilities do drive the system toward the stabilities, and in this sense order the system, but the ultimate structure that emerges is a re-equilibration of driving force and dissipative force that expresses the system's attempt to maintain integrity. **Competition** turns into **cooperation** in service to the maintenance of system unity: another characteristic of self organizing systems.

Self organizing systems must be **open to energy and mass input**. Any act of organization requires energy. Self organization is the transformation of energy into ordered behavior. The system must be **dissipative**. The dissipative structure contracts the number of possible states and allows for organization. As discussed above, a self organized structure expresses the cooperation or equilibration of driving and dissipative forces. Self organizing systems exhibit **amplification and autocatalytic** behavior. As discussed with the laser example, mechanisms in which external input resonates with internal structure result in amplification. The fundamental structure of codependent elements in systemic relationship constitutes a feedback arrangement that can facilitate amplification or autocatalytic behavior.

During the process of self organization new parameters, or what are termed in the literature **collective variables or order parameters, emerge**. As we saw in our example of the vibrating string, the individual behavior of the molecules or string elements was summarized by new parameters that expressed and summarized the order of the system as a whole. Frequency and amplitude along with the emergent structure of a sine wave were sufficient to completely specify the actions of the individual elements. The individual actions of the string elements or molecules contributed to and created these parameters. But, because of the systemic relationship of the string elements or molecules, once the structure began to form, these parameters in turn influenced the behavior of the elements of the system through **circular causality.** This behavior is quite characteristic of systems, and in particular, nonlinear systems. There is both top-down and bottom-up influence wherein the action of the parts impact the whole while the coordination of the parts with each other and the constitution of the whole and its structure, reciprocally influences the parts; Attributes of the whole which influence the parts are expressed in terms of the emergent collective variable, or order parameters, which reflect the cooperative actions of the different elements of the system or the **agency of the system, as opposed to expressing attributes of the agents**. Last but not least, it is worth noting that self organization constitutes an adaptation. **Nonlinear organization enables the system to adapt to changing circumstances by modifying its structural organization.**

Neuroscience

We can attain an understanding of the mechanisms of multiple realizability and the interplay of different logical levels by considering recent research into the neurological basis of reading and, in particular, the latest research on dyslexia. Dyslexia is a term used to describe reading failure in children who are otherwise unimpaired: adequate intelligence, no social -emotional defects, and adequate instructional support. The historical view of dyslexia, and the view that is still prevalent in popular culture, is that dyslexia is a visual processing disorder. A classical behavioral example cited is the inability to distinguish or discriminate letters such as d and b or w and m. There is a growing consensus among investigators in the field that dyslexia should be viewed more broadly as a phonological processing disorder. The phonological theory of reading asserts that a reader must not only recognize and discriminate letters and letter combinations (orthography) but also correlate these representations with the sounds of spoken language. To read, a child has to develop the knowledge that spoken words can be broken apart into elementary components of speech (phonemes) and that the letters in a written word represent the sounds of these elementary components (Shaywitz, Lyon, & Shaywitz, 2006). The technical description of this process is the correlation of graphemes (letter representations) to phonemes (sound units). Results from large and well-studied populations with reading disability indicate that a deficit in phonology is the strongest and most specific correlate of reading disability (Ramus, Rosen, Dakin, Day, Castellote, & White, 2003). Inferences regarding the neural biologic underpinnings of reading and dyslexia come from postmortem studies of brain specimens and imaging studies. These studies have suggested that there are differences in the temporal-parietal-occipital brain regions between readers with dyslexia and those with no impairment (Shaywitz, Lyon, & Shaywitz, 2006).

The most prevalent brain imaging tool currently used to measure different levels of activity in various parts of the brain is functional magnetic resonance imaging (fMRI). An increase in fMRI signal results from the combined effects of increases in blood flow, volume, and oxygenation to specific brain regions. When an individual is presented with a stimulus or task, the brain regions which process the stimulus or enable the performance of the task receive increased flows of oxygenated blood. It is these increased flows that the fMRI signal responds to. The fMRI signal level is therefore an indication of the relative degree of activation of specific brain regions involved in processing the task or stimulus (Reisberg, 2006). Researchers employing fMRI scans have found significant differences in brain activation patterns between dyslexic and non-dyslexic readers during tasks that made progressive demands on phonological processing (Shaywitz & Shaywitz, 2004; Shaywitz, Lyon, & Shaywitz, 2006; Henderson, 1986).

During the 1980s and continuing in some measure to today, a battle emerged between two competing philosophies of reading instruction. One side stressed reading for meaning, while the other focused on reading as decoding or phonics. Another way to express the debate is a dialectic between top-down (meaning) versus a bottom-up (language structure) approaches to literacy development (Ely, 2005).

The most popular variant of the top-down approach is termed "whole language". The philosophy of whole language is that children best acquire literacy through meaningful interactions with text. The texts children encounter should contain "whole" meaningful language that elaborates new information or knowledge. Texts are viewed as sources of meaning. The function of language (derivation of meaning) is stressed rather than the form of language. A large site vocabulary of words is emphasized, as well as the use of context (other words, pictures) as a means of understanding unfamiliar words. Children are expected to make a best guess as to the meaning of unknown words. In this model, reading is viewed as a psycholinguistic guessing game of making and testing hypotheses, wherein it is assumed that children will employ a variety of guided top-down procedures to decode words (Ely, 2005). Attention to the mechanics of decoding is viewed as secondary to the goal of obtaining meaning from text.

In contrast reading as decoding, or phonics-based methods, emphasize bottom-up skills (Adams, 1990). These methods explicitly teach: identifying and naming letters of the alphabet, segmenting and blending phonemes (letter or letter commendations sounds) and learning grapheme (written letter) - phoneme correspondence rules. Reading for comprehension is felt to be contingent upon first being able to properly decode words. The basic process consists of "phonological recording" wherein letter strings are transformed into a pronunciation which is then recognized as a word (Ehri,1998).

If both of the above approaches appear to have merit to the reader, this is the right impression. The above is one more in a long string of pointless debates or dialectics we encounter in this Dissertation. There is no need for the ideological wars that have resulted between factions on different sides of the phonics -whole language debate. Both forms of processing are necessary and beneficial. Certainly the ultimate goal of literacy is the creation of meaning. However, it is apparent from a considerable body of research that we impede progress toward this goal when we fail to provide children with the ability to understand language structures, the relationship of spoken and written language and basic written-language decoding procedures. The creation of meaning and language decoding are psychological, as well as neurological processes that are intimately related but exist at different logical levels. Their relationship is hierarchical. FMRI studies of capable adult readers indicate that brain areas associated with basic phonological processing are active during reading. This is in spite of the fact that experienced adult readers rapidly recognize, process, and lexically associate with meaning, complete words. This is also indicative of the fact that biological systems do not completely reinvent themselves but adapt and evolve pre-existing systems so as to make them more effective and efficient with respect to the demands of an environment and a goal within the context of an environment.

The phonics - whole language debate was in some measure resolved with the publication of the results of the blue ribbon National Reading Panel (2000). After reviewing the extensive body of literature on reading instruction, the Panel concluded that children who received formal instruction in phonics were able to read more quickly and recognize more words than children who received less explicit instruction. The panel endorsed instruction in phonics, development of fluency, reading comprehension activities, age-appropriate vocabulary development and oral reading. Comprehension strategies endorsed included self-monitoring (meta-cognition), posing and answering questions and text summarization activities (National Reading Panel, 2000).

Ely (2005) summarizes the components of reading that must work together in order to make reading a seamless process that facilitates the construction of meaning:

1) Letter recognition
2) Grapheme -Phoneme correspondence rules (including segmentation)
3) Word recognition
4) Semantic knowledge (word meanings)
5) Comprehension and interpretation of texts (summarization)

We will now examine the neurological and psychological correlates of these activities. First, in order to identify a letter, a child must recognize its **defining features.** Our visual system senses input from the visual field in terms of features. David Hubel and Thorsten Wiesel (1959), using single-cell recording, discovered the existence of neurons in the visual system each of which has a specific visual trigger. Certain neurons, for example, termed "dot detectors," fire or activate when light is presented in a small, roughly circular area in specific positions within the field of view. A number of detectors fire when an edge of specific orientation appears. Some cells fire when a vertical edge is present in the visual field, some fire when a horizontal edge is present, while others are sensitive to edges with specific angles in between. There are detectors sensitive to corners and notches also. Still other neurons are sensitive to specific directions of motion. For example, a stimulus moving left to right across the visual field will excite specific neurons, while a right to left motion will excite others.

The visual system handles color in a similar fashion. Cells which parse color are selectively sensitive to certain frequencies of light corresponding to three different ranges in the visual light spectrum. We perceive color by comparing outputs from these different detectors. For example, if only cells sensitive to the highest frequencies of the visual light spectrum are activated, we sense the color purple. If the visual cortex is also receiving some input from cells sensitive to the mid range of frequencies, we would sense the color blue.

Our visual sensing circuitry is particularly sensitive to edges. Cells in the retina responding to light input inhibit adjacent cells. If the object we are viewing is uniformly illuminated, we have difficulty discerning features. In areas of the visual field where light intensity is lower, inhibition of adjacent cells is reduced. Cells at the edge of this change in intensity are therefore less inhibited and send a stronger signal than cells on either side of the change in intensity. This creates an edge enhancement effect (Reisberg, 2006). It is interesting to note that this effect was empirically discovered by Renaissance artists. In Italian, the effect is called chiaroscuro. Renaissance artists discovered that they could create the impression of three-dimensional shape and volume in paintings by using shading or an apparent change in light intensity created by a change in color. The painter Caravaggio also noticed that extreme changes also created an emotional response. Illumination in his paintings is as if a spotlight were shining on otherwise dark objects. This creates a dramatic effect in his paintings.

Another discrimination in the visual field, is between fine detail processing and the discernment of the general shape and arrangement of objects. Moving from the periphery toward the center of the retina, the number of cells called cones increases. Cones have greater acuity or capacity to discern fine detail. The other type of cell in the retina, called rods, has less acuity and is more concentrated in the periphery of the retina. These cells are specialized to discern gross and relational features of the visual field. The center region can resolve fine detail but only a small portion of the visual field at a time. The peripheral cells or rods are an order of magnitude less acute, but cover an angular field three orders of magnitude larger in area (Fischer, Rose, & Schneps, 2007). Information then is coarsely sampled by peripheral cells, but in sufficient detail to discern what objects are and how they are spatially related (Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001).

The center of the retina is utilized to undertake more detail-oriented tasks such as the recognition of faces, while the periphery is better at discerning and discriminating scenes, spatial arrangement and large objects such as buildings, due to its larger angular field of processing (Levy, Hasson, Harel, & Malach, 2004). When we wish to perceive something in detail, our attentional system moves our eyes so that the object is centered on the fovea: the very center of the retina (Reisberg, 2006). This separation of information (detail versus coarse grain) is preserved from the retina into the primary visual processing area of the cerebral cortex (occipital lobe). Coarse-grained information in the visual system is transmitted by cells called magnocellular neurons. These cells are specialized to have larger receptive fields and fire only when a stimulus appears in the field of vision and when it disappears, but not in between. This specialization makes magnocellular systems adroit at processing tasks such as discerning the broad outline of objects, detecting motion and depth perception. Detailed information from the cones is primarily processed through cells called parvocellular neurons. These neurons have a smaller receptive field and fire continuously as long as the stimulus is in the visual field. They are specialized for detailed analysis of forms (Reisberg, 2006). Functionally, these two systems can be considered to be separate but complementary (Fischer, Rose, & Schneps, 2007).

There is mounting research evidence that many dyslexic individuals exhibit a bias toward the peripheral field of vision and a deficit in processing the central field of vision (Fischer, Rose, & Schneps, 2007). Fischer et al. (2007) make a compelling case that these initial biases are strengthened and reinforced by subsequent experience, resulting in differential abilities with time. Those with biases toward the center of the visual field perform better on attenionally-driven, temporally-sequential visual processes such as reading or visual searches. Those with an initial bias toward peripheral vision tend to do better at tasks that involve visual or spatial representations of relationships. It is interesting to note that these abilities are important in domains which require an understanding of spatial relationships, such as science or art. Fischer et al. (2007) point out that dyslexics often excel at such tasks.

The preference for visual search versus spatial comparison has pedagogical implications, particularly in science and math, where visual representation of concepts is an important skill. Instruction can be designed to exploit preferences or scaffold deficits. As we will see later in the Dissertation, directly addressing deficits through focused instruction can, in fact, alter neurological configurations and effect improvements, particularly in young children (Shaywitz, Lyon, & Shaywitz, 2006).

The peripheral vision system is also a fast reaction system. A similar duality manifests itself in other human systems, for example, our emotional system. As with the visual system, our emotional system has a fast reaction, largely tacit, gross feature subsystem which complements a slower acting, attenionally (consciously) and memory-involved system. This bifurcation likely represents an evolutionary adaptation and differentiation that facilitated survival. In a hazardous environment, the ability to quickly, although only approximately, recognize a threat and initiate a quick motor response with automaticity would significantly favor survival. It is better to be partially correct about a threat and be alive than to be absolutely certain, after a detailed analysis, and be dead.

The duality of biological systems has significant pedagogical implications. It is, however, an area that has not received much in the way of research attention. To summarize, our slow reaction system:

1) examines the fine details of the objects of our consideration
2) requires attentional resources
3) involves memory
4) can consider and construct a variety of relationships and
5) facilitates the construction of plans, strategies and alternatives.

In contrast, our fast reaction system:

1) examines the broad outline or features of the objects of our consideration
2) is largely tacit or subconscious and does not require attention
3) typically invokes only the most highly sensitized fraction of memory (recent, frequent or emotionally charged /valenced) and
4) returns only the most probable relationship or meaning.

Given the above, if your instructional goals are to encourage depth of understanding and meaning creation, would you administer a lengthy timed test that invokes fast-reaction systems? When testing both an expert and novice, such a test would differentiate the two. This is due to the fact that experts, as a result of years of experience, have a considerable portion of their knowledge base contained within their tacit memory system. Much of this knowledge can be drawn from memory with very little in the way of attention-driven conscious processing. For example, as a professional engineer for several decades, I was able to process certain types of problems with complete automaticity and expend very little conscious effort.

Dastardly (did I spell this right?) professors, who want to make sure their tests have a normal distribution of grades, will often put the trick questions at the very end of a lengthy, timed test. Students in a hurry will parse the most probable meaning of the question and often not discern words like never, or not, in the question. Or, a professor can employ a strategy I always loved, putting options like: a) and b), a) and c), or none of the above, in the last three questions of a timed 250-question, multiple-choice test.

The point I am trying to make is that educators need to be certain that their educational goals, both content and process, are congruent with their assessment methods as well as their pedagogy. In the case of novice learners at about the same level of expertise, the depth of knowledge exemplified on an assessment should be expected to have some proportional relationship to the amount of time given to supply an answer. In an age where the timed, standardized test reigns supreme, considerable pedagogy is directed toward training students to supply automatic pat answers to content or definitional forms of knowledge. It is small wonder that students know what things are, but possess little ability to utilize or apply knowledge. This also has the effect of confining them to narrow universes of knowledge and disabling their ability to see alternatives or to craft alternative relationships with which to explain things.

Fischer et al. (2007) predicted advantages for students with a bias for peripheral vision processing in learning concepts involving visual comparisons across a single figure and disadvantages where visual concepts are developed by comparisons across multiple figures (e.g. on different pages). They also predict advantages in identifying objects embedded in distracting but familiar backgrounds and disadvantages in locating and identifying objects if the backgrounds are unfamiliar. The task of identifying objects in an unfamiliar background requires visual search and attentional resources. Again the deficits occur in attentionally focused, acute visual processing of multiple stimuli requiring memory resources for comparison. Conversely, students with a bias for peripheral visual processing demonstrate advantages in tasks that require simultaneous comparison of features within a given field of vision, such as seeing the symmetry in a figure or graph. Additional research is required for empirical validation of these predictions and the evolution of pedagogical strategies which recognize and make advantageous use of these learning differences (Fischer, Rose, & Schneps, 2007).

Neurological studies confirm that different areas of the visual processing sections of the brain address different content or features (**characteristics**) of the sensory field. For example, a specific area of the occipital lobe of the cerebral cortex, designated MT, is sensitized by the direction and speed of motion of objects. An area designated V4 is sensitized or activated by a certain range of colors and shapes (Reisberg, 2006). These various areas can be thought of as feature maps that work in parallel to permit an analysis of input with each area or map acting to enrich and inform the others. There is not an obvious seriation or prioritization logic to this process. For example, it is not the case that the motion-detection system would necessarily receive priority over the shape- detection system. Multiple systems work simultaneously to effect a consensus solution satisfying the contents of all of the system maps (Van Essen & De Yoe, 1995).

I interpret this as one more instance or articulation of a biologic system as a nonlinear dynamical system. The feature maps act in a way to effect a dynamic equilibrium, through self organization between the variables or features within a specific feature map and also, in hierarchical fashion, effect a dynamic equilibrium between feature maps. Through this process, meaning is created from sensory input, and a summarization is created at the higher logical level of conscious processing.

On a generalized basis, some information from the visual processing cortex (occipital lobe) is transmitted to the cortex of the temporal lobe. This pathway has been called the "what pathway" and plays a major role in identification of visual objects. Another pathway, from the occipital lobe to the parietal lobe, called the "where system," appears to be involved in guiding actions based on the perception of where something is. These interpretations are based, in part, on lesion studies. Patients with lesions in the occipital- temporal pathway have an inability to recognize visually presented objects, in spite of the fact that they can reach out and grab the unidentified object. For example, if you show such a patient a ball, he cannot tell you what the object is, but he has no problem taking it out of your hands. Conversely, those with lesions in the occipital-parietal pathway can tell you what the object is, but cannot reach out and take it from you because they are unable to locate it spatially (Damasio, Tranel, & Damasio, 1989).

Since visual information is represented in the brain through neuronal configuration that can be thought of as a series of feature maps which are recombined in the associational areas of the cerebral cortex, the question arises as to how the pieces get put back together. This broad issue is called the "binding problem." While the binding problem is far from being solved by neuroscience, there are certain elements that are known to play a role.

While certain maps record shape, others record motion, and still others, color, it appears that all maps contain information with regard to spatial position. Reassembly is done, in part, based on spatial position (Reisberg, 2006). The brain can utilize spatial information to relate the whiteness of the baseball, for example, to its spherical shape and its motion.

In addition, there is a temporal aspect to reassembly. If, for example, a baseball is crossing the visual field from right to left, how does the brain connect the motion detecting neurons to the neurons that sense spherical shape? If the baseball is the object of our attention, both sets of neurons fire at approximately the same rate, about 40 times a second, a rate called gamma-band oscillation (Buzsaki & Draguhn, 2004). If neurons are firing in synchrony, then the attributes represented by the neurons are combined (bound) and registered as belonging together.

The temporal binding mechanism is closely associated with attention. Evidence for this comes from various sources. For one, it is readily observable that overloading one's attentional system with multiple stimuli produces binding errors. In tumultuous situations, people often miss-associate features of objects (Reisberg, 2006). Those suffering from severe attention deficits, because of damage to the parietal cortex, are particularly impaired in conjoining features of objects (Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997). Additionally, animal studies show that gamma band oscillation does not occur unless an animal is specifically attending to a stimulus (Reisberg, 2006). Information available to the neurons, therefore, includes which cells are firing, how often they are firing and the rhythm or temporal synchronicity with which they fire.

Visual perception depends on object recognition. In our discussion of visual processing, we discussed how objects are represented in terms of features or feature maps. More than 30 such maps have been documented (Gazzaniga, Ivry, & Mangun, 1998). In general, an object is recognized by the relationship of its parts. This is done at all logical levels. For example two circles connected by a line can evoke in us a correlation to a barbell, a pair of glasses or, in general, the class or category of all objects for which such shapes are **iconic** or **characteristic.** We can also state this as the characteristics or attributes which are **similar** or common between objects.

Features in this way have a building-block attribute. Let me also call to the reader's attention the fact that we also have a system that has the characteristic of **productivity.** Given 30 feature maps and a multiplicity of features within each map, we can construct a virtually unlimited set of representations of the world. Features can be thought of as iconic of the objects from which they are drawn. This attribute sets up a system with capacity for metaphor and analogy. As we will see later, metaphor and analogy are two particularly robust instructional strategies. For example, when we call a house an A frame, we invoke the iconic similarity with the letter A, or two angled lines terminating at their upward intersection, with a horizontal connection between them. The shape of the house looks like the letter A to us. This results from the fact that the features of the shape of both objects share **iconic similarity**.

Every productive system manifests a grammar or logic of permissible relationships between elements. I would like to suggest the hypothesis, consistent with prior discussion, that this grammar is a consequent result of experience rather than a- priori (before experience), and that it represents or reflects stable relationships of elements (features) summarized from experience. This is a very large presumption. It implies that rules, grammar and logic are the consequence of experience and learning. It also implies that contexts are emergent from experience and not a-priori.

We now look at a theory of pattern recognition that, while old (Selfridge, 1959), coincides with the recent evidence we have discussed above. We will also focus on shape features and word decoding. The first mechanism in reading is the combination of basic Hubel and Wiesel features into the shapes we recognize as letters. To initiate 3 and 4-year-olds into the reading process, it is typical to show them depictions of letters while we pronounce or articulate the sound of the letters. The thought is that the child, through repetition, will make the association between the shape (grapheme) and the sound (phoneme) and commit this association to memory. This activity is association in pure form.

As previously stated, the first process that occurs is the detection of features in the visual field and subsequent recombination to form the neural representation of letters. The evidence from lesion studies and imaging studies is that this process occurs in the left occipital-temporal association area of the brain. (Shaywitz & Shaywitz, 2004; Schulte-Korne, et al., 2007; Cohen & Dehaene, 2004). Many fMRI experiments show that this area responds to written letters and words. As Dehaene (2007) points out, this area also responds to objects and faces and constitutes a principal shape recognition area of the brain. Dehaene (2007) reports that several research teams have recorded neurons that are selective for fragments of objects, some of which have the approximate shapes of letters. He hypothesizes that, with experience and continued exposure to writing, networks organize and form a hierarchical pyramid of neurons capable of recognizing letters. Post recognition, letters are assembled into graphemes, morphemes (smallest units of meaning), and ultimately words (Dehaene, 2007). FMRI experiments show that the left occipital-temporal area progressively develops its abilities for processing strings of letters between the ages of 6 and 12 (Dehaene, 2007). Shaywitz (2006) has found a strong positive correlation between reading skill and the degree of activation of the left occipital-temporal area of the brain. In individuals with dyslexia, this area is significantly under- activated in comparison to normal readers.

Dehaene (2007) points out that this region does not learn by globally recognizing complete words, it works by "decomposing words into letters, graphemes, and morphemes which have to be connected to the phonemic [sound] and lexical [vocabulary/meaning] units of spoken language" (p. 40). As such, he asserts that neurological evidence corroborates evidence from research on teaching practices (Ehri, Nunes, Stahl, & Willows, 2001) that confirm the benefits of phonics instruction. I would advise some measure of caution on the part of the reader in visualizing these brain areas as stand-alone units which process in either linear or sequential fashion. In reading tasks, multiple brain areas fire simultaneously with the occipital-temporal area. For example, the nearby posterior parietal- temporal area, hypothesized to be heavily involved in orthographic processing of words (letter combinations, word structures, grapheme-phoneme correspondences), is contemporaneously activated. These areas are connected in both directions and likely operate with compensatory feedback dynamics. A better way to visualize the operation of the various brain areas in undertaking the process of reading is as a heterachy of task-specialized areas simultaneously cooperating and supporting each other in fulfillment of the overall function or task, in other words, as a collection of task-specific brain areas in systemic relationship.

In parsing language, letter recognition is only the beginning. We read and recognize words based also on specific associations between letters. We can read and recognize a word like HELP or even think that something like HIRP might be a word. We, however, would never conceive of HZRQ possibly being a word. Why is that? Certain letter combinations appear in written language frequently while other combinations are nonexistent. Trying to pronounce HZRQ orally may provide a hint as to why certain letter combinations are preferred over others and are of higher frequency.

The neurological result of this probability distribution of associated words is that certain neural networks representing the higher frequency combinations are much more frequently activated. A neuron must reach a certain level of input or threshold before it fires. Two things that determine the level of the threshold are how frequently it has been activated or fired in the past and how recently it has been activated. If a given neuron is often activated, its firing threshold is lowered, and it is said to be "sensitized" to subsequent input. If the neuron was activated recently, it is also more responsive to subsequent input.

These cellular mechanisms manifest themselves at the behavioral level. For example, if we have seen a word recently, we recognize it more quickly. Also, more common or frequently used words are also recognized more quickly and easily. Every neuronally-controlled system in the human body manifests this effect. For example, the more we exercise a muscle group, the faster and more effectively we can utilize it. If we don't use it, there is muscular as well as neurological atrophy and the system is most difficult to activate. If we have frequently and recently performed a physical activity like shooting a basketball, it is easy to repeat the action. If we wait 20 years between basketball shots, we can barely perform the act and do so quite poorly.

A favorite instructional strategy is called the KWL procedure. In the K step, students are asked to recall what they know about a topic. This is intended to activate their prior knowledge. The neurological correlate for this activity would be increasing the recency, or priming, of the neurological circuits containing the representations of information relevant to the lesson. The second step of the procedure is asking students to form questions that define what they want to know about a topic. This is the W step of the process. This step sets the goal and context for the activity. The last step of the process calls for a summary of what has been learned as a result of the instructional activity. This is the L of the procedure. This step is intended to foster meaning creation. The above strategy is sound practice and congruent with what we have discussed before. It is, however, a skeleton. There is a complex neurological, psychological and epistemological foundation underneath this basic process that determines how and how well it will work. For example, if the object of the lesson is very specific, the teacher may want to start with the W step and set a specific context for the lesson. The K step would then concern activating prior knowledge about the elements that constitute the characterizations within this context and their attributes. The teacher could elect to guide this process with scaffolding activities (questions, information, etc.). As we have seen from prior discussions, the K step is both requisite for and seminal to achieving success in the L step. Conversely, if the goal of the lesson is the creation of a new perspective, the K step should go first and scaffolding activities would be engaged to expand the universe of possible attributes, characteristics and relationships inherent in the objects of consideration. The goal of the W step is then to evolve a new context in which to create the new relationships that will be fashioned during the L step. To summarize, recency and frequency effects will manifest themselves in educational settings and can be appropriately exploited with strategies such as the KWL procedure.

In the pattern recognition model we referenced previously, the detection of high-frequency letter pairs is performed at a higher logical level using input received from the letter detectors. The most recent and frequent combinations are the ones detected. This facilitates correct parsing of the word. In technical terms the second level or letter-combination detectors deal with the orthography of language. The orthography relates to the combinatorial structure of letters and corresponding phonemic (sound) structures. Spelling rules, segmentation or the breaking of words into constituent phonemes and permissible and non-permissible letter combinations are all part of the orthography of a language. These tasks or orthographic processing are not intuitive; they must be learned (Ely, 2005). For example, the letter i can have different sounds (phonemes) depending on what other letters it is associated with. Conversely, the same sound can be articulated by different letter combinations, such as the letters ew and ou in the words new and you. This is a happy circumstance for poets. How to segment such words into phonemes is sometimes learned informally, but many children require formal instruction (Bryne & Fielding-Barnsley, 1998).

The term given for this cognitive activity is orthographic processing. Much of the orthographic processing is carried out by a system proposed initially by Logan (1997) which analyzes words, operates on individual units of words like phonemes and graphemes, requires attentional resources and processes slowly. Shaywitz, et al. (2006) postulates that these activities involve the posterior parietal-temporal areas of the brain based on fMRI imaging and lesion studies. Specific areas identified include the angular gyrus and supramarginal gyrus of the inferior parietal lobe and the posterior aspect of the superior temporal gyrus. A roadmap of the cerebral cortex from Kolb and Whishaw (2003) is shown below for those interested in locating these areas.

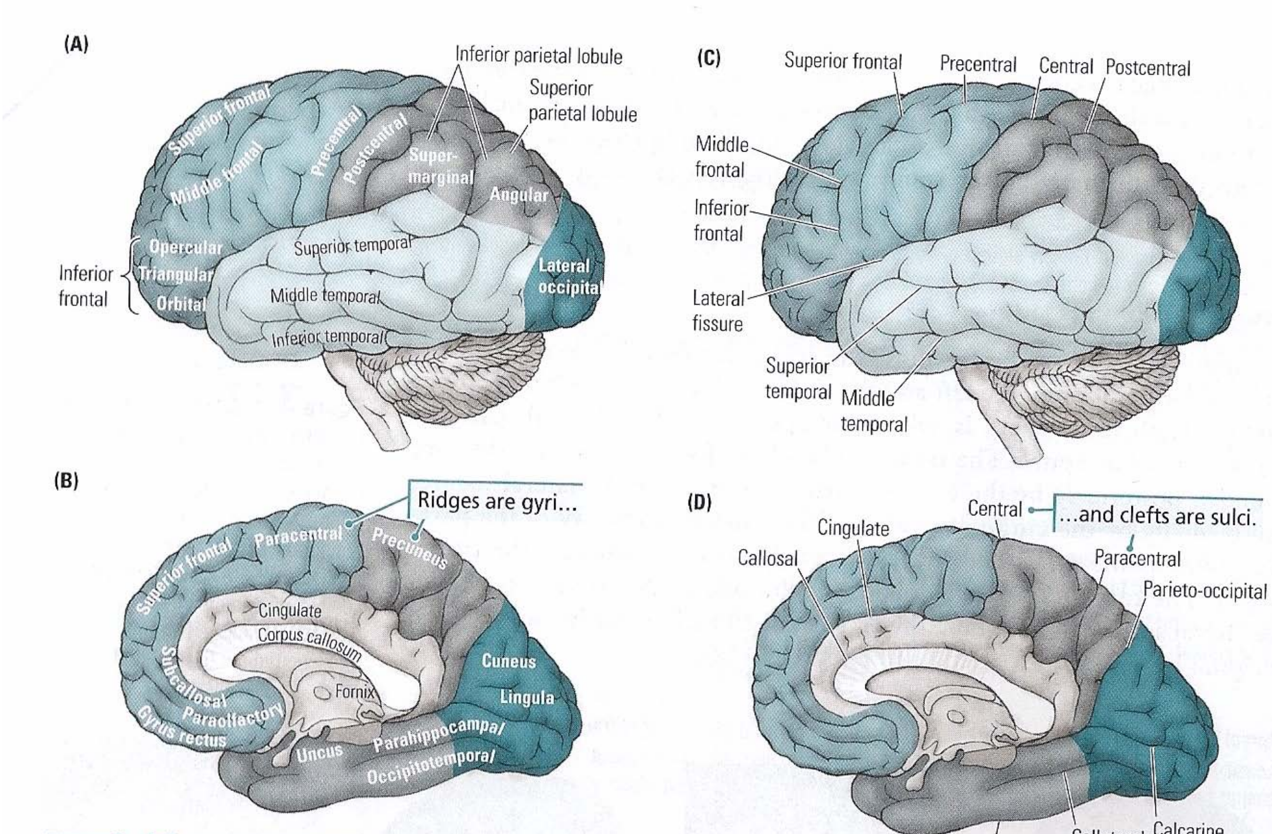


Figure 3.13 Gyri and sulci: lateral (A) and medial (B) views of the gyri; lateral (C) and medial (D) views of the sulci.

Some rules of thumb are: 1) superior, middle and inferior refer to the top, middle and bottom respectively, 2) anterior refers to front, posterior to rear, 3) gyrus is the positive area of the folds of the cerebral cortex and sulcus is the valley, and 4) the major divisions of the cerebral cortex are, from back to front, the occipital, temporal, parietal, frontal and pre-frontal lobes. By example, the posterior aspect of the superior temporal gyrus means the rear part of the top positive area of the temporal lobe.

Lesion studies indicate that the areas designated above are pivotal to mapping the visual perceptions of print onto the phonological structures of language (Damasio & Damasio, 1983). Thus, the analysis of words, or the transfer of the orthography into the underlying linguistic structures of language is postulated to occur here.

The posterior aspect of the superior temporal gyrus is an area that has been historically called Wernicke's area. Based on lesion studies conducted by Wernicke in the last quarter of the 19th century, this area has long been known to be a principal language processing area (Bear, Connors, & Paradiso, 2007). Patients with lesions in this area can speak, but have poor comprehension of words. One characteristic of their speech is correct use of sounds but sounds arranged in the wrong sequence, for example, saying plic instead of clip. Patients can also use categorically similar but incorrect words to describe something, for example, using knee when the correct word is elbow or describing a piece of paper as a piece of handkerchief (Bear, Connors, & Paradiso, 2007). Patients with Wernicke's aphasia cannot follow instructions, either verbal or written. They appear to read words, but act as though they do not understand their meaning. Due to its location adjacent to the primary auditory processing area, it is thought that Wernicke's area plays a role in relating incoming sounds to their meanings that it is an area for storing memories of the sounds that make up words. Wernicke's area may be an area for higher-order sound processing in the same way as the inferior temporal cortex is thought to be a higher-order area for visual recognition (Bear, Connors, & Paradiso, 2007). It is clear then that this area, along with the proximal parietal lobe areas discussed previously, perform functions vital for both phonological and orthographic processing of written words.

One of the important points to understand about orthographic processing or, in fact, all processing at the neuronal level, is that the "knowledge" of the system is not directly or locally represented. The "knowledge" is distributed throughout the system and connected or related as required or needed. We are dealing with a productive system that "creates meaning" through relationship.

A neuron fires or activates as a result of depolarization of the electrical potential that exists at its resting state. The activation or firing of the neuron is called an action potential. Depolarization is brought about by the influx of ions from the fluid surrounding a neuron. The admission of the ions which cause this depolarization or firing is controlled by ion channels which are normally (in the resting state) closed, but can be opened by the action of protein-based chemicals called neurotransmitters, which act at the connection between neurons. This connection is called the synapse, and is, in fact, a small gap between sending and receiving neurons. The firing or activation of the sending (input neuron) sets off electrochemical events within this neuron which stimulate the release of neurotransmitters into the synapse between the sending neuron and connected receiving neuron. The neurotransmitter lodges in a site on an ion channel of the receiving neurons and chemically reacts with the proteins of this channel in such a way as to open it. This action can be thought of as a key which opens the door for ions to enter the receiving neuron. Once opened, ions flood into the receiving neuron and depolarize or fire it. The figure below from Bear, Connors & Paradisio (2007) schematically illustrates this process.

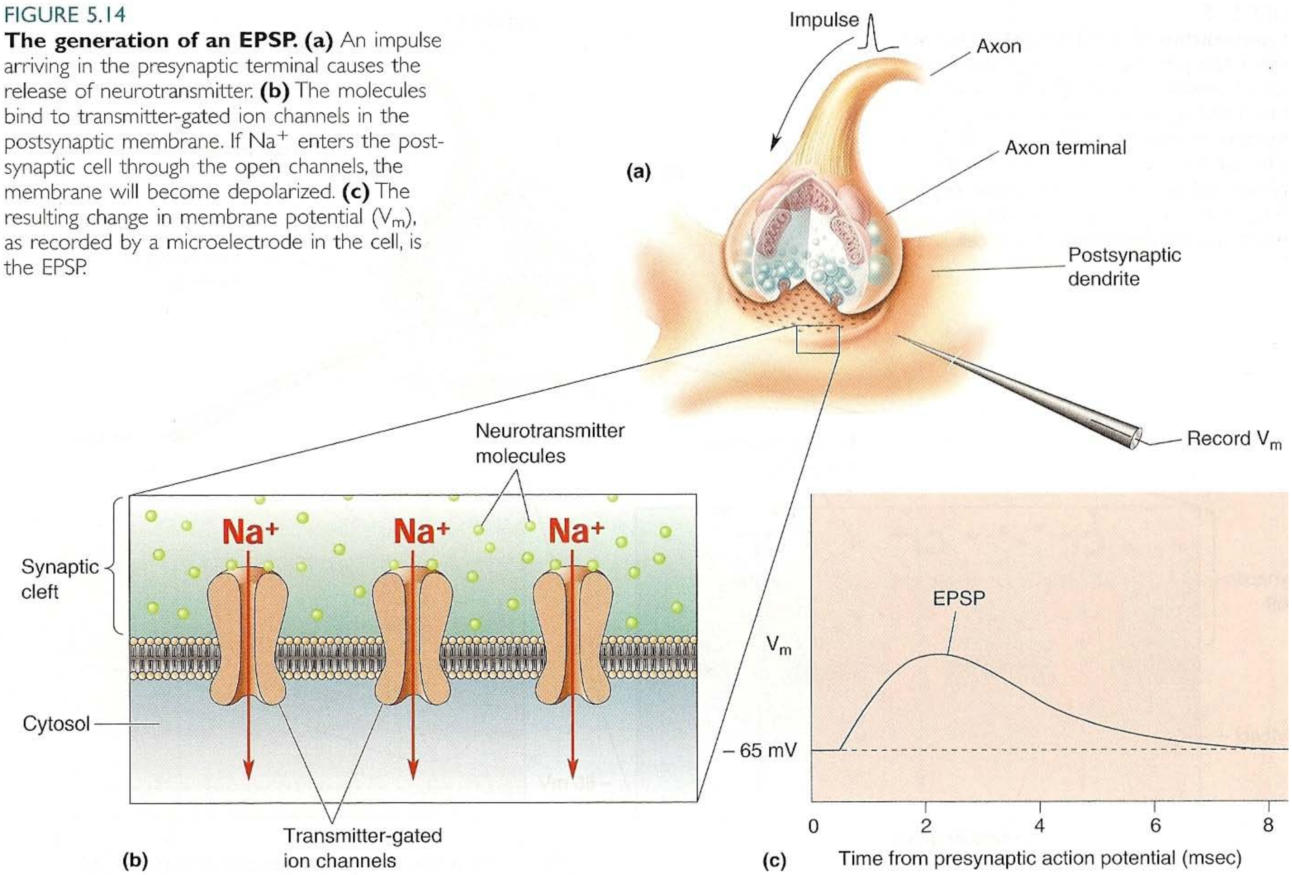


FIGURE 5.14
The generation of an EPSP. (a) An impulse arriving in the presynaptic terminal causes the release of neurotransmitter. **(b)** The molecules bind to transmitter-gated ion channels in the postsynaptic membrane. If Na^+ enters the postsynaptic cell through the open channels, the membrane will become depolarized. **(c)** The resulting change in membrane potential (V_m), as recorded by a microelectrode in the cell, is the EPSP.

There are over a hundred different types of neurotransmitters and numerous types of ion channels which are gated or opened by a number of different mechanisms. For our purposes, we will discuss only the most common type. A typical neuron in the cerebral cortex has a number of different types of ion channels at the input (dendrite) and output (axon) terminal sites of the cell. The two ion channels which predominate in many neurons are called AMPA receptors and NMDA receptors. Both are ion channels that are keyed or opened by the neurotransmitter glutamate, an amino acid. The NMDA receptor has two distinguishing characteristics. First, this receptor's channel is blocked in its resting state by a magnesium ion (Mg^{2+}) . For the NMDA channel to open it must receive a glutamate neurotransmitter and the receiving cell in which it is located must be sufficiently depolarized to dislodge the magnesium ion which blocks the channel. The second distinguishing feature of the NMDA receptor is that it is selective for calcium ions (Ca^{2+}) . In other words, the ions it allows to pass through are calcium ions. This contrasts with AMPA receptors which are open by glutamate immediately and allow sodium ions (Na^{+}) to pass through. Sodium ion influx is the principal mechanism by which a cell depolarizes and subsequently fires an action potential (is activated).

In newly created synapses, there are principally only NMDA receptors. These fledgling neurons and their connections are largely silent. As the number of connections to a neuron increase and as input levels increase, there is ultimately enough input to depolarize the receiving neuron to the level required to dislodge the magnesium ion, open the NMDA receptor and allow calcium to enter the receiving neuron. Calcium influx has the effect of causing additional AMPA receptors to be inserted into the synaptic membrane of the receiving neuron. This makes the neuron easier to trigger on the next go round. We can see then that the ease of activating and firing a neuron is contingent upon the number of connections it has and also contingent upon simultaneous firing of those connections. There is an input threshold that must be reached before a neuron will activate and fire an action potential. In this way, a neuron has a developmental history contingent upon experience. A stimulus experience excites certain neurons and neuronal groups or collections. With repeated simultaneous excitation, the ease of firing and the strength of firing of a neuron or neuronal collections are enhanced. This process is called Long Term Potentiation (LTP). If we view memory in the abstract, as a fixed change of state consequent to a prior event, the Long Term Potentiated neuronal group can be said to have a "memory" or "knowledge" of past events. There is more to the memory story and neuronal "learning," but the forgoing provides some level of insight for our current discussion.

Conversely, and interestingly, if NMDA receptors are not activated, the reverse effect occurs: AMPA receptors are lost from the synapse. This is an effect called Long Term Depression (LTD). It is hypothesized (but not yet conclusively known) that this also results in synapse elimination and a loss of connection between neurons. The above is schematically illustrated by the figure below from Bear, Connors & Paradisio (2007).

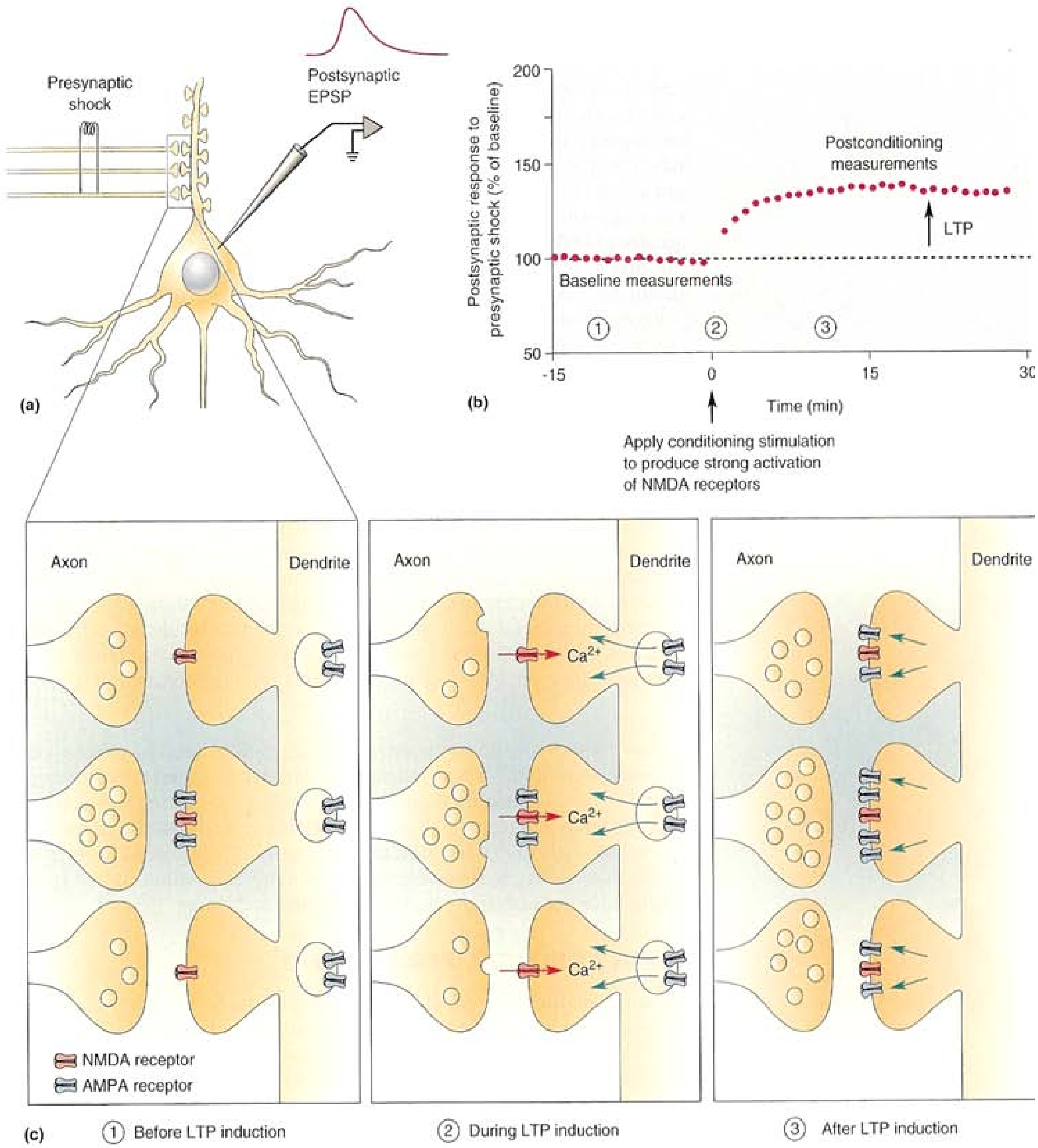


FIGURE 23.27

The lasting synaptic effects of strong NMDA receptor activation. (a) An experiment in which presynaptic axons are stimulated electrically to evoke an action potential and microelectrode recordings of the resulting EPSPs are made from the postsynaptic neuron. **(b)** This graph shows how the strength of synaptic transmission is changed by strong NMDA receptor activation. The conditioning stimulation consists of depolarizing the postsynaptic neuron via current injection through the microelectrode, at the same time that the synapses are repeatedly stimulated. LTP is the resulting enhancement of synaptic transmission. **(c)** LTP at many synapses is associated with the insertion of AMPA receptors into synapses that previously had none. The circled numbers correspond to the times before

The above is summarized by Bear et al. (2007, p. 716) with two rules for synaptic summation:

1) When the pre-synaptic axon [output] is active and, at the same time the postsynaptic neuron is strongly activated under the influence of other inputs, then the synapse formed by the pre-synaptic axon is strengthened. **Neurons that fire together wire together** [Hebb's hypothesis].
2) When the pre-synaptic axon is active and, at the same time, the postsynaptic axon is weakly activated by other inputs, then the synapse formed by the pre-synaptic axon is weakened. **Neurons that fire out of sync lose their link.**

Let's take a look at how the cooperative aspect of neuron firing could result in the forming of associations. Let's say that a neuron receives input from three sources: A, B, and C. Initially, no single input is strong enough to create an action potential in the receiving (postsynaptic) neuron. Let's also say that inputs A and B repeatedly fire at the same time. Because of the spatial summation of these inputs as well as the temporal, the receiving neuron reaches a threshold for activation and subsequently undergoes Long Term Potentiation. Note that only the synapses corresponding to inputs A and B will be potentiated. The degree of potentiation could be such that input from either A or from B could fire the receiving (postsynaptic) neuron. Note that long term potentiation creates a "logic" or connection. In this way, Long Term Potentiation has caused an association of inputs from A and B (Bear, Connors, & Paradiso, 2007). The figure below from Bear et al. (2007, p.780) is highly simplified but illustrates the above point.

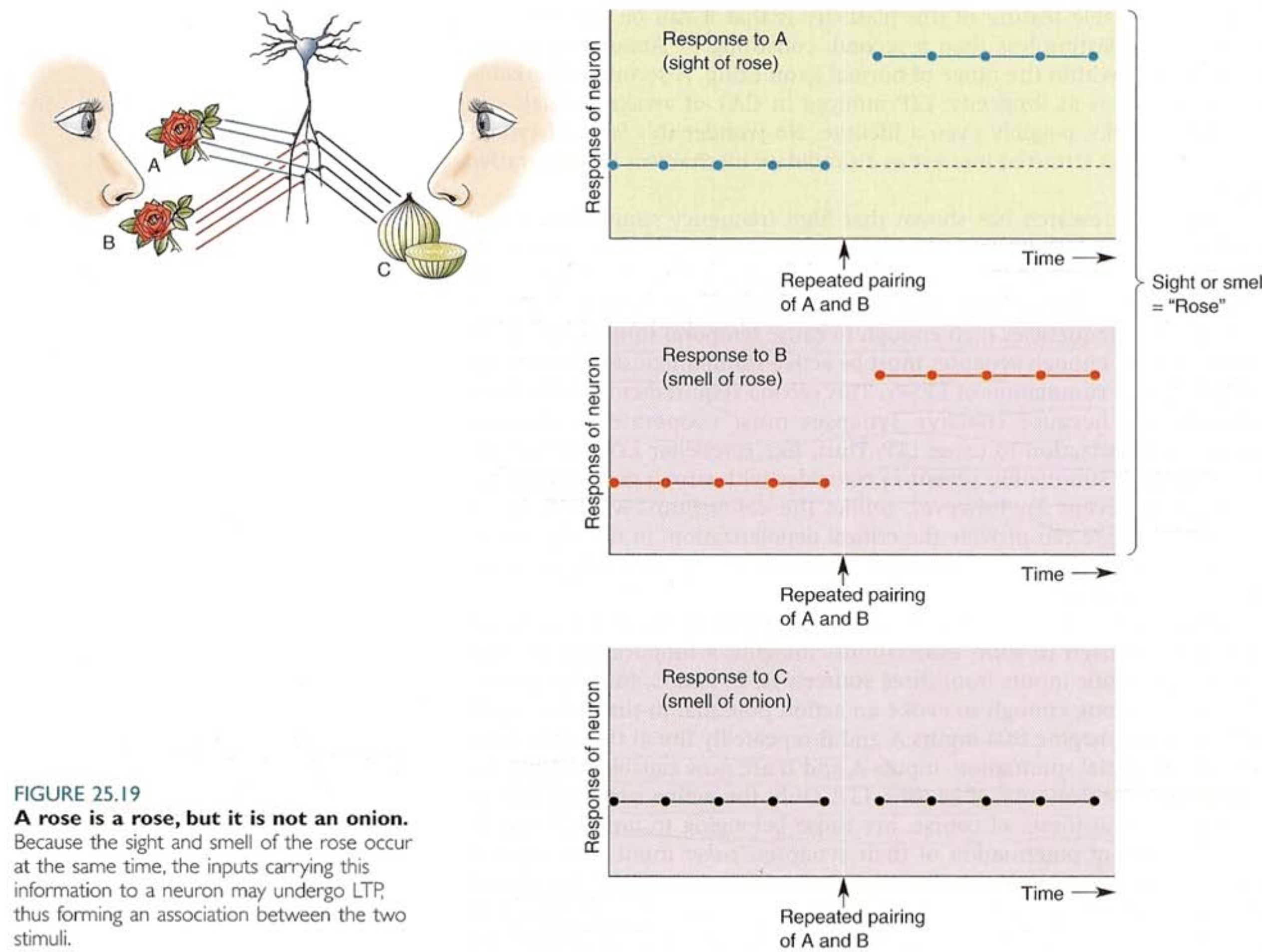


FIGURE 25.19
A rose is a rose, but it is not an onion. Because the sight and smell of the rose occur at the same time, the inputs carrying this information to a neuron may undergo LTP, thus forming an association between the two stimuli.

It is clear from empirical experience that not all memories last for equal lengths of time. An understanding of the strength and length of a memory requires a more detailed look at the biochemistry of the synapse area. When calcium ions enter a postsynaptic neuron they activate two protein kinases: protein kinase C and CaMKII (pronounced cam-K-two). Both kinases act to increase the effectiveness of existing AMPA receptors by adding a phosphate ion to them, a process called phosphorylation. CaMKII also activates a process whereby new AMPA receptors are delivered to the synapse. The newly inserted AMPA receptors are also phosphorylated by either of the two protein kinases. Phosphorylation, however, as a long-term memory mechanism is problematic for two reasons: 1) it is not permanent, and 2) protein molecules themselves are not permanent. Recent evidence, however, shows that CaMKII can stay on long after calcium ions have fallen back to low levels (Lisman & Fallon, 1999). Under normal operations, the presence of calcium ions is required to activate the phosphorylation action of CaMKII. However, if the initial activation of CaMKII by calcium ions is sufficiently strong, an autocatalytic reaction (reaction where a molecule stimulates or catalyzes its own production) occurs and CaMKII remains active and continues its phosphorylation action at a rate that exceeds the natural dephosphorylation of AMPA receptors. We saw how autocatalytic systems can stabilize concentrations in the nonlinear dynamics chapter. The idea that this mechanism could account for information storage at the synapse is called the molecular switch hypothesis (Lisman & Fallon, 1999).

The inhibition of protein assembly by messenger RNA is known from animal studies to inhibit learning and development of long-term memory. These studies reveal that when brain protein synthesis is inhibited at the time of training or shortly thereafter, animals learn normally but fail to remember when tested days later. Memories become resistant to the inhibition of protein synthesis as the time between training and the injection of the inhibitor is increased. These findings suggest that new protein synthesis is required during the period of memory consolidation, or change from short-term memory to long-term memory. The current hypothesis is that even with the aid of persistently active kinases, as described above, long-term memory creation requires the delivery of new proteins to the synapse to convert temporary changes to more permanent ones (Bear, Connors, & Paradiso, 2007).

The first step in protein synthesis is the generation of an mRNA transcript of a gene. This process is regulated by transcription factors in the nucleus. One identified transcription factor is called CREB. CREB binds to specific segments of DNA called cyclic AMP response elements (CREs). There are two forms of CREB: CREB-2 inhibits gene expression when it binds to the CRE;

CREB-1 activates transcription, but only when it is phosphorylated by protein kinase A. CREB-1-regulated gene expression has been found by experiment to be critical for memory consolidation in Drosophila, Aplysia and mice. The control of gene expression by CREB offers a molecular mechanism that can control the strength of a memory (Bear, Connors, & Paradiso, 2007).

Returning to our discussion of orthographic processing, we can see how cellular dynamics influence dynamics at the functional level. Through reading, or perhaps as a result of direct instruction, we encounter certain letter combinations or juxtapositions of letters quite frequently and other combinations virtually never. For example the letter combination CO is a frequent occurrence, while the combination CF is not. It is therefore the case that neurons firing when the letter C is recognized will often be contemporaneously firing when those recognizing O are firing. As we saw previously, this greatly facilitates the likelihood that these neural sets will make a connection and that long-term potentiation of this connection will result. The more frequently we experience this combination, then, the more primed (in the words of Reisberg (2006)) we are to recognize the combination or the more likely it is that the combination will become long-term potentiated (in the language of neuroscience). It is through this process that we learn the rules of spelling and the orthography of a language. A way to look at this is that the **neuronal system records frequency of occurrence**. The most frequently co-occurring stimuli become the most easily recognized and decoded in subsequent encounters. This is how the neural network "knows" that CO is a common combination in English words and why it appears to "anticipate" or expect the combination, and why, given ambiguous or partial input it will "infer" CO rather than CF or CQ. Knowledge, expectations, and inferences emerge as a consequence of activation levels. In a neurological context, they emerge from experience as a consequence of the long term potentiation of specific neural synaptic connections.

The neurological system is a productive system. It works on the basis of the **relationships** (such as space-time proximity) between levels of activation of different neuronal collections. To understand emergent phenomena of the system, we need to see how these activations are distributed within the system and related or connected. These distributions and connections will cause one functionality or outcome to be more influential or likely than others. In that the system is productive, it has the flexibility to create multiple combinations and produce flexible outcomes. This is particularly the case if intentionality invokes attentional resources.

Note that long-term potentiation and long-term depression create the emergent consequence of what appear, at the psychological or behavioral level, to be rules. For example, after seeing words millions of times through years of reading, letter combinations and their corresponding frequencies of occurrence will result in long term potentiation and depression such that we will "learn" the **rules** of spelling. Note also, that what occurs has the characteristic of **induction**. If neuronal systems that respond to white and the shape and other characteristics of swans continue to fire contemporaneously in space and time, these feature recognition systems will connect and long-term potentiate in such a fashion that the rule "all swans are white" will emerge. It will not require college training in the rules of enumerative induction to arrive at this conclusion. Note that considerable learning can be tacit or subconscious.

Conditioning and association are also handily explained. They are emergent from spatiotemporal coincidence and consequent neuronal connection and long term potentiation/depression in response to stimuli or stimuli/consequence pairs, in the case of operant conditioning. The fact that they are "learned" in the behavioralist sense of the term is a manifestation of the fact that potentiation/depression occur over successive and multiple instances. They are usually not one-shot, one-event occurrences.

Reisberg (2006) states that what we see in the spelling system is that with simple elements correctly connected to each other, the system appears to know the rules of English spelling and make inferences, but the actual system has neither knowledge nor an apparatus for making inferences. Inferences occur and knowledge is manifest, but it is through the pieces (he terms them detectors) working together. To state this in the language we have been using in this Dissertation, we can say that knowledge and inference is an emergent property of the systemic relationship of the elements of the system. Reisberg (2006) states:

> You and I see how inferences unfold, taking a bird's eye view. Instead the activity of each detector is locally determined and influenced by just those detectors feeding into it. When all of these detectors work together, though, the result is a process that acts as if it knows the rules. But the rules themselves play no role in guiding the network's moment-by-moment activities (p. 84).

Let us summarize the foregoing and recast it in terms of our emergent model of knowledge and meaning creation. The sensory system appears to be sensitive to certain **features** of the external environment. The visual system, for example, records features characteristic of shape, position, motion, color and so forth. These features or feature maps are recombined in sensory processing and association areas of the brain. The association areas enlisted are contingent upon the goal and the requirements of the cognitive task, as well as the logical level of the specific task being performed. Sensory feature maps or representations are bound or combined based on spatial position, temporal coincidence (neurons firing at the same time) and frequency (neurons firing at the same rate). We should note that, in map like fashion, proximal neurons record proximal areas in the visual field. Also, temporal binding is facilitated if it is attentionally driven. In other words, the neural correlates or representations of the items or attributes focused on fire at the same time and at the same rates. This rate is the gamma band oscillation discussed previously.

Depending upon the specific neurologic processing operation being undertaken, contemporaneously and proximally firing neurons responding to a stimulus will long-term potentiate. Those without input will long-term depress or even disconnect. This potentiation has the effect of making subsequent activation quicker, easier and stronger. This process can be viewed as creating memory from experience. The **relationship of co- activated neural collections which connect in this fashion can also be visualized as the creation of rules from experience, those rules being a reflection of the consistent relationship expressed by stable combinations of the co-stimulated neural groups**. Potentiation is **statistical** in the sense that repeated frequency of the experiential stimulus affects the level of potentiation. Rule creation is enumeratively **inductive** and reflective of the consistent connection and activation of specific neural groups. Subsequent experience and attenionally focused conscious processes can change, re-potentiate and reconfigure networks.

In addition, this model can operate in a tacit fashion. A good deal of what we term "common sense" is, perhaps, the largely-subconscious imprinting of experience, in the fashion described above. The temptation to ascribe "common sense" to some a-priori logic undoubtedly stems from the fact that a lot of this "worldly" knowledge is tacitly or subconsciously obtained.

The important implication for this Dissertation is that the above description is consistent with an emerging picture of meaning creation derived from other domains at a higher logical level: meaning creation is the equilibration of stable relationships among the abstracted attributes of the objects of our consideration.

Biological systems are nonlinear with compensatory feedback loops and mechanisms that facilitate homeostasis or equilibrium. Any theory of neurological information processing must therefore consider and incorporate these effects. One lesson from the analysis of biological systems is that they never reinvent themselves from scratch, or in a way inconsistent with or independent of their ontogenetic or phylogenetic history. They evolve an adaptation to a changing environment which is usually a self-organized recombination of existing elements. This self organization can result in a qualitatively different structure at a higher logical level. As there is no determinate mechanism that guarantees the efficacy of such an adaptation, some revised configurations survive the changed environment while others do not.

One way to characterize compensatory feedback action is to note that systems exhibit both bottom-up and top-down influences. As summarized by Kolb and Whishaw (2003), "a characteristic of cortical connectivity is reentry: each cortical area is reciprocally connected with many, but not all, other regions in a given sensory modality. Cortical activity is influenced by feedback loops, not only from other cortical regions, but also from subcortical forebrain regions such as the amygdala and hippocampus" (p. 248). It is therefore imperative that we understand neural activity within a context of nonlinear dynamics and systems theory.

As illustrated by previous discussions, compensatory mechanisms can be either positive and reinforcing or negative and corrective. Some neurotransmitters, for example, shut down or inhibit neuronal activity. We discussed the inhibition mechanism in visual processing and how it is utilized to enhance our perception of edges. In general, inhibition serves to clarify and differentiate in order to achieve stabilization within a system. For example, the occipital - temporal shape-identifying system of the cerebral cortex could use feedback compensation and inhibition to assist in clarifying that an object was a "this and not a that". Again, the goal of feedback compensation is a stable equilibration of sensory data.

These mechanisms manifest themselves in an apparent top-down logic of perception. (Reisberg, 2006):

1) perception seeks a hypothesis that fits [equilibrates] all of the data
2) perception prefers the simplest explanation
3) perception renders the most probable explanation (Reisberg (2006) expresses this as avoidance of coincidence).

The compensatory feedback mechanism can be thought of as a top-down reinforcement of a specific structural morphology: the morphology that results in the most stable configuration of system elements. We can think of this in terms of system dynamics as a combination of the parts creating the whole, but the whole reacting upon the parts so as to create stability for the aggregation. Back-and-forth action, or combined top-down and bottom-up processes ultimately stabilize the system into a cooperative relationship expressing an equilibration of individual component attributes and the systemic requirements imposed by the connective relationship. It is, however, not necessarily the case that this occurs. Systems unable to achieve stability dissipate. We see examples of both cases at the behavioral level in Piaget's (1985) theory of the equilibration of cognitive structures.

Top-down excitatory or inhibitory compensation also explains the susceptibility of perception to previously formed schemas. Most of us have experienced the exercise of looking at a visually ambiguous picture after being given a suggestion as to what the picture represents. One of the classics is an ambiguous picture which could be interpreted as either a circus scene or a formal ball. In experiments, it is virtually 100% the case that people given the circus prime will see things like a seal with a beach ball on its nose, while those given the formal ball prime will see a woman in a gown and so forth. What is occurring is top-down activation of neural networks representations within the context primed and inhibition of alternative contexts. This is a natural consequence of a system configured and created as described previously. It also points out the enormous impact of context on pedagogy. The imposition of a specific context in an instructional setting will greatly influence and determine the type and extent of cognitive processing and the resulting behavioral manifestations of students. As we have discussed previously, contexts imposed prior to sense making or meaning construction activity control the metrics or attributes (elements) deemed relevant to the construction of meaning, the nature of relationships deemed permissible or stable and the depth and breadth of created meanings. If you tell students that they are looking at a circus they will see clowns and a seal with a beach ball on its nose. These are the elements found within the context of the circus. The relationship between the beach ball and the seal is, in addition, a stable relationship consistent with their prior experience within circus contexts. Children can also predict and infer what additionally could manifest itself within this context. It is likely, for example, that one clown will hit another, causing that clown to fall in a humorous fashion. An important decision in designing classroom activities, therefore, is not only selection of a context but when, or even if, a context is to be imposed. If it is desired that students expand their contextual frameworks, it is better to evolve the context from relationships among an expanded set of features. The beginning classroom activity under this scenario would be to assist students in expanding the way something could be characterized, beyond their initial inclinations, and having them explore a greater multiplicity of possible relationships between these expanded sets of features, relationships that would impart meaning (e.g. explanation) to the subject being studied. This is the meaning of "looking outside the box." The context is the box. Epistemologically, this is equivalent to the dialectic between the scientific paradigm and the paradigm of qualitative research. In scientific investigations, the context is imposed initially, while in qualitative research the context evolves or is consequent from the investigation.

Learning to spell, or orthographic processing, is an exemplification of both top-down and bottom-up processes. From the foregoing discussion, it appears that letters are first recognized individually. Letter combinations are then subsequently detected and ultimately a stable configuration of these letters, which represents a word, is interpreted. Through the feedback compensation process, prior to stabilization and detection of a specific word, neural circuits at the level of letters are interacting with circuits or connections at the level of letter combinations, which in turn are interacting with circuits or connections at the level of whole words. There is back-and-forth interaction or top-down and bottom-up interaction representing compensatory stimulation and inhibition during this process. For example, as previously discussed, certain more common or frequently occurring letter combinations will be more strongly activated due to long-term potentiation of the connections between representations of these letters. Similarly, circuits or connections associated with more frequently and commonly occurring complete words and their letter combinations will be more strongly potentiated. This back-and-forth activity among logical levels and between logical levels continues until stability is reached with the initially sensed visual stimulus. This process can be thought of systemically as the whole reacting upon the parts, which in turn react upon the whole cyclically or recursively until a stable word morphology or recognition emerges. The emergence of a word or word recognition is a consequent phenomenology of this systemic interaction. The process, in this manner, is both top-down and bottom-up. I would hypothesize that this process occurs at each logical level moving up a hierarchy of increasing complexity and ultimately expressing itself in phenomenology at the psychological and behavioral level.

Another pointless dialectic in education is whether it is better to approach instruction from a top-down or bottom-up basis. This debate is epistemologically equivalent to the previously discussed debate between whole language and phonics. These debates center on questions such as:

1) Is it better to have students decode complete words or break them down into phonetic elements?
2) Is it better to present abstract theory and then flesh out the details with examples, or
3) is it better to start with concrete examples and derive abstract relationships that are consistent summarizations of the relationships inherent in the examples?

Let me ask an epistemologically equivalent question: Is it better to exhale or to inhale? Given the nature of neurological processing, and the relational dynamics of the brain, both processes occur. The parts relate to create the whole, and the whole reacts upon the parts in an effort to create equilibrium and stability within this relationship of parts. If a student is presented with theory, his mind will immediately seek out parts that can be related in a fashion so as to corroborate the presented theory. All of us have had the academic experience of being presented with a theory in a classroom, the logic and necessity of which we initially did not comprehend. We find ourselves immediately wanting to see concrete examples which express, exemplify or justify the theory. The mind immediately asks: Does this theory mesh with my prior understanding or experience of the world? Is it a summary or "**rule**" that "makes sense" or is congruent with, or valid within, the context of my prior experience and knowledge? The relationship articulated in the theory is invariably clearer to us as a relationship between the more familiar parts and elements of the concrete examples. What we end up doing either tacitly or consciously, is abstracting consistent features from the examples and relating them in order to justify or verify for ourselves the presented theory.

Conversely, when presented with the myriad of detailed concrete examples, our natural tendency is to want to affect a summarization rather than to try and memorize the myriad details as unrelated items. This summarization process is precisely the one described above:

determination of similar defining features, and the placement of these features in a stable relationship that in effect summarizes the exemplars and their myriad details. We can therefore say that, if you ask a student to inhale, he will naturally exhale, and if you ask him to exhale, he will subsequently inhale. The answer to the top-down versus bottom-up question is then: Yes, both. They are inseparable processes that mutually reinforce each other. The implication for the design of instructional activities is that they are enhanced when both top-down and bottom-up processes are applied recursively until a stability of understanding is achieved.

Some modern educational researchers (McConnell, 2007) view learning as an error correction process. What they mean by this is that all initial learning demonstrates an incomplete and somewhat unstable characteristic or structure. For example, when theory is initially presented and learned, it is rare that the student can correctly apply it. McConnell's (2007) idea is that learning actually occurs by the process of attempting to apply one's initial theoretical understanding to concrete problems, making the inevitable mistakes, affecting a correction or compensation, trying again and repeating the cycle or recursion until a correct answer is obtained. To paraphrase this more abstractly, it involves applying the theory to lower logical-level circumstances from whence the theory was derived and undertaking an iteration until stability is achieved between relationships expressed in the theory and those that exist in the concrete exemplar.

If we teach Newton's Law or Einstein's special theory of relativity, in the abstract, it is rare indeed to find a student who could immediately, correctly apply these abstract principles to solve real problems in the physical world. The way we conduct much of our instruction presumes that such is the case, that application is naturally facilitated and enabled by theory. The difficulty with this presumption is that student’s understanding of theory is initially both incomplete and unstable. Practical application has the benefit of creating experience that is invaluable in stabilizing and completing the student's theoretical understanding. McConnell's (2007) thesis is that this occurs by making the inevitable mistakes in applying the theory, effecting corrections and trying again. This process is repeated until the concrete and the theoretical coincide. Said abstractly, the process is repeated until the relationship of the parts (concrete examples) is stable with respect to the whole (summarizing theory). In addition to employing both top-down and bottom-up instructional strategies in developing theoretical understandings, we can also add and stress the importance of students having ample opportunity to stabilize and strengthen their understanding through the iterative and self corrective process of applying theory to concrete, practical and real problem-solving applications and activities.

We can examine why teaching theory doesn't immediately result in correct application. First, the student didn't derive the theory from his personal experience; either the teacher derived it or simply presented it as Isaac Newton's, Einstein's or somebody else's theory. The theory therefore is not a stable relationship of elements abstracted from the student's past knowledge or experience. Worse yet, the new theory is often counterintuitive with respect to the student's past knowledge and experience. To make it his theory would require a bottom-up process of abstracting items from past experience and creating relationships in the manner previously described. The reader should note that a teacher deriving the theory on a blackboard is not what we are referring to here. Recall that theory has to ultimately belong to the student or "be of the student, by the student and for the student" before it can be considered stable and capable of correct application. Said another way, students must know and understand the elements and "see" the logic of the relationships among them. In the case of professional students, like doctoral students, blackboard and lecture explications of theory are fairly effective. This results from the fact that doctoral students can be expected to have a considerable breadth of knowledge concerning elements and relationships. As we move down the pyramid of educational experience, we can expect this to be less and less the case.

The second problem is that theories are summarizations of selected properties and characteristics abstracted from objects that are more complex and possess a myriad of other properties and characteristics. When confronted with an application, the first issue that a student confronts is creating a connection between the theory and a real multidimensional object. He must find the abstracted elements and relationship of the theory within these real objects. For example in physics, beginning students first learn Newton's laws in one-dimensional form and, unbeknownst to them, under the presumption that properties like mass can be considered to be concentrated at a point. After being presented with theory in this fashion, a traditional problem that students are asked to solve concerns finding the value of some unknown variable of a block initially at rest on an inclined plane. The question is typically: Given a specific mass and coefficient of friction, how steep an angle can we have before the block starts to move?

The student becomes immediately perplexed. An inclined plane has two dimensions and the block has three. The theory they know concerns motion in one dimension. The first "trick" the student needs to know is that the mass of the three-dimensional block can be concentrated at a point, the center of gravity. The next "trick" the student needs, is the knowledge that when gravity is the only driving force involved and the blocks composition is homogeneous, the inclined plane will confine the motion of the block to one dimension, that dimension being down the angle of the inclined plane. If the student aligns the reference frame or x-axis with this angle, then the problem reduces to one of one-dimensional motion of a point mass. In other words, if the student applies these "tricks," he has enough theoretical knowledge to solve the problem. Said another way, the elements and relationships of his learned theory match the elements and relationships of the actual circumstance. Let me try to state this emphatically: The key to successful application of theory is the creation of these precise relationships. This is often not a trivial task, nor is it automatic or obvious in many cases. Instructional activities should therefore include formal instruction on how to create or recognize these relationships. Let me state this once again with feeling: **Successful application of theory requires that the abstract elements and relationships of the theory be directly connected to the concrete elements and relationships existing in the real object to which we are applying the theory.**

Let us consider an even more difficult problem from the study of Literature. Let's suppose that a 10th grade teacher is covering a novel like: A Scarlet Letter, Mc Beth, or Billy Budd. The teacher pronounces to the students that the book has meaning at more than one level and that factual story items are symbolic and convey a deeper meaning. The teacher then asks the students to try to find this deeper meaning. What the teacher has done is to request that the students make an unguided attempt at interpreting multiple ententes. I would say: "good luck with that!"

The aforementioned works are sophisticated novels produced by literary geniuses for a sophisticated audience. For example, to thoroughly understand Lady Macbeth, it would be helpful to have a hermeneutic understanding of the cultural context of male/female, husband/wife relationships in the time of Shakespeare and before. Having been in a marital relationship oneself would also be of assistance. A key to understanding Lady Macbeth is to understand that at this point in history, women were generally not granted formal power or the ability to actualize their will through direct action. Clever and ambitious women, like Lady Macbeth, became quite adroit at recognizing the strengths and weaknesses, as well as the desires and ambitions of their male partners and exploiting this knowledge to manipulate their partners in a way to actualize their own ambitions and will. These are relational dynamics that are unlikely to be directly a part of the episodic life experience of a modern 10th-grader.

Is there value then in covering a work like Macbeth? Yes there is, but let us look at an approach more in concert with our emerging theory of understanding. First, there is universality in the psychology of Lady Macbeth. Students will undoubtedly have had the episodic life experience of someone with limited power and authority using manipulative strategies to further their goals and ambitions. Going to mom, extolling her virtues and engendering references to tender moments in the past, while making a request that dad is likely to oppose or has already opposed, is one example. A friend who informs students of negative comments made by another friend about them in an effort to win their exclusive loyalty, would be another. The key dynamic is to relate relationships from prior experiences with the relationship present in the situation at hand (Lady Macbeth), so that a generality or universal is emergent from a comparison of the relationships within the exemplars. The abstracted entity in this case is the form of relationship. A considerable number of the arguments posed by Socrates in Plato's dialogues consist of abstracting relationships from a string of exemplars with which the parties in the dialogue are familiar. We will discuss the pedagogical power of instruction with analogy in more detail later. An interesting attribute of an abstracted relationship is that it often survives movement to several logical levels. For example, the use of manipulation as a source of power is easily transferred from an interpersonal level to a societal level. After World War I, the emasculation of Germany by the League of Nations was an important factor in creating the environment that led to World War II. It created an environment where in a cleverly manipulative despot (Hitler) could prey on the pride, nationalistic sentiments and angry frustrations of a population in order to further his personal ambitions. In general, emasculation of a person or population creates instability. Subsequent perturbations usually result in either a withering away or death, or an explosive rebellion or war. There is an inevitable cost to creating compliance by rendering the subject(s) impotent.

One of the great benefits of studying classical literature and history is the generalization of relationships and the learning of lessons that can provide guidance for future actions and strategy. In this way, hopefully, students can avoid some of the adversity and pain of the past. It is obvious to me that many of these lessons were lost on those responsible for formulating U.S. foreign policy in the last decade.

The theme above also relates to the issue of **relevance** in learning. Why make literature and history relevant to students? First, it greatly facilitates their ability to understand and make sense of the material when understanding the universality (invariance) of commensurate or analogous relationships from their episodic experience is part of the process. Next, it facilitates subsequent application of the universal or general principle. At first blush, it would be hard for students to answer how their manipulative friends, Lady Macbeth, and Hitler are related. Once the universality of the dynamic is understood, it could also be applied to the emergence of Islamic fundamentalism in the 20th century: something quite germane and relevant to their lives.

Another important understanding derivable from a study of classical literature and history is the impact of underlying context and environment on system dynamics. The underlying psychological process structure of characters in classic literature is often quite similar. These psychological processes will, however, play out differently in different circumstances or contexts. The hermeneutics of pre-colonial New England have a lot to do with how the storyline progresses in A Scarlet Letter, as does the socio-cultural context of medieval Scotland in Macbeth. If students can compare the dynamics of analogous psychological processes in different contexts, they can learn a lot about the impact of context and environment on the outcomes of systems.

At the dedication ceremony for TCU's new Education Complex, the dean of the Brite Divinity School gave me a copy of TCU's first student handbook. During the first semester of study, every student took a course on hermeneutics. It was apparently deemed important that students knew something about the socio-cultural context in which the books they were about to study were written. In modern philosophy, hermeneutics refers to theories concerning the methods of interpretation and understanding of texts and systems of meaning. While a worthy endeavor, perhaps a more narrow definition of hermeneutics, as creating an understanding from someone else's point of view and the appreciation of the cultural and social forces that influenced their outlook is a more pragmatic goal for K-12 education. And, I mean to imply that it should be the goal for K-12 education.

In general, interpretation and meaning creation in literature involves abstracting concrete elements of the story into symbols and abstracting concrete relationships in the story into a relationship among the abstracted symbols. It is a twofold abstracting process, whereby meaning is created within each logical level and between logical levels. This is not an intellectually trivial task. To do it competently requires considerable teacher assistance. I will now proceed to harp on one of the themes of this Dissertation. It is entirely too often the case that educators unknowingly presume that complex cognitive processes will somehow be appropriately undertaken by the student without guidance and direction. This happens when we ask a student to apply a purely theoretical lesson to the solution of a practical problem, as was discussed previously, when we tell a student to summarize complex material, to derive, on his own, symbolic meaning in a piece of literature, or, by some unknown osmotic process, extract a universal from a historical event. What I am advocating here, is formal instruction in the process of abstraction and meaning creation. As discussed before, this is a natural cognitive activity that the mind undertakes. As such, it is a powerful potential application of scaffolding interaction. It is too often the case that students ask themselves introspectively: "what do I do next?" Teaching students process skills is not intellectually limiting. Expanding the intellectual depth and breadth of an academic activity is more closely related to how we handle the issues of context and goal. These are the variables that exert greater control on the depth and breadth of an academic endeavor.

The complexity involved in interpreting multiple ententes is nicely illustrated by considering Herman Melville's novel, Billy Budd. In this novel we can discern several symbol systems or ententes. Virtually every Melville novel examines the dialectic between the individual and society. Billy Budd is no exception. In this novel, each ship is symbolic of a different form of society. Billy is a seaman on a ship called the Rights-of-Man, who is involuntarily impressed into service on a British warship called the Bellipotent (which means power of war). It is the nature of every created society that individuals abrogate a portion of their individual freedom and autonomy in exchange for the benefits of what can be accomplished through societal cooperation. Societies become increasingly powerful. As the power of society increases, there is a commensurate decrease in the rights of the individual. Taken to the extreme, this ultimately results in the alienation of the individual. This alienating process is a common theme in 20th century existentialist literature. Societies, for example, can compel men and women to participate in war. The symbolism of Billy's impressment hence becomes clear. Melville also examines the tenants of Christianity and Christian society symbolically. He does this by creating parallels between Billy’s story and the imagery, language and stories of the Bible. Recall that in Genesis, Adam and Eve’s expulsion resulted from their having eaten an apple from the tree of the knowledge of good and evil. All characters on Billy's new ship have taken a healthy bite of this apple. The seamen aboard the Bellipotent are unable to trust one another. Consequently life aboard the ship is governed by a set of rules. Everybody trusts the rules and not the honor or conscience of individuals on board the ship to maintain order. Melville also alludes to another consequence of this type of society. Men fail to take direct action against evil because they fear the consequences of confronting evil directly and therefore leave other good men to fend for themselves, once again abrogating personal responsibility and relying on the societal rule of law for the maintenance of order and the containment of evil. Melville's implication here seems to be that people play roles in order to fit into society, rather than act on their own impulses, personal moral convictions or judgments.

Billy Budd is extremely attractive physically and has a generous affable nature. He is well liked and admired by his fellow crewmen. His most striking characteristic, however, is his complete innocence. Billy has not eaten an apple from the tree of the knowledge of good and evil and lacks awareness of the potential for evil that lies within the heart of mankind. Along with a naïve trust in his fellow seamen, Billy has a speech impediment which prevents him from communicating when he is under stress. Billy's principal antagonist is a ship's officer named Claggart. Claggart is the personification of evil. His motives are more sophisticated and subtle than Billy can comprehend. He makes frequent use of deception to further his intentions. Claggart's jealousy and anger toward the affection, respect and admiration that Billy receives from his fellow seamen induces him to concoct a plot (mutiny) intended to lead to Billy's demise. When confronted by his accuser, Billy's speech impediment renders him unable to respond. In frustration, Billy strikes Claggart with a blow of sufficient force to kill him. Melville then invokes a bit of symbolism when he describes Claggart's dead body as that of a snake on the ground. The symbolic interpretation here is that Claggart represents the snake in Genesis and that Billy through his act, like Adam or Eve, is induced to cross the line (snake 1, mankind 0).

The symbolism in the entire scene, however, is not that simple. Melville is operating at a minimum of four levels of entente. For example, throughout the book there are allusions to revolutions, such as the French Revolution, and references to historical instances of mutiny. These allusions and references are likely intended to call to the reader's attention, circumstances wherein the social contract or rule of law failed to render justice, and individuals acted according to their conscience and undertook what they felt to be just action. The way Melville builds the story, the reader cannot help but feel that Billy's actions represent a form of natural justice. The problem, of course, is that Billy has violated the law.

Through various symbolic devices, Melville examines, at a minimum, the tenants of Christian theology, the psychological nature of mankind, the dialectic between the requirements of society and the rights of the individual, the nature of truth and the relationship between these thematic elements. On the psychological level, Melville is contending that innocence invites its own destruction in a world in which evil exists. The innocent is completely disarmed and impotent in such a world. The ability to exercise power to defend oneself is contingent upon knowledge of both good and evil, and the ramifications of this dialectic.

Scholars of Melville have argued for years whether this work praises Christian doctrine or condemns it (Goodheart, 2006; Yannela, 2002). One of the interpretational difficulties is that the symbolic mapping is not one-to-one. Melville makes allusions to both Genesis and the Passion of Christ. The correspondence between Billy Budd and Christ is not complete: Christ is flawless and all-knowing, while Billy is flawed and naïve. The imagery that Melville creates when he describes Billy hanging from the mast of the ship is explicitly reminiscent of the Crucifixion. Both Billy and Christ sacrifice their lives as innocent victims of society. Billy, however, is more symbolic of Adam in Genesis, in many parts of the novel. The relationships in the two biblical chapters also do not map directly to the storyline of Billy Budd. In addition to drawing upon figures and images from the Bible, Melville invokes pagan history (Plato's conception of evil), political history (the French Revolution) and naval history (the story of Lord Nelson) (Goodheart, 2006). As Goodheart states, "Billy Budd is variously seen as Adam before the fall, as a noble barbarian, as Isaac the sacrificial victim, as an unconscious embodiment of the revolutionary spirit, and as a Christ figure". The story does not follow the structure of an allegory, it has the form of a Greek tragedy (Yannela, 2002), including a tragic flaw (speech impediment) within the protagonist that leads to his demise. The use of this structure is in and of itself a symbolic statement.

Some of the symbolism is direct and explicit, such as the character Captain Vere. The name itself suggests that he is likely to oscillate between his inner feelings and his social obligations. Captain Vere, like Pontius Pilate, is obligated as the captain of a British warship to carry out Billy's execution in spite of the fact that he likes Billy, suspects that Claggart's charge was a fabrication and personally feels that the execution is morally wrong. It is still his responsibility to society or more directly to the British Navy, to carry out the execution, thus ignoring his conscience and abrogating his individuality. Melville is clear in implying that in a society where policy and laws are crafted with the presumption that they are necessary to maintain order and contain the evil motives of mankind, these laws will impinge upon the individual rights of mankind, and outcomes will occur that we intuitively regard as unjust. He is also clear in his insinuation that in such a society evil ultimately triumphs over good. This is due to the failure of individuals to exercise their power and discretion to combat evil or as a consequence of the societal curtailment of individuality. A pro-Christian interpretation of this novel is that such a circumstance necessitates the existence of a God representing ultimate good, in order to satisfy our intuitive requirement for justice in the universe. Melville, however, introduces more obtuse symbolism at the end of the novel, when he illustrates how events can be transformed into legends. This could be interpreted as skeptical of Christian theology.

As tempting as it is to explore this further and offer a reconciliation of the interpretation of this novel, I will stop here, as that would require many more pages of text. My principal point with the above discussion was to point out first, the level of complexity involved in interpreting multiple ententes, second, the requirement for considerable pedagogical assistance, and last but not least, the remarkable similarity in the fundamental cognitive processes of interpreting literature and solving many other kinds of problems.

While Herman Melville is one of the more complex authors of American literature, most classic literature requires considerable background knowledge of history, philosophy, mythology and preceding literary works, as well as a hermeneutic and biographical understanding of the author. In short, it is highly contingent on the reader's background knowledge and experience. This experience is then employed in detecting and interpreting the author's symbolic devices. Once these symbolic abstractions have been made, the reader must construct a logical relationship among the symbols derived from abstraction of the relationships in the story in order to interpret the author's meaning, thus decoding the entente. I would contend, then, that this process is abstractly analogous to previous meaning construction processes that we have discussed.

McConnell (2007) offers another experience-derived colloquialism: You can’t teach someone something they don't almost already know. A similar colloquialism is: Education is the processes of helping someone organize what they already know. A way to view this, in the context of our emergent model, is that teaching is the process of assisting in the stabilization of students’ partially or incompletely-formed conceptual structures. This views teaching as a compensation process. An analogy would be a governor on an engine, which increases fuel supply when demands require it and decreases fuel supply when the system is in danger of runaway, or perhaps, the pilot of a sailboat who turns the vessel or adjusts the sails in response to changing conditions in the environment. In all cases, there is a process underway that requires compensation (guidance, direction, adjustment, support) in order to keep the system on a steady course toward a goal. The teacher, pilot or governor in this view, does not undertake or provide for the fundamental process. The student, engine, or sailboat does. The function of the compensators is to adjust the control parameters of the system to increase functionality and achieve goals. This idea is explicit in Constructivist educational philosophy. The teacher is viewed as guide, coach, resource and facilitator to the primarily student-driven process of constructing knowledge and meaning. As a general idea, Constructivism is consistent with the ideas being developed in this Dissertation.

Vygotsky's (1986) concept of the Zone of Proximal Development expresses the same idea as McConnell's colloquialism. This idea is that during development there are certain problems or cognitive tasks that the child is on the verge of being able to do or accomplish, but that require the assistance of a more knowledgeable other (teacher, peer). The child needs support or scaffolding to be able to accomplish the task. Woolfolk (2004) summarizes scaffolding as:

1) supplying cues (reminders, prompts)
2) supplying additional information
3) demonstration of a process (walking through steps or partial solution of a problem)
4) feedback and revision
5) questions to focus and direct student’s attention and activities
6) encouragement to continue trying.

The Zone of Proximal Development is where, when supplied with the scaffolding or structures listed above, the child can solve the problem or accomplish the task. According to Vygotsky

(1986), it is in this Zone where instruction can succeed, and learning can take place. Some problems and tasks are simply beyond the developmental level of the child. In these cases, no amount of scaffolding will succeed. Consistent with Vygotsky's (1986) socio-cultural context, his contention is that what first is socially accomplished with others becomes internalized and can subsequently be accomplished by one's self.

During the coursework portion of my studies, I tutored a sixth-grade student in math at a local middle school. The course I was taking required that I utilize Vygotsky's (1986) Zone of Proximal Development idea as the basis for the tutoring. I learned through experience, and from reports prepared by fellow classmates, that successful application of this idea required dimensions beyond those explicit in the theory. As alluded to previously, this is invariably the case when applying theory to real situations. As Kieran Egan (1998) points out, this process is greatly facilitated by developing intrinsic motivation within the student and developing lessons around this motivation. The process is also facilitated by letting the child guide the course of progress according to his needs and interests (Rogoff, 1990). My student, who as a sixth-grader could not divide and had only partially memorized the multiplication tables, was convinced that she could not learn math and demonstrated a level of interest and motivation consistent with this belief. My first and foremost challenge was creating motivation and interest for the learning goals that I had in mind for her. She did not engage in a learning process until I created interesting mathematical games using manipulative objects.

In addition, my student demonstrated behavior consistent with Constance Kamii's (Kamii & Joseph, 2004) research and theory which show that many students studying math become proceduralized. Because of the nature of instruction, they see math as a series of algorithms rather than relationships. Kamii and Joseph (2004) cite research showing that teaching mathematics algorithmically to students is harmful. Elementary school children often invent their own odd little devices, which Kamii and Joseph (2004) call "buggy algorithms" because they cannot make sense of the algorithmic procedures of borrowing or carrying. Not understanding underlying relationships or **meanings** in math, students begin to rely completely on memorizing algorithms (formulas and process steps) to "learn" math.

The student I was tutoring was, for all practical purposes, completely bereft of any conceptual knowledge concerning mathematics. In solving math problems, she halted at every step and could not continue until I gave her the procedure for the succeeding step. She could not complete or finish a problem unless she was able to memorize or ingrain within herself the procedural steps. When I attempted to scaffold her and elicit an interactional dynamic in accordance with the Zone of Proximal Development idea, it became apparent that there was very little conceptual framework to support or scaffold. My subsequent tutoring became re-teaching and I concentrated on helping my student build a basic conceptual framework for arithmetic.

We can view mathematics as possessing both syntax and semantics. The syntax involves the logical connection of the symbolic elements, while the semantics express the meaning of symbols and their relationships in terms of the things symbolized. Once words or referents are abstracted into symbols, these symbols are manipulated and operated upon according to a logic which is independent of the initial referents. In this process an enormous number of logical operations can be carried out very quickly and efficiently. This is the power of mathematics. The problem for understanding is that a direct correspondence between these symbolic logical operations and relationships between the referents articulated in language does not occur. To express a mathematical solution to an average problem involving differential equations in terms of a verbal relationship involving the actual items being represented symbolically would involve a large number of pages of text and a fair degree of difficulty in capturing and describing everything that was occurring during the mathematical operations. This is why it is so much more convenient to undertake these operations mathematically. Complex mathematical problems cannot practically be connected step-by-step to relationships between referents. This is why it is imperative that semantics within the logical level of mathematical representations or the meaning of mathematical representations, operations and relationships be understood at the logical level of mathematics itself. In the words of Devlin (2000), we need to create the house of mathematics. If students do not understand relationships and meanings at the logical level of the mathematics, then operations are simply memorizations of syntactic rules and any relationship between these symbols and operations and the things being referred to by them (referents) are lost. For arithmetic and parts of algebra and geometry, we can fairly readily effect a mapping between the symbolic world and the world of things being symbolized. This ability to directly connect the two logical levels greatly facilitates understanding. Using procedures such as those described by Hiebert and Wearne (1998), we can increase our chances for success. Students will begin to understand and make sense of relationships at the logical level of mathematics in terms of the more familiar and easily understood relationships present in those things being referred to or symbolized mathematically. As stated above, it is also imperative that students begin to create meaning within the logical level of mathematics itself, separate from the lower logical level of referents due to the previously discussed disconnect that occurs between the two, for reasons of practicality and efficiency. If students' mathematical knowledge is simply algorithmic, this will not occur and students will remain forever mathematically challenged. Since application requires a conceptual understanding, at minimum, it goes without saying that they will be unable to apply whatever mathematics they may have "learned".

We now return to our discussion of the neurological correlates of reading. Recall that we discussed parietal- temporal neural circuits and their role in orthographic processing. We, in addition, discussed how a specific occipital-temporal area responsible for shape recognition, functions to identify and recognize letters. This circuit, with time and development, evolves into an automatic word recognition system that processes input extremely fast and does not require attentional resources. These circuits engage even before a word has been consciously perceived (Shaywitz, Lyon, & Shaywitz, 2006). It is not surprising, then, that level of activation of these circuits is directly and strongly correlated with behavioral measures of reading skill (Shaywitz & Shaywitz, 2004). An additional site involved in the reading process is the inferior frontal gyrus, an area historically designated as Broca's area. Broca's area, which is directly proximal to the motor cortex and specifically the portion of the motor cortex responsible for controlling the mouth and lips, has been associated with the formation of words in speech production (Bear, Connors, & Paradiso, 2007). It is involved in silent reading and in naming (Shaywitz, Lyon, & Shaywitz, 2006). Patients with lesions in Broca's area have difficulty saying anything, often pausing to search for the appropriate word. A hallmark of their inability is a telegraphic style of speech. They use mainly content words such as nouns and tend to leave out function words such as conjunctions or connectives. The difficulty does not appear to be recognizing sounds since patients can recognize and use words such as "bee" and "oar", but cannot recognize or use words such as "be" and "or." The difference is whether the word is a noun (Bear, Connors, & Paradiso, 2007). These difficulties are generally referred to as Broca's aphasia. These difficulties suggest that Broca's area is not only involved in articulating word sounds but also plays a role, along with nearby areas of the cortex, in making grammatical sentences out of words or in putting together the relational structure of language. Bear et al. (2007) summarize speech for those with Broca's aphasia as being non-fluent and agrammatical. For those with Wernicke's aphasia, speech is characterized as being fluent and grammatical, but without meaning. A reasonable hypothesis is that Wernicke's area handles the object-recognition tasks of language processing while Broca's area handles the relational or logical connective tasks. In that damage to either area disables understanding, it is also reasonable to assume that they work together in the creation of meaning from language input.

Numerous fMRI studies show that dyslexic children demonstrate considerably less activation of sites predominately in the left hemisphere (including the inferior frontal, superior temporal, parietal-temporal and middle temporal -middle occipital gyri). A few right hemisphere sights are also under activated (including an anterior side around the inferior frontal gyrus and two posterior sites, one in the parietal-temporal region, the other in the occipital-temporal region) (Shaywitz, Lyon, & Shaywitz, 2006).

Recent research by Shaywitz et al. (2006) has revealed two types of reading disability. Shaywitz et al. (2006) investigated three groups of young adults who were classified as either persistently poor readers (PPR), accuracy-improved readers or readers who were initially poor, but whose reading had improved over time (AIR) and a group who read consistently well over time(NI). During a pseudo-word rhyming task, principally a phonological processing task, both groups of originally poor readers (AIR,PPR) demonstrated under-activations consistent with previous studies, that is, under- activation of the posterior neural systems located in the superior temporal-parietal and occipital-temporal regions. We have discussed previously these two systems and how they are involved in word recognition and orthographic processing.

When imaging participants in their study during a real word-reading task, they witnessed surprising results. Despite significantly better reading performance by NI readers, left posterior reading systems were activated during reading real words in both NI and persistently poor readers (PPR). In contrast the reading-improved readers (AIR) showed under activation of these regions. Shaywitz et al. (2006) hypothesized that PPR readers were reading the simple words primarily by memory. PPR readers were accurate when reading high-frequency words but far less accurate when reading low-frequency and unfamiliar words. Follow up fMRI imaging studies by Shaywitz et al. (2006) confirmed this hypothesis. Targeted investigations of connectivity did indeed confirm that in PPR readers there was demonstrated functional connectivity between the occipital-temporal area and the right prefrontal area associated with working memory and memory retrieval. In contrast, NI readers demonstrated strong connectivity between the left occipital-temporal region and the left inferior frontal gyrus (Broca's area). This confirmed their hypothesis that NI readers process print in a linguistically structured manner while in PPR readers, the occipital-temporal area serves as a visually-based memory system.

Shaywitz et al. (2006) examined demographic differences between the two groups of readers with disabilities (AIR, PPR). Both groups began school with comparable reading skills. There was a strong trend, however, for the persistently poor readers (PPR) to come from families with lower socioeconomic status and to attend more disadvantaged schools. They concluded these children were doubly disadvantaged in being exposed to a less rich language environment at home and then less effective reading instruction in schools. They also concluded that the presence of compensating factors such as stronger cognitive ability and better instructional support permitted the reading-improved group (AIR) to mitigate the consequences of their phonologic deficits. These findings are in agreement with a large body of evidence that indicates that the impact of dyslexia can be modified and compensated with an increase in semantic knowledge (word meanings), the use of context (surrounding words used to determine word meaning) and an increase in lexical vocabulary (knowledge of more words) (Snowling, 2000). As children progress through their schooling, semantic knowledge and reading comprehension become increasingly important and increasingly the central focus of reading instruction. It stands to reason that a larger vocabulary, better reasoning skills and the use of context would greatly assist students in decoding words and creating meaning from text, even if word sounds and orthographic processing are impeded. Shaywitz et al. (2006) postulate that the greater number of ancillary systems found active in the fMRI scans of AIR versus PPR readers represents the neural correlates of such compensation.

Shaywitz et al. (2006) also investigated the plasticity of neural systems and their responsiveness to a phonologically-mediated reading intervention. Three groups of children were scanned: 1) a group who received a specific, systematic, explicit phonologically based intervention (EI), a group (CI) that received whatever intervention their schools may have provided (specific phonologically based interventions were not used in any of the schools) and a control group (CC) of consistently capable readers. Those children receiving the intensive intervention improved their reading accuracy, fluency and comprehension. FMRI scans demonstrated increased activation in the left hemispherical regions, including the inferior frontal gyrus and the posterior aspect of the middle temporal gyrus (Shaywitz, Lyon, & Shaywitz, 2006). A year after the intervention had ended, scans of the EI group indicated they were activating the bilateral inferior frontal gyri, left superior temporal sulcus, the occipital-temporal region involving the posterior aspects of the middle and inferior temporal gyri and the anterior aspect of the middle occipital gyrus, the inferior occipital gyrus and the lingual gyrus (Shaywitz, Lyon, & Shaywitz, 2006).

These findings are interesting from several perspectives. First, there was increased activation in the traditional reading processing circuits employed by capable readers (inferior frontal gyrus, posterior aspect of the middle temporal gyrus, and middle occipital gyrus). In addition, it appears that several ancillary areas or areas proximal to the traditional processing areas were recruited (right inferior frontal gyri, left superior temporal sulcus (traditional area is the left superior temporal gyrus), the inferior temporal and occipital gyrus, and the lingual gyrus). I think we can summarize this by saying that a direct intervention targeted at the deficit neurologic areas acts to stimulate those areas to the extent that neurological circuitry permits and also effects connections or recruits proximal areas to undertake requisite functions and provide compensatory assistance. These results illustrate both the value of directly targeted intervention and the brain's remarkable plasticity. The results also represent a form of experimental validation of Jerry Fodor's functionalist philosophy. In my view, it also represents a great example of a nonlinear system effecting an adaptation to environmental circumstances.

Many in education express hesitancy concerning the application of neuroscience to instruction. The principal fear is the attempt to reduce complex phenomenology at the instructional level to neuronal activity. Said succinctly, they are concerned with reductionism. The historical record would indicate that this is a legitimate concern. It must always be the case that, when moving from one logical level to the next, we understand that relationships produce phenomenology, context and metrics unique to the higher logical level and not manifest at lower levels. At the highest level, scholars and researchers such as Dehaene, the Shaywitz's or Elena Grigorenko (genetics researcher) are both knowledgeable of and attendant to these issues. Papers written by these researchers examine evidence from and create reconciliations and isomorphic relationships between logical levels (genetic, neurological, psychological and instructional). There is a considerable amount of misinformation, reductionism and downright quackery that is promulgated by less vetted and credentialed practitioners, who portend to offer brain-based solutions to educational issues. Teachers and practitioners need to be wary of oversimplified, faddish "brain-based" offerings. For example, determining whether your students are left or right-brain oriented and emphasizing instruction that is either verbal or graphical depending on some questionable prognosis of this inclination. Many of these programs, offered to classroom teachers in in-service settings, are breathtakingly oversimplified and often inaccurate. Their attraction is that they often appeal to or are congruent with intuitive generalizations that people have made about themselves and others. This dynamic is not dissimilar to that of an individual who feels like the description of a Gemini is an accurate description of his personality and subsequently buys into astrology.

Kurt Fischer, Dean of Mind, Brain and Education at Harvard University has put forth a Herculean effort to create a dialogue between geneticists, biologists, neuroscientists, cognitive and developmental psychologists, and educators. His efforts have resulted in research by prominent figures in these fields directed toward problems in education, the creation of an international professional society dedicated to cooperation between these fields, in-service educational issues (IMBES), national and international conferences, a peer-reviewed journal and the formation of graduate school programs at other universities dedicated to the confluence of mind, brain and education, such as the program started by Dr. Marc Schwartz (a graduate of Fischer's program) at the University of Texas at Arlington. I have found the work of Dr. Fisher and IMBES members extremely beneficial to this Dissertation and would recommend them to anyone interested in how research across these diverse domains can have meaningful application to issues in education.

We mentioned a lot of brain areas in the above discussion, which may have been somewhat confusing to follow. Let me briefly summarize the principal areas involved in implementing the reading process steps summarized by Ely (2005). Letter recognition is undertaken by the left middle temporal-middle occipital gyri. As discussed, with development and experience, this area develops into a rapid word-recognition system that communicates directly with the word-relationship area of the left anterior inferior frontal gyrus. This permits the exceedingly fast processing of written words seen in proficient readers. As also discussed, this rapid process does not require attentional resources and occurs almost tacitly. Critical for early readers (age 12 and less), and still important for older readers attending phonological tasks such as rhyming or interpreting lesser-known words, are the neural circuits that handle orthography and letter - sound correspondences. These areas are the posterior aspect of the superior temporal lobe (Wernicke's area), the temporal -parietal area, and the angular and supramarginal gyri in the parietal lobe. Broca's area or the left anterior inferior frontal gyrus processes word relationships, and as such, is important in semantic (meaning) processing. As mentioned previously, I feel it is reasonable to hypothesize that Broca's area and associated circuitry systemically combine with the circuits in Wernicke's area (temporal- parietal area) to create meaning from language. It is also reasonable to hypothesize that higher-level comprehension tasks will invoke memory retrieval and the organizational areas of the prefrontal cortex.

The work of Shaywitz et al. (2006) showed that remediation targeted specifically at deficit areas activated those areas and caused associated areas to be enlisted as compensatory adjuncts. It is interesting to look at the specific phonological remediation regime that was employed (Blachman, et al., 2004). The remediation sessions, conducted every day, lasted about an hour and included five steps. The first step was a review of sound-symbol associations learned in the previous session and the introduction of the new sound-symbol correspondences. Index cards were used for each of the graphemes and attention was called to the vowels by coloring them red. Children were taught to continue saying a sound until the next phoneme was reached. They then practiced shortening the time interval between phonemes in a word. For example let us say that the words sat, Sam, sap, and sad were in the day's lesson. Children first practiced the "sa" sound as described above. The teacher would cover the ending consonant sound on the word card until the sa sound was articulated, then reveal the ending consonant, and ask for the word and its full sound.

In the second step, children were asked to create words using Scrabble tiles in response to sounds. For example, after hearing the word sat, children were asked to find the vowel in the word, then they were asked what was the first sound they heard, to put in front of the vowel, and then, what was the last sound they heard. They were also asked to change the vowels and see what other words could be created. This process was done very systematically, in a way that reflected particular syllable relationship patterns. For example, in certain words, like sad, the vowel is closed between two consonants. The child would initially be asked to manipulate letters surrounding the vowel to create new words like sag from sat or fan from fat. Once the vowel was mastered, the children were asked to create new words by changing the vowel to another vowel, as in changing fan to fin. Sometimes a silent syllable occurs at the end of a word. Words with this characteristic were taught by having the child change words like shin to shine or fin into fine. Several other vowel pattern (syllable structure) regimes were also illustrated (open vowels, vowel teams or pairs, vowels that say themselves in words, like the letter u in use).

The next activity was designed to develop fluency and sight recognition of complete words: the words they had practiced in the previous activity with the Scrabble tiles. They saw the word and had to say it without sounding it out.

The fourth step of the process was oral reading of the words learned in the lesson, in context. Phonetically controlled books were utilized. The intention of this activity was to teach children word relationships and meanings as well as to reinforce prior activities. The final round of each lesson consisted of teachers dictating words used in the earlier steps of the lesson and asking students to write them. This was in effect an assessment of the prior lessons. Generally six-to-eight words and two sentences were dictated (Blachman, et al., 2004). While billed as a phonetically directed intervention, we can see that the above lesson covers every aspect of the reading process described by Ely (2005), from letter recognition to comprehension, and represents very robust and well thought-through early reading instruction. As a child progresses through school, grades 4 and beyond, reading revolves increasingly around comprehension, with decoding presumed to be a given. Text materials evolve from single perspectives on the subject matter (grades 4-9) to multiple viewpoints from multiple sources (grades 9-12) (Chall, 1996).

Conclusions

This section begins with a statement of 29 premises derived from the body of the Dissertation. These premises are the proposed epistemological predicates for the development of curriculum and instruction. They result from abstraction of patterns of relationship both within and between sections of the Dissertation. Three principal methodologies were employed in evolving these premises. The first method was a variation of the Hegelian dialectic. The assumption in the method is that two seemingly divergent and incommensurable entities, thesis and anti-thesis, often reflect the range of states of a concept or principal at a higher logical level. The operational task involves finding a similarity construct between thesis and anti-thesis such that they can be synthesized as the range of states of a single encompassing super-ordinate conception or principal. For example, pleasure and pain, while seemingly different entities, are synthesized as the range of states of a behavioral modification mechanism. As discussed in the body of the Dissertation, the former encourages recurrent behavior, while the latter discourages it. In this way, pleasure and pain are synthesized under a super-ordinate construct. The dialectic unification of thesis and anti-thesis offers a powerful tool with which to resolve a great number of dualities.

Faith in the resolving power of this methodology is based on the foundational belief that all entities that manifest themselves ultimately exist in some form of systemic relationship to one another. This belief, in turn, relies on Pierce's (Hoopes, 1991) idea that separate existence or identifiable unity requires that totality first be differentiated with respect to attribute or characteristic and then connected through relationship to that from which it was differentiated. Absent a relationship, the entity or unity is devoid of meaning. I would like to point out that Pierce’s (Hoopes, 1991) description coincides with Vygotsky's (1986) definition of concept development: abstraction of differentiated attributes and characteristics of entities and subsequent connection through relationships that express logical judgments concerning these attributes and characteristics. The clear implication here is that the fundamental unit of knowing or meaning is the concept. This immediately creates an epistemological dilemma. Concepts are created through an inductive process. As inductive, a concept cannot possess the property of logical necessity. This immediately brings to mind the contention of Hume (1982), which has in contemporary thought been reprised by postmodern philosophers: that concepts are derived a posteriori (subsequent to experience) and therefore contingent and incapable of expressing necessary and universal truths. Postmodernists would add that since concepts are context-contingent they are also necessarily subjective.

Pierce's (Hoopes, 1991) position is extremely intuitive and would be tempting to adopt as a self-evident foundational belief. Technically, however, it consists of synthetic judgments, to use Kant's (1982) terminology. Kant (1982) defines a **synthetic judgment** as a proposition wherein the predicate concept contains more information than is contained or thought in the subject concept. A synthetic judgment amplifies or adds to what is contained in the subject concept. The statement *all swans are white* is a synthetic judgment. In an **analytic judgment**, the predicate concept merely explicates what is in part or whole contained within the subject concept. Analytic judgments therefore are necessarily true or false based on the rules of formal logic. Their truth ultimately depends on the principle of contradiction. The statement, "*all bachelors are unmarried,"* is an analytic judgment. Hume (1982) takes the position that all matters of fact or existence are knowable only a posteriori (subsequent to experience). While Kant (1982) agrees with Hume (1982) that all a posteriori (empirical) judgments are synthetic, he denies that all synthetic judgments must be a posteriori. Both Kant (1982) and Hume (1982) held that any judgment wherein the truth is knowable a priori expresses a necessary or universally valid truth.

Hume (1982) demonstrates that any causal principle cannot be analytic but must be synthetic. Hume (1982) also showed that no universal truth could be justified by a posteriori means. Taken together, the implication is that true causal knowledge is impossible. In summary, there can be no such thing as objectively true science. Hume's (1982) arguments also eliminate the possibility of metaphysics and objectivity in general. Kant (1982), I believe successfully, demonstrates the existence of a priori synthetic judgment in his *Critique of Pure Reason* and restores the possibility of objectivity and science. I will discuss later, in more specific terms, the results of this work because they are germane to several of the conclusions of this Dissertation.

If we look at Pierce's (Hoopes, 1991) position in light of the above discussion, we can see that within the concept of unique existence the ideas of differentiation from totality and relationship (at least with respect to totality) are analytic and hence necessary. That things uniquely exist at all is, however, a posteriori, synthetic and contingent. The concept of unique existence is an inductive generalization from experience. It is alternatively possible that what we regard as separable, unique existence is in fact an attribute or manifestation of a still intact totality. For example, a universe conceptualized through the Strings of theoretical physics conceptually implies such a totality. Matter in this theory consists of kinks or irregularities in the string fabric of the universe. It could be the case that our conception of separability is simply a consequence of our specific perceptual and sensory capabilities. The results of the Theory of Relativity and Quantum Mechanics can be interpreted to imply the existence of a mechanism enabling universal systemic relationships within the universe.

The existentialist, the postmodernist, and the rationalist will likely take exception to the manner in which the succeeding premises were developed: specifically, the direct movement from science to epistemology. Let us examine Kant's (1982) conclusions presented in the *Critique of Pure Reason* in order to begin to address these concerns. Kant's (1982) term for a mental representation derived from sensory input and presented to consciousness is an **intuition.** Kant addresses the question of how is it possible to construct such a representation from sensory experience of an object. It is possible only if the intuition has some form. This form is of necessity a priori and universal. Without the form, representation and perception are not possible (sensory input would be an unorganized jumble). To preserve a priori status, the form cannot in any way be contingent on the substance or content of any particular intuition derived from experience or condition imposed by the objects "in themselves." The forms of intuition also constitute formal conditions for intuition insofar as all objects, if they are to be intuited, must conform to these formal requirements.

For Kant (1982) the forms of intuition are space and time. If we omit from empirical intuitions everything empirical or belonging to sensation, space and time still remain and therefore are the forms that exist a priori as the basis of the empirical. It is a condition of the possibility of mental representation and perception that an external object be intuited as situated in space and time. For Kant (1982) the cost of this necessity is that we cannot know things in themselves but only know how things appear to us as dictated by the forms. In that the objects themselves could have a reality independent of our sensuous experience of them, he terms the idealization consequent to the necessities of intuition, “transcendental idealism,” ideal in the sense of unchanging and universal, transcendent in the sense of their a priori foundational status.

In order to claim knowledge about any particular object or event, we need to be able to form a judgment concerning them. Intuitions or mental representations must therefore be related in a way that a judgment is involved. Asserting that something is the case requires one to have an intuition and that the intuition be brought under a concept. As with intuition or mental representation, the possibility of empirical, synthetic a posteriori judgments is contingent upon the existence of synthetic a priori principles or concepts. In a manner similar to the way that the forms of space and time enable the capacity for empirical intuition, these pure a priori concepts or principles enable the capacity to make synthetic a posteriori judgments. These pure a priori concepts are transcendental in the same manner as space and time. For an object to be a possible object of judgment, it must be subsumed under the pure a priori concepts or principles. These principles Kant (1982) terms the Categories. Kant's (1982) task is to demonstrate that the Categories are a priori and that subsuming intuitions under these categories is required in order to render institutions suitable objects for empirical judgment.

Kant (1982) begins his derivation of the Categories with what he considers to be the basic forms of judgment: the propositional forms of formal logic. He determines that there are precisely 12 forms of pure judgment. These he divides into four groups, each containing three moments:

1) Quantity (universal, particular, singular)
2) Quality (affirmative, negative, infinite)
3) Relation (categorical, hypothetical, disjunctive)
4) Modality (problematic, assertorical, apodeictical)

Every judgment takes a moment from each group. For example a judgment may be universal, affirmative, categorical and assertorical: *all swans are white*. A judgment could also be singular, negative, disjunctive, and problematic: *that animal might be neither swan nor goose.*

To arrive at the pure concepts of understanding, Kant (1982) identifies concepts that both correspond to the logical functions of judgment and have the capacity to organize intuitions. These concepts or categories he sets out as:

1) Categories of quantity (unity, plurality, totality)
2) Categories of quality (reality, negation, limitation)
3) Categories of relation (inherence and subsistence, causality and dependence, community and reciprocity)
4) Categories of modality (possibility/impossibility, existence/nonexistence, necessity/contingence).

By way of example, corresponding to the logical function of hypothetical judgment (if p then q) is the category of causality. Corresponding to the logical function of categorical judgment (A is a B) there corresponds the category of substance.

To restate Kant's (1982) position, all empirical judgments are organized and enabled through the above a priori Categories of pure judgment. Subsuming of intuitions under these Categories is required in order to render institutions as suitable objects for empirical judgment. The Categories constitute formal principles of possible experience. He states that these principles will be true of any possible object of experience because satisfaction of them is requisite in order for something to be a possible object of experience. They are a priori requirements that make empirical judgments possible.

A significant portion of Kant's (1982) *Critique of Your Reason* concerns supporting the claim that conception of an object under the Categories is a necessary condition for that object being a possible object of an experiential or empirical judgment. Kant's (1982) arguments, while brilliant, are extremely complex and constitute a web of understanding rather than a linear progression of justification. In this brief summary, it is perhaps sufficient to consider his argument for the necessity of the categorical conception of causality, drawn from a section entitled , “Analogies of Experience”. His argument here is fairly straightforward and serves as a good example of his thought process.

In the first Analogy, Kant (1982) demonstrates that all perceived change must be regarded as a change in substances. The question that immediately follows is how change can be referred to objects and substances rather than to the subject. The concept of substance alone is not sufficient. It is also necessary that one be able to think of the succession of appearances as a succession in the objects themselves, independent from the succession occurring in the subject's representations. In other words, the succession of representations experienced objectively occurs within the object itself. To explain his point, Kant (1982) asks us to consider two examples: one in which the experience changes while the object remains the same, and another in which experience changes because the object itself is changing. In the first example he asks us to consider the apprehension of a house. One might first perceive the roof and ultimately the foundation, or vice versa. One might also perceive the house by going from left to right or from right to left. There is no determined order which necessitates beginning at one point and ending at another. The series of subjective representations and perceptions are successive and reversible. The house itself remains unchanged, and the changes are just in my subjective experience of the house from different perspectives. Kant (1982) now asks us to consider his ship floating down the stream of a river. In this case, one's perception of its place lower down the river follows upon the perception of its place higher up the course of the river. In apprehending the ship, perception and experience change because the object itself is changing. It is not the case that these perceptions could have occurred in reverse order; that would be a different experience altogether. In the case of the ship, there is an objective sequence or succession that corresponds to one’s subjective sequence of apprehension. The difference between the two cases is that, in the case of the ship, **one organizes experience according to a rule which makes the order in which the experience is apprehended necessary and irreversible**. It is an orderly sequence in time. It cannot be the case that one apprehends the ship as first downstream and then upstream; the order of the apprehension in the specific experience is regulated, necessary and irreversible. The concept of a necessary and irreversible succession is the concept of a causal relation. The a priori Category of causality is justified, therefore, in that only an a priori rule, whereby one apprehension can be regarded as necessitating another, allows one to refer the change to the object rather than the subject - a requirement for an objective time order.

What Kant (1982) demonstrates in the *Critique of Pure Reason* is that objective experience is possible. It is, however, objectivity with a caveat. It is the objective rendering of the experience of the individual. It is experience in the context of the forms of space and time and of the Categories. As such, it renders the thing, in itself, unknowable. Implicit also in Kant's (1982) treatment is that all will share the same objective experience. We understand today that one's interpretation of an experience is contingent upon the history of his past mental organizations. These past organizations or schema exert influence and provide the context for the interpretation of current perceptions and mental organizations. An important conclusion implicit in Kant's (1982) work is that the nature of the knower has a lot to do with what can be known. Regrettably, this theme was not followed up by Kant's successors. It was not until the 20th century that this theme was seriously pursued. Philosophies subsequent to Kant took a different turn. The influence of romanticism in German literature, following Kant, "placed spiritual, quasi-religious demands on the intellect which a philosophy of finitude such as Kant's seemed to frustrate" (Gartner, 2005, p. 332). The inability to know the thing in itself and the reduction of the world to the perspective and projection of the individual also proved problematic for subsequent philosophers. German idealism subsequent to Kant revolved around a perceived need for first principles, systematicity and the pursuit of the thing in itself.

Hegel (Taylor, 1975) rejected Kant's notion of a single set of categories determining human experience. Hegel, influenced by German idealists who preceded him, contended various **forms of consciousness**, each of which structures experience and truth in its own way (Taylor, 1975). There are different **perspectives**, each of which may permit a partial grasp of truth. It is in Hegel's dialectic process that differing perspectives get reconciled through synthesis, producing a "truer" perspective which supplants prior perspectives. This new perspective, however, is tentative and subject to future dialectic process. Hegel abandons epistemology and instead looks to **historical development** as the source of philosophic insight. This methodology was to have enormous impact, influencing subsequent philosophers such as Marx, Engels, Foucault and psychologists such as Vygotsky. With his enterprise, Hegel introduces the ideas of the **context contingency** of knowledge, the **ontogenic and phylogenetic progression of knowledge** in both the individual and mankind in general, **the socio-cultural impact** on knowing, and the idea that subject and object distinction is potentially resolvable through the **integration and development of consciousness**.

Contemporaneous with Hegel, Schopenhauer rejects Kant from a different perspective: reprising the supremacy of **subjective** knowing. For Schopenhauer (Durant, 1927) the route to understanding the mind and reason do not lie in understanding how we process external objects but in a subjective examination of the nature of our own minds. By examining matter first and then proceeding to mind, we get only images and names (words - concepts of things external). Our search for the nature of knowing should begin with what we know directly and intimately - our own minds. We cannot determine the real nature of things from without. If we can ascertain the ultimate nature of our own minds, then perhaps we can find the keys to the world outside ourselves (Durant, 1927). Schopenhauer rejects the notion, from the ancients, that the essence of mind is thought and consciousness (man as rational animal). Instead, he contends that consciousness is merely a surface or crust. Under conscious intellect is the conscious and unconscious **will**; a striving persistent vital force. The will is primal; it directs the intellect. The will prescribes where to go, and the intellect determines how to get there. Man is desire cloaked in reason. We do not want because we have reasons, we find reasons because we want; philosophies cloak desire (Durant, 1927). From the above, it should not come as any surprise to the reader that Schopenhauer was a principal influence on Sigmund Freud. In summary, Schopenhauer expands the philosophic debate concerning the nature of reason by adding the dimension of the will, as well as placing subjectivity in the forefront. Subsequently, Nietzsche (1844-1904) proposes the fundamental drive of the universe as the **will to power**. He describes a Superman - someone who has refined the will to power to the extent that he has freed himself from all outside influence and has created his own values. For Nietzsche, the will to power reflects an instinct for **freedom** and autonomy. Nietzsche also takes Hegel's idea of perspective to its logical limit and pronounces that there is no absolute truth, merely different **perspectives (**Durant, 1927). In Nietzsche's view, Metaphysicians, Idealists, Realists and Thomists had constructed an unchanging world of universals and certainty as a philosophical tranquilizer for people who could not accept the reality of a world that was incomplete, changing and always in a state of becoming (Gutek, 2009). Martin Heidegger's (1899-1976) philosophy of Existential Phenomenology advocated a self-defined, authentic person for whom truth was not found in universal categories such as Plato's Forms, but was the result of his own constructions based on intuitions, perceptions, and reflections consequent to his own experience. Free from metaphysical antecedent and postulated universal truths, the individual could create an authentic existence or "Dasein” (Gutek, 2009).

The preeminence of subjectivity also received endorsement from the philosophy of Kierkegaard (1813-1855). Kierkegaard begins with the idea, from Descartes, that the most fundamental thing we know is the **subjective** knowledge of our own existence. This is knowledge that cannot be expressed or demonstrated objectively. Kierkegaard also articulates the **contingency of understanding**; ideas can be put forth from a variety of points of view; no single view can be taken as "correct.” Individuals decide subjectively which viewpoint to take, hence, what counts as knowledge becomes ultimately, subjectively determined. Kierkegaard does not refute the existence of objective knowledge; he simply states that this knowledge relates to the external world, is confirmed by reference to outer criteria and addresses questions of "what" things are. The most important knowledge and truth for Kierkegaard are subjective knowledge and truth because these are the most fundamentally related to existence. Subjective truth is contingent upon our values and their foundations. To a considerable extent, these values determine what we regard as facts. He states that pagans and Christians "see" different worlds. For Kierkegaard, the absolute correctness of our values is less critical than our commitment to them. As we can see, Kierkegaard's positions are as much a prescription for how life should be lived as they are philosophy. He states that we have two ways in which we can live our lives. We can live for ourselves and for our own pleasure, what he terms the aesthetic life. This life however lacks stability and certainty. It expects everything from without and relies on the external world and its contingent nature. Ultimately, this life is out of the control of the will, and what we experience is simply what the world has to offer. We generally fail to actualize our will and can end up in despair. In despair, we can accept our fate, but in so doing, we disavow our freedom and any responsibility for our lives.

Conversely, we can **choose** to live what Kierkegaard terms the ethical life. We can exercise our freedom and take responsibility for what we make of our lives. Life becomes a self-creation by conscious choice. Subjectivity is absolute - choosing for oneself. We can aim for a "higher life" by choosing a set of ethical standards. The ethical individual's life is not contingent or accidental; he expresses the universal in his life (good, duty). The individual seeks to know himself and change himself by choice, not simply accepting what is discovered but improving upon it. The ethical life becomes necessary, consistent and self-creating. The individual is the creator of his own world. The individual **creates** the world according to his values: the ones that make him what he is. Individuals, in this fashion, are **responsible** not only for themselves but for the world they inhabit.

As a consequence of these positions, Kierkegaard is largely credited with providing the intellectual basis for existential philosophy (Noddings, 2007). For the existentialist, there is **no pre-existing order** or meaning in the universe; no preformed human nature. Humans have complete **freedom** to define themselves and to create meaning. Meaning is not predefined in terms of universal laws that exist external to the individual; we do not **discover** meaning, we **create** it. Man is what he makes of himself. What you and I do defines what it means to be human. Meaning is created by the individual through his actions and interactions with others; meaning is created as we live our lives reflectively - existence before essence. Our identity is not granted by any system or institution. Humans are free to make choices and must bear responsibility for those choices. We cannot substitute ideology or science and free ourselves from the **responsibility** of defining both ourselves and the world we live in (Noddings, 2007).

The contentions of postmodern philosophers concerning the nature of knowledge and truth, as articulated in the works of postmodernists such as Michel Foucault (1926-1984) and Jacques Derrida (1930-2004), reflect in one form or another the totality of criticism levied against metaphysics and epistemology since the time of Kant. Foucault (1972) uses historical analysis as his source of philosophic insight. He construes that historical attempts to construct systems of knowledge that reveal truth are reflective of a **truth- power relationship**. His contention is that the grand philosophical systems of the past that portended to produce universal, timeless and objective principles were the product of power relationships existing in society, politics, economics and education at the time of their construction. These meta-narratives rationalized and explained systems of knowledge that empowered one group at the expense of others (Foucault, 1972). With such inferences, it seems as though he has undertaken Hegel's enterprise and viewed his results through the eyes of Nietzsche. He adopts historical analysis as his methodology and interprets, consistent with Schopenhauer, that Will guides the intellect, and consistent with Nietzsche, that the guiding will seems to be the will to power. Postmodernists, including Foucault and Derrida, dismiss the ability of metaphysical or epistemological enterprise to render universal and timeless truth free of socio-cultural context. In fact, they contend such Truth (truth with a capital T) is nonexistent. In general, it appears that postmodernists concur with the existentialist position that there is no pre-existing order or meaning in the universe; meaning is a construction not a discovery.

Periods in history exhibit what Foucault (1972) terms an **episteme** or set of framing postulates and assumptions that direct intellectual activities within a society during these periods. Epistemes influence the manner in which people view their social and economic circumstances as well as their institutions (Gutek, 2009). They set parameters that fix the permissible range of discourse. For example, church-approved doctrine set the framework for discourse in Medieval Europe. In similar fashion, Marxist-Leninist doctrine controlled discourse in Soviet Russia (Gutek, 2009). Truth-power relationships produce

regimes of truth: ideologies, institutions and sets of practices utilized to direct, control and define individuals within a society (Gutek, 2009).

Foucault (1972) is particularly critical of the contentions of the Enlightenment (modern thought). He and other postmodernists dismiss the premise of the Enlightenment and modern thought that individuals using logic, reason and the scientific method can discover truth in the form of an objective body of knowledge. They dispute the existence of eternal, universal and objective truths that explain the structure, functions and patterns of human or natural phenomena (Gutek, 2009). Again, this is consistent with the view that there is no pre-existing order or meaning in the universe. Foucault and postmodernists discount the Enlightenment view that such scientifically obtained "objective" knowledge is accessible to all and that it can equally benefit all by providing guidance for the conduct of human activity.

Postmodernists have particular disdain for the social and behavioral sciences: sociology, economics, political science, anthropology and psychology. The contention is that, using allegedly objective research, social scientists developed guidelines for what should be considered "normal" socially prudent behavior. This had the effect of "othering", marginalizing and disenfranchising those who fell outside the norm. Again it is contended that this sanctioned official knowledge became the mechanism whereby one group categorized, manipulated, and exercised power and control over other groups (Gutek, 2009). Foucault wrote several books from the perspective of those "othered" and institutionalized as a result of experts' norms.

The continual characterization of life as primarily a power struggle and the characterization of the development of traditional systems of knowledge as devices principally constructed to enable one group to control another, I believe, create difficulties for postmodernists. It inhibits large-scale adoption of their ideas and prevents many from giving proper consideration to serious issues they raise. While most would agree that thinkers like Plato, Descartes, and Kant were undoubtedly influenced by zeitgeist or the spirit of their times, most would not think of them as pawns of a power elite or as thinkers primarily influenced by personal power motives. Foucault (1972) presents a compelling and largely accurate rendition of the uses, or moreover, abuses of systems of knowledge. It is clear that those in power use these systems to advantage their own circumstances and rationalize their intentionality. I think that what Foucault saw was a manifestation of what I would term intellectual Darwinism. In every age, those ideas that best adapt to the contingencies of the socio-cultural environment are naturally selected and survive. Those ideas incongruent with this environment either die or remain dormant until discovered by a thinker in a later era: an era in which the zeitgeist supports its existence. For example, Descartes and Arnauld were contemporaries with competing philosophic outlooks. Descartes's philosophy resolved a political problem between the Church and the scientific community. As such, it prevailed and Descartes is a figure known to all who receive a formal education, while Arnauld is known only to students of philosophy. In similar fashion, Kant's philosophy prevailed over the competing philosophy of Goethe. Kant's philosophy restored faith in the Enlightenment paradigm after Hume's philosophy had called its fundamental assumptions into question. Given what historians have told us of Kant's biography, it is difficult to consider his efforts as anything other than an erstwhile attempt to further knowledge and understanding.

Derrida's (1976) principal focus was the analysis of texts (any form of communicative or semiotic device) and the language used to communicate knowledge and implied truths. Sharing Foucault's view that these documents were invariably context-contingent and socio-culturally influenced, and hence demonstrative of bias, he devised a method of analysis known as **deconstruction.** Functionally, deconstruction involves determining the origin and the specific development of the meanings conveyed by the text, with a special sensitivity to justifications based on metaphysical assumptions, rational principles or foundational beliefs. Derrida (1976) terms these influences, which are artifacts of Western culture and philosophy that claim to represent universal timeless truths, **logi.** Deconstruction also involves determining how the author's knowledge claims, meanings and interpretations affect the reader's ideas, beliefs and interpretations. Another goal is to develop an understanding of how the text is a culturally and historically situated construction that invariably involves political power relationships. Deconstruction should provide an understanding of how rationale builders used language to construct meaning and to legitimize their positions in society: what assumptions justify the meanings imputed (Gutek, 2009).

The technical detail of deconstruction is quite complex and cumbersome. Derrida is aware that words themselves do not convey universal, timeless and fixed meanings. They depend on relationships with other words to convey meaning. Meaning therefore is contingent upon the specific workings of language: the specific choice of words and word relationships. Derrida invented the word **Differance** to express this. This word combines the concepts of differing and deferring. The meaning of the word is different from the word itself. Words in themselves do not contain meaning; they simply refer to something; they defer to their ability to give meaning to other words. Deconstruction involves an analysis of word choices, word relationships, examples and metaphors. Language is analyzed as it is used in social relationship (Gutek, 2009).

At this stage, it would be fair to ask, what is it that postmodernists consider to be legitimate sources of knowledge? In concert with existentialists, meaning is a creation. "Post-modernists look to discourses and local narratives constructed by individuals in their immediate relationships in their groups and communities. Each of these different expressions exists freely without a need to constrain experience to conformance to some contrived universal principle" (Gutek, 2009, p.139). Postmodernists advocate trusting the validity of personal and communal relationships rather than relying on meta-narratives that propose to claim universality and authority over personal, group and cultural norms (Gutek, 2009). Postmodernists argue that there are many legitimate claims to truth. In concert with

Hegel, Schopenhauer and other intellectual antecedents, they contend that all knowledge and claims to truth occur within contexts. No one context is preferable or constitutes "the" way of ascertaining knowledge and truth. The inability to determine criteria that are absolute assures this. Further, they contend that it is not permissible to abstract from multiple perspectives or contexts and universalize a single generalized truth through this abstracting process (Guba, 1985). Knowledge emerges as morphology of understanding through a simultaneous, democratic consideration of multiple contexts. In general, postmodernism is antagonistic to any form of universalization whether by metaphysics, science or social consensus. In summary, knowledge is constructed, subjective, context-contingent, pluralistic, local and subject to evolutionary change.

In large measure, philosophy finds itself in much the same position as it was at the time of Kant. In addition to the concerns of Hume, which Kant so ably answered, we have added additional concerns that have arisen in 200 years of philosophical inquiry subsequent to Kant. Since this Dissertation intends to offer an epistemological basis for curriculum and instruction, and since epistemology has been under siege since the time of Kant, it is required that I address these concerns. As illustrated in the foregoing, postmodernism contains a compilation of all of the concerns and criticisms directed toward metaphysics and epistemology in the past 200 years. I will therefore direct my responses directly to postmodern positions. I believe I have developed an epistemological system that addresses and resolves these critiques. Of course, the reader is the ultimate judge of that.

In response to the contention that there is no pre-existing meaning in the universe, I answer in the affirmative, with caveat. Meaning is in fact consequent to relationship. There is however a pre-existing systemic connectivity among things in the universe. Absent this nonlinear connectivity, the possibility of meaning could not exist. Going back to my prior discussion of Pierces philosophy, relationship is requisite for unique existence and meaning. In a universe where all things are possible, in which no connectivity is a priori and where all events are random and completely subject to change at every instance there can be no meaning. If all is possible, nothing is possible. As discussed previously, the fundamental ability to form any type of concept depends on the existence of some form of invariance among the things of the universe. Said alternatively, meaning creation and conception are contingent upon the existence of “kinds" of things. Everything in the universe cannot be uniquely different or capable of random change at any instant. It is the systematic connectivity of the universe and the resulting conservations (which articulate as invariants) resulting from this systematic connectivity which allow meaning creation.

Relativity reveals that space and time are in nonlinear relationship. One expression of this connection is the Minkowski relationship. As Taylor (2005) demonstrates using this relationship, if the speed of light were not constant and conserved, and if any speed were possible in the universe, it would be the case that effects could precede causes. Causality would then have no meaning. It would be possible to go back, for example, to the Battle of Appomattox, put on a Union uniform and kill your Confederate great-great-grandfather. In this case, we would have someone who did not exist killing someone who did exist: an event without meaning. It is nonlinear systemic connectivity of the universe that allows for the creation of meaning.

The above discussion illustrates the second strategy used in developing the epistemological premises to follow. Analogous to the manner in which Kant asked what a priori conditions were required to enable the mind to construct mental representations and to undertake empirical judgments, it can be asked what a priori conditions must be present in the universe in order for there to be meaning. The a posteriori evidence for meaning is provided by physics and the existence of the necessary rules of formal logic. As with Kant, we can ask what synthetic a priori relationships need exist such that the possibility of synthetic meaning as derived from physics is enabled. The derivation is a universe which must be connected in systemic nonlinear relationship. This relationship produces invariants or characterizing parameters which are conserved, such as the speed of light or Planck's constant. It also enables the existence of the Categories of Kant and the rules of formal logic. For example, nonlinear connectivity enables unique existence (substance) and causality. Unique existence in turn produces the logical principal of contradiction. Causality produces the logical principle of hypothetical judgment, as Russell (1993) shows with these or any two logical functions, presuming the remaining principles of formal logic can be derived.

In response to the postmodern contention that all knowledge is context-contingent, subjective, local and in a constant state of becoming, I again answer in the affirmative, but again with caveat. The creation of meaning requires a context. We are free to choose contexts, as they are an imposition (something imposed). Once imposed, context determines elements and attributes (metrics) and controls the type and nature of permissible relationships that can be constructed between elements. Relationships that equilibrate within these contexts create meaning, define reality, and can be considered objective within the confines of the context. If our system is open and elements can enter which do not equilibrate within the given context, then the context must be expanded and evolved. As discussed in the body of the dissertation, this is the process of expanding referentials and relativizing relationships in order to construct a revised context at a higher logical level that permits equilibration between elements and accommodates new input.

In response to a postmodern contention that all contexts are created equal, no single context is preferential and no universal criteria can exist with which to judge different contexts, I respond as follows: Contexts are the product of intentionality or goals. Expressed in existential or postmodern terms, contexts are invoked by the Will. It is the contexts themselves that create the criteria for judgment. Equilibration within the contexts becomes the determinant of whether criteria have been met and the desire of the Will or intentionality has been satisfied.

Under a postmodern conceptualization of contexts, a paper by a high school sophomore written about Shakespeare could be equally worthy to one written by Oxford University's leading Shakespearean scholar. In the absence of universal criteria with which to judge these two separate contexts, this could be the case. As you will recall, postmodernists reject the notion that experts in possession of universal and canonical-knowledge claims have unquestionable authority to pass judgment with respect to worthiness. Let us consider the circumstance in which their contentions would be intuitively agreeable. If our intentionality were such that we wished to understand which work was a complete rendering of the individual's knowledge and which work was most expressive of the individual's personal meaning and direct connection with Shakespeare's work, a context imposed and its consequent metrics which permitted this judgment to be made, could well indicate that the high school students paper was, in fact, more worthy. If our intention is to ascertain which paper shows a greater depth and breadth of knowledge, then the scholar's paper, without question, prevails.

The point of the above discussion is that context dependence does not eliminate the possibility of objective judgment, if individuals share intentionality. Objectivity, reality, judgment and meaning construction occur, however, within the confines of context and intentionality. As discussed previously, contexts need not be limiting. They are readily expanded and evolved to accommodate discrepancy and apparent contradiction.

To the postmodern contention that language is a circular system wherein every word depends for its meaning on another word, I express agreement. Since words are concepts, and concepts are synthetic a posteriori constructions and therefore contingent, all texts are contingent. Derrida (1976) and Foucault (1972) would add that since objectivity is nonexistent, then all texts are ultimately both contingent and subjective. In addition, they would contend that texts are always intentional and specifically intentional with respect to the power motives of the constructor. They also are socially and culturally impacted by that zeitgeist or perhaps episteme of the era in which they are written. In light of the above, Derrida

(1976) would advise that we deconstruct the text to disclose its pretensions and discover the predicates for its contentions of truth.

While there are many cogent observations in the above, I would recast this in a more constructive fashion. First, all conceptually representative sign systems (language, mathematics) are indeed systemic and hence circular by definition. They are codependent elements that when put into relationship have the possibility for equilibration and the rendering of meaning. Concepts are indeed constructions from experience and hence synthetic and contingent, as indicated above. As also shown above, the imposition of a context under the direction of intentionality, offers the prospect for a contingent form of objectivity and reality. For example, if I made the statement that *I jumped into a pool and swam to the other side*, the receiver of these words would judge that their relationship equilibrated and conveyed a meaning. This indicates that the sentence represents a stable relationship between the concepts that the words represent. If I said I jumped into the pool and swam to my car in the parking lot, the receiver of these words would be disequilibrated and assert that the statement had no meaning. This is a consequence of the fact that the relationship of the words is incongruent with the meaning of the concepts represented by the words. This relationship of the elements (words) does not equilibrate. There is nothing in anyone's concept of pool and swim that would allow this relationship to express meaning.

To the assertion that texts are necessarily subjective, I respond with Wittgenstein's (Morton, 1997) argument regarding the impossibility of a private language (completely subjective). For communication to even be possible, word meanings must result from public concurrence that they represent the same things when used by different people. In addition to referential stability, the inter-subjective connection of word relationships within what we might define as a group with shared intentionality, will often equilibrate into shared meanings that we can regard as objectively the same among the participants of the group. Again, we have the same requirements pertaining to intentionality, context and equilibration of relationship, as well as the same caveat with regard to the limits of objectivity. In this case, it is confined to the group. The concept of absolute word meaning, in fact, has no meaning. An absolute meaning would imply a meaning absent a relationship and therefore could relate only to absolute totality or to nothing.

As to the context dependency of text, I wholly agree with this premise. Text must have context to have meaning. For example, consider the following sentences:

1) She got a good deal on soap at Costco.
2) Please deal me in.
3) This means a great deal.

The word deal has a different meaning in each of the above three sentences. In the first two sentences, word relationships are sufficient to establish meaning, and the context which impacts meaning is implicit (shopping, actual or metaphorical card game). The third sentence is ambiguous. The context of *shopping* and *a circumstance of great importance* are potential contexts in which this word relationship would equilibrate to a meaning. The specific meaning is contingent upon which context the word relationship occurs in.

Given that context arise from intentionality, I now address the contention of postmodernists that power motives underlie text meaning. The basic purpose of any knowledge system is the understanding of patterns of relationship in the universe so as to further intentions. Knowledge allows prediction and therefore a measure of control over outcomes. In this politically and socially inert sense, the desire for the accumulation of knowledge is in fact the Will to Power. Power here is defined as something that enables: a definition consistent with its Latin derivation.

Thus far, we have meaning, reality and objectivity confined to contexts fixed by intentionality. Is this as far as we can go? The third epistemic methodology utilized in this Dissertation is a modification of Husserl's phenomenological method (Nodding, 2007). Instead of bracketing out contexts, I, instead, abstract invariant forms of relationship that occur across multiple contexts in diverse domains or alternatively, look for what remains invariant as contexts are changed within a single domain. The inspiration for this came from the study of Einstein's Theory of Relativity. Einstein began with the postulate that the laws of physics and the speed of light remained invariant, independent of the relative motion of frames of reference or imposed contexts. The relationships he obtained between reference frames while he maintained a constant speed of light and invariant laws of physics provided considerable insight concerning the nature of space and time: framework elements of his context.

In all of the knowledge systems evaluated in the dissertation, meaning was emergent when a triadic relationship equilibrated. In biologic systems the triad was intentionality-biologic organization-environment. In nonlinear dynamic systems, it was the equilibration of system input or driving force (the relationship between system variables) boundary conditions. In language it is the desire to communicate-words in relationship-context. These triads were abstracted to form the conclusion that meaning consists of the equilibration of intentionality-relationship-context.

As these are all open nonlinear systems which can exhibit all of the behaviors of nonlinear dynamics, including the capacity for evolution and significant qualitative change through self organization, we must think of the equilibration of the triad as a specific event in time. We therefore need to add a fourth element to our formulation of meaning: history. In nonlinear dynamics, this would articulate as initial conditions; in biology, it is phylogenetic history, as articulated in an organism's DNA.

Having addressed the relevant epistemological concerns, what follows are the 29th premises proposed as the epistemological basis for the construction of curriculum and instruction. The sections from which the premise was drawn are indicated in the brackets.

1. We (things) exist - "I think therefore I am" – Descartes
2. We (things) exist uniquely in space-time - [Relativity, Quantum Mechanics]
3. The universe is connected in systemic nonlinear relationship(s) that conserve certain quantities (e.g. c - the speed of light, λ - Planck's constant, $E = mc^2$ - mass and energy) [Relativity, Quantum Mechanics, Nonlinear Dynamics]
4. These systemic relationships and conservations permit the creation of meaning. Without them the universe is devoid of meaning (e.g. the Minkowski relationship which nonlinearly relates space-time and conserves the speed of light; if the speed of light is not constant, there can be no causality - effects could precede causes). [Relativity, Quantum Mechanics]
5. Things within the universe do not exist "in and of them selves" but within the universal relationships noted above. These relationships impart a potentiality or range of realizability to entities (e.g. Schrödinger's wave equation). [Relativity, Quantum Mechanics]
6. Meaning and reality in the universe are emergent and consequent to specific relationships between entities within contexts (e.g. measurables in Quantum Mechanics and gravity in Relativity). [Articulated in every chapter]
7. All states are not possible in the universe, and things cannot infinitely vary. Such a universe is devoid of meaning. [Follows from the above]
8. The fundamental construct of meaning or what we can "know" is therefore invariance or constancy. [Follows from the above and is implicit in all chapters]

9. The creation of meaning involves the stable equilibration of a nonlinear system consisting of driving force (goal, input), context (environment) and the relationship (intrinsic and extrinsic) between entities (elements). [Articulated in all chapters]

   Examples:

   Motivated goals – DNA – environment: the individual

   Need to communicate - words in relationship – context: meaning of sentence

   System input (control parameter) - relationship between system variables -boundary conditions: self organization of a nonlinear system

10. Resolution of disequilibrium evolves new contexts at higher logical levels by
    a. Expanding referentials (elements, attributes, characteristics)
    b. Relativizing relationships (new organizational structure at higher logical level to accommodate original discrepancy). [Piaget]
11. Contexts have the following properties:
    a. They set the nature of the metrics (units of analysis, attributes, characteristics) and the nature of permissible relationships that can exist among the metrics in the meaning creation process.
    b. They control the nature of meaning created.
       i. Type and kind
       ii. Depth and breadth
       iii. Logical category/level
    c. They unambiguously describe phenomena.
    d. They are necessary for meaning creation.
    e. They cannot possess the quality of logical necessity (be "the context").
    f. They do not control the nature of the "universal relationship".

g. They are an emergent consequence of relationship.

h. They undergo ontogenic and phylogenetic progression with time.

i. They create a "reality" (within the context).

12. The meaning creation process involves:

    a. A preliminary context which defines the metrics (elements, attributes) and type of permissible relationships (ones that form logically closed groups within the context)

    b. An act of distinction of undifferentiated totality according to metric or attribute

    c. A relational structure that equilibrates the three-part system previously defined. This is the organization that defines the unity (entity) within the context.

13. Meaning is derived from or the articulation of the specific relationship(s) which allow or result in the equilibration of the previously defined three-part system. This meaning is the semantic structure of the organization and its "reality" in the imposed or evolved context.

14. The organization which creates meaning expresses an invariant:

    a. Physical characteristics (sensorial)

    b. Consistent attributes of a collection (physical or nonphysical)

    c. Consistent relationship among elements

    d. Relational consistency through transformation or change

    [Premises 11-14 express an emergent structure that results from relating all chapters]

15. Characteristics within the context of a nonlinear system include:

    a. Codependent systemic relationships that conserve certain quantities

    b. Expression of an organization of possible states of being

c. The capacity for self organization and the creation of phenomenology at a higher logical level characterized by emergent combinatorial parameters or metrics (order parameters)

d. The capacity for qualitatively different emergent structures contingent upon:

   i. The relationships among elements

   ii. System inputs

   iii. Environmental contingencies

   iv. Initial conditions

e. A landscape of stable, transitional and unstable states determined by:

   i. Fixed points - one-dimensional systems

   ii. Fixed points, manifolds, and limit cycles - two dimensional systems

   iii. Fixed points, manifolds, limit cycles and fractals - three dimensional systems [Nonlinear Dynamics]

16. A nonlinear system that self organizes has the following characteristics:

   a. An instability far from equilibrium

   b. Symmetry breaking at this instability

   c. The confluence of determinism and chance at the instability

   d. A dissipative structure

   e. Openness to continuous input

   f. A cooperation between competitive forces (drive versus maintenance)

   g. Feedback leading to amplification, resonance or autocatalysis

   h. Circular causality - simultaneous top-down and bottom-up influences

   i. The emergence of order parameters at higher logical levels (the agency of the agents)

j. Unstable configurations that drive the system toward the stabilities

k. The capacity for adaptation and the expression of ontogeny and phylogeny [Nonlinear dynamics]

17. The neurological attributes and configurations of the brain enable the creation of meaning (as meaning was previously defined):

    a. Sensory systems through acts of distinction (similarity that remains after differentiation) detect and store features of objects and events.

    b. Neuronal cellular dynamics and connectivity (long-term potentiation/depression, stabilization of experience modified protein structures, and reciprocal connectivity) enable:

        i. Representation and memory of features and their frequency of occurrence

        ii. Feature association (space-time, part- whole, object-attribute)

        iii. Generalization through feature overlap

        iv. The capacity for statistical associational inference

    c. Cellular organization at the functional level (executive function, working memory, language function) enables:

        i. Rule building (concept, theory) - relational invariance

            1. Consistent physical relationships

            2. Physical invariance preserved in transformations

            3. Consistent abstract relationships (invariant relational structure of a collection of physical relationships)

            4. Abstract invariance preserved in transformations (e.g. equilibrium, commutativity, linearity)

   ii. System building - equilibrated collections of rules that span a context and define, for example, a society, abstract game, culture or knowledge system [Vygotsky, Piaget, Cognitive Psychology, Neuroscience]

18. A functional characterization of the mind is as a rule builder operating on a statistical inference mechanism [Cognitive Psychology, Neuroscience]
19. The mind will exhibit certain characteristics:
    a. A **productive system**: elements (e.g. features) that can participate in virtually unlimited representations and combinations
    b. A **nonlinear system**:
       i. Equilibrations that conserve invariants
       ii. Adaptive ability and plasticity
          1. Qualitatively different structures/organizations contingent upon experience
          2. Organization/self organization to higher logical levels of meaning
    c. An **information system**:
       i. Bayesian network characteristics for certain types of reasoning
       ii. Sequential statistical inference abilities
       iii. Iconization, indexing and symbolization [Cognitive Psychology, Origins of Language, Neuroscience, Conclusions]
20. Abstract representation through language expresses the neurologic creation of meaning:
    a. Iconization - recurrent invariant features across multiple events/objects
    b. Indexing - association of iconic features

c. Generalization of feature nets - words as reference (signifiers)

d. Nonlinear equilibration of words in relationships with other words -words as symbols (signification) or semantic structures [Vygotsky, Origins of Language (Deacon), Neuroscience]

21. Basic cognitive activities include:

    a. The creation of units (acts of distinction) through differentiation to discern invariance

    b. The creation of categories (similarity classes)

    c. The determination of relational constancies

    d. The determination of relational constancies through transformation (changes of state)

    e. The attachment of emotional valence (importance, priority, relevance)

22. The form of mental representation (re-creation) is developmental and controls the nature of relationships that can be constructed, the nature of meaning that is created and the reasoning and problems solving strategies that can be employed:

    a. Algorithms, procedures and sensorimotor schemes that connect means and ends (produce goals)

        i. Trial-and-error problem solving

        ii. Beginning use of analogy (trial-and-error application of algorithms)

    b. Images (physical relationships)

        i. Associational inference (statistical)

        ii. Pre-generalization

    c. Concrete words - articulation of invariant physical relationships that express a rule, concept or theory derived from consideration of multiple images

i. Concrete induction

ii. Concrete deduction - rule-based reasoning

iii. Physical planning and strategy development

d. Abstract words - relationships that express an abstract rule, concept or theory derived from generalizing the form of relationship manifest in a collection of concrete rules or series of transformations (changes in state)

i. Abstract induction

ii. Abstract deduction - concept and theory-based reasoning

iii. Abstract planning and strategy development

e. Super-ordinate words or word aggregates that express an equilibrated system of abstractions that span a context (system, abstract games, cultures)

i. Application of law, public policy or governance structures

ii. Philosophical, mathematical or scientific systems of reasoning[Freud, Vygotsky, Piaget, Cognitive Psychology, Neuroscience for premises 21 and 22]

23. Language exhibits the following attributes:

a. Directs a significant portion of thought

b. Reflects semantic structure

c. Reflects the cognitive organization of experience

d. Permits knowledge to become "objective", and

e. Is socio-culturally influenced and reflective of ontogenesis and phylogenesis

24. Reasoning and structural grammars (e.g. language grammar, mathematics) proceed and derive from the **semantic structure** of representations (e.g. words as symbols, operators in mathematics)

Examples

The psycholinguistic interpretation of the rules of grammar

Johnson-Laird et al. model of logical reasoning

[Freud, Vygotsky, Quantum Mechanics, Nonlinear Dynamics, Psycholinguistics, Cognitive Psychology for premises 23 and 24]

25. Consistent with a phylogenetic interpretation of the human organism:
    a. The human views change in terms of movement to a state in a universe of possible states within a context
    b. The fundamental categories by which experience is organized are
        i. Space
        ii. Time
        iii. Substance (part/whole, object/attribute)
        iv. Causality
        v. Logic (and, or, not).
    c. Abstract terms (ideas, concepts) are metaphors for physical relationships (2 above) derived through analogy (comparison). [Psycholinguistics]
26. Human executive function enables intelligent action and provides a template for instructional scaffolding activities
    a. Intelligence can be defined as the ability to attain goals in the face of obstacles by means of decisions based on rational rules. The process involves specifying goals, assessing one's current state and applying a set of operations to reduce the difference between goal and current state.

b. A significant number of instructional activities, collectively known as scaffolding can be viewed in the context of, and in conformance with, human executive function:
    i. Directing attention
    ii. Invoking prior knowledge and mental organizations
    iii. Planning and executing appropriate mental operations
    iv. Scheduling and acquiring resources
    v. Switching and compensating activities in response to feedback in order to achieve goals
    vi. Decision-making [Piaget, Neuroscience, Conclusions]

27. The epistemic framework previously discussed suggests a model for concrete and abstract rule-based (concept, theory) learning which involves cyclic, recursive and nonlinear equilibration:
    a. Inductive process applied to experience
        i. Similarity/difference, invariance – iconization
        ii. Categorization - relational indexing
        iii. Generalization - symbolic connection
    b. Deductive application of inductively-derived rule, concept or theory
        i. Correspondence of symbolic representation to characteristics and attributes of real objects and events
        ii. Determination of new information and knowledge through the relational structure or semantic of the rule, concept or theory
    c. Comparison of results to goals and the implementation of required compensations

   i. Student meta-cognitive activity
   ii. Teacher and/or peer scaffolding activity

28. The most successful instructional activities will be those most congruent with and supportive of the brains natural and inherent mechanisms for creating meaning from experience.
29. The goal of education is to help individuals to create meaning for their lives.

Goal

Our journey began with the work of Skinner, Freud, Vygotsky and Piaget. Within each of these systems of thought, it is explicit that human action originates from a **motivated goal**. Skinner's view of human action or behavior was the reaction of a genetically formed organism to the contingencies of an environment, in accordance to Thorndike's (1913) Law of Effect. The current state of the individual was a reflection of chance mutations in the individual's phylogenetic history that induced behaviors which were adaptive to the contingencies of past environments. As these behaviors were adaptive, nature selected the ancestors of the individual, as per Darwin's theory of evolution. Current behavior proceeds according to the principle of operant conditioning: those behaviors that are rewarded are repeated, while those behaviors that are punished are diminished. It is the contingencies of the environment that administer the rewards and punishment. In this sense, behavior is adaptive to an environment. Skinner therefore views human goal and subsequent action to be guided by this pleasure -pain principle. The human endeavors to maximize the former and minimize the latter.

Freud likewise visualized pleasure-pain dialectic to be operative in human goals and motivation. Freud interpreted two primal forces within the human psyche:

1) the Eros, or an instinct for life and creation, which drives pleasurable behaviors such as eating and sex and contains the unbridled passions, and
2) the Thantos, or death wish, which creates a desire to give up the pursuit of happiness and life's struggles and leads toward a static state of disorganization.

Since the individual exists within the context of an environment, he cannot immediately and completely satisfy his passions in the pursuit of happiness. Freud (1960) therefore postulates a mechanism, termed the Ego, which seeks to bring the influence of the external world to bear upon the passions and endeavors to substitute the reality principle for the pleasure principle. The Ego operates according to reason and common sense. Motivation and goal in Freud's (1960) system, therefore, reflect the dynamic interaction between the passions (Id), the Ego, and the Superego (internalized parental and societal values). The process is, however, initialized by forces emanating from the ID: the Eros and the Thantos.

Vygotsky's (1986) context is socio-cultural. Through the mechanism of language, a society's historically formed system of meaning, including its values and implied goals for individuals, is imparted from one generation to the next. As such, an individual's goals are the result of social and cultural influences. Motivations are strongly driven by social expectation.

Piaget's system is biological. While he never speculates with regard to specific human goals, he does specify an ultimate goal for development: the evolution of logical mathematical thought. This capacity enables humans to understand relationships manifest in their environment and to make predictions regarding outcomes before undertaking actions. With this capacity humans can exert control over their environment rather than simply respond reflexively to the contingencies of this environment. We can perhaps impute from this that his conception of goal is control and mastery of environment. Piaget's theory (1985) is a theory of equilibrium. We could, therefore, also impute that an implicit goal of the individual could be to **optimize** the equilibrium between himself and the environment, or achieve a state in which the goals of the individual, whatever they may be, are actualized in harmony with the environment.

There is certainly no scarcity of theory concerning human goals and motivations in the academic literature. The theory of Maslow (1970) is among the more famous. Maslow (1970) envisioned two levels of human need. The first level he termed deficiency needs. These needs have to be fulfilled before the human can set a goal, the fulfillment of higher-level needs. These needs are in order: survival, safety, belonging and self-esteem. Once these are fulfilled, the human pursues higher-level needs. These are in order: intellectual achievement, aesthetic appreciation and self-actualization or the realization of one's potential. While extensively referred to in the literature, this implied sequence of needs has drawn criticism, most notably as a result of the observation that people routinely ignore a lower level need in order to pursue a higher level need (Woolfolk, 2004).

When examining different systems of thought regarding their conception of human needs and motivated goals, several thematic elements emerge. First, they all imply an equilibrating process or the process of creating harmony between the individual and the environment. There is also an element of growth involved and the implication that this growth is the result of increasing levels of organization by and within the individual. In the case of Piaget (1985), there is additionally the implication that these increasing levels of organization, or said alternatively, meaning creation, enable the individual to control his environment and thereby create an optimized equilibrium that allows the actualization of higher-level goals and needs. We can therefore view **the creation of higher levels of organization or meaning as empowering the achievement of goal**. I submit for consideration, the following quote from psychiatrist and scholar Rollo May (1972) concerning the nature of human power:

> We can see the vicissitudes of the emergence of power as soon as a baby is born into the world - in his cry and in the waving of his arms, in demand that he be fed. The cooperative loving side of existence goes hand-in-hand with coping and power, but neither one can be neglected. Our appreciation of the earth and the support of our fellows are not gained by abdication of our powers, but by the **cooperative** use of them. The infant's capacity to cope with necessities becomes, in the growing adult, the struggle for self-esteem and for the sense of significance as a person. This latter is his psychological reason for being in contrast to the infant's biological one. The cry for recognition becomes the central psychological cry: I must be able to say I am; to affirm myself in a world into which, by my capacity to assert myself, I **create meaning**. And I must do this in the face of nature's magnificent indifference to my struggles.

I would submit the following then as a definition for education: Education is empowering individuals to create meaning for their lives. We see also the inseparability of meaning and human goal. Since our philosophical goal is epistemological and not ethical, we need not be specific with regard to how individuals specify meaning or goal. As noted previously, they are often transmitted through socio-cultural influence. As Freud (1960) would attest, they can emerge from the passions. To one individual, meaning in life could be created through the act of raising and guiding children to become happy, healthy and productive members of society. To another, meaning in life could arise from conducting oneself in a manner pleasing to God. And to yet another, meaning could be realized by the discovery of an important scientific breakthrough or principle. The list is endless. As stated previously, we need not stake out a position as to what could or should constitute the meaning/goal system of an individual. We need only note that **the creation of meaning requires an organization that serves to guide actions toward the fulfillment of goal.** The triumvirate of **meaning, organization** and **goal** is inseparably linked.

We have touched lightly in this dissertation on the affective aspects of education, since our goal is principally cognitive and epistemological. The above does, however, suggest some broad guiding principles regarding the structural coupling of teachers and students:

1) Treat children like they matter and count for something (their thoughts and decisions are consequential) - create a culture of caring.
2) Create in children a sense of significance by enabling them to effectively interact and influence others-facilitate constructive social interaction.
3) Give children the sense that they have some control over outcomes in their lives - let them participate in setting instructional goals and objectives.
4) Empower children to create meaning -meaning relevant to both your goals and theirs.
5) Recognize and celebrate success.

Based on 30 years of experience as a manager, I offer the following definition of leadership: Leadership is the art of aligning institutional goals and actions with the human needs and goals of those responsible for carrying out those actions. **The long-term success of an institution is contingent upon the extent to which institutional and individual goals and actions cooperate, reinforce and catalyze each other**.

Context

Perhaps the clearest structure that emerges when relating Freud, Skinner, Vygotsky and Piaget is the impact of context on the construction of meaning. As discussed above, intellectual process begins with goal. The goal in turn specifies, and, in fact, requires the specification of a context within which to create meaning. Once specified, the context controls:

1) the elements or metrics (characteristics/attributes) that are utilized in the meaning creation process [units of analysis],
2) the nature of relationships that can exist among elements,
3) the type and kind of meaning that can be created,
4) the depth and breadth of the meaning created , and
5) the logical level of the meaning created.

Please note that the imposition of a context is epistemologically equivalent to the imposition of definitions and postulates in an argument or proof involving logic and reason. Deductive argument requires initial definitions and postulates from which logically necessary consequences proceed. The inductive process requires a context in order to define elements and the nature of relationships that can be constructed among elements.

When we add Einstein to our stew of Freud, Skinner, Vygotsky and Piaget, we can infer the following with regard to context:

1) it must allow for unambiguous description of the phenomena,
2) it is necessary for understanding and the creation of meaning,
3) it does not possess the quality of logical necessity or constitute "the" way of characterizing phenomena, and
4) It does not control the nature of the relationship existent in the "thing in and of itself."

If we now add Bateson and the results of Quantum Mechanics to our stew, we can additionally infer the following:

5) Context is an emergent consequence of relationship, and
6) in a dynamic universe, phylogenetic and ontogenetic progression will result in context being expressed as an emergent pattern with time.

Point five above expresses the fact that contexts change as a result of the specific relationship that the objects of our consideration enter into. Whatever preliminary context we impose will be altered by the nature of the relationship between the objects. In fact, the relationship between our self as an observer and the objects of our consideration enters into the equation. For example, if we set up an experiment to measure the particle properties of an electron, the electron will behave as a particle. If we set up an experiment to measure the electron's energy attributes, it will behave as a wave or electromagnetic energy. Point six above expresses the fact that we live in a dynamic universe in which relationships change. Consequently, contexts will change and evolve.

It appears that we have created for ourselves a bit of a "chicken and egg" problem concerning context. The resolution is as follows. Contexts are, in essence, imputed characteristics of the objects of our consideration. Rather than being independent entities, they are constituted of the initially imputed properties of the objects themselves. For example, in physics, when we impose Cartesian coordinates and a time clock, we presume material objects have properties of extension (space dimension), move in response to some causality, and express a trajectory through the medium of space and time. The important point is that our context consists of the presumed properties of the objects themselves. The context therefore is not independent of the object. These properties, in fact, exist in a nonlinear relationship within and among the objects themselves. The context is not independent of the object. In a nonlinear system, stability is achieved in a conservation which requires a stabilization of the relationship between all elements of the system **simultaneously**. In physics, space and time are not separable from objects. As Einstein demonstrated, to define them requires a knowledge concerning other attributes of the objects (like mass) and the specific relationship that these objects enter into. Space and time are then consequent to the dynamic equilibrium of the nonlinear relationship between the elements of the system. In this equilibrating process, there is conservation, for example, the speed of light in relativity or Planck's constant in quantum mechanics. The objects and their context are therefore inseparable. In quantum mechanics, this articulates itself as the experimenter entering into the context of the system and becoming part of the ultimate nonlinear conservation or equilibration. If we accept the arguments above, we can express the universe as a nonlinear system in which certain quantities are conserved. We can also articulate a universal statement of ecology: All elements of the universe ultimately exist in systemic relationship and are interdependent.

Skinner's goal was a comprehensive explanation of all human behavior and phenomena in the context of operant conditioning. He began with guiding paradigms that formed his context. First was the basic modern paradigm: Objective truth exists external to the individual. It is through the application of logic and reason to external experience that objective truth is discovered. Skinner's position also articulates the logical positivist incarnation of the modern paradigm: If we cannot articulate a premise that can be proven true or false with logic and reason, the premise has no meaning. Once Skinner set this goal and context, it set his metric or unit of analysis: externally manifest behavior. This context also set the nature of relationships he could construct: behavioral response to external stimulus. His context controlled the nature of the meaning he constructed: Human behavior is dictated by the principle of operant conditioning. In finality, the logical level of the investigation was fixed--externally manifest human behavior. In that Skinner held fast to his context or paradigm, he was unable to address and answer questions like how different people experiencing the same stimulus could have different perceptions of the stimulus and responses to it. Data that imply that the impact of the stimulus is determined by the inner thoughts of the individual are irreconcilable within the context of Skinner's paradigm. Neither the metrics nor the type of relationships necessary to develop an explanation exists within his paradigm. He could have chosen to evolve his paradigm to a higher logical level in order to accommodate this evidence. He chose instead to hold fast to a logical positivist position and assert that because we cannot scientifically measure an individual's thought, any questions concerning this are questions without meaning.

Vygotsky's work was cast in the context of a socio-cultural paradigm. While this permits a much more expansive system of meanings than the context and paradigm of Skinner, it too imposes limitations. The position that development is guided by language and the socio-cultural system of meanings implicit in language cannot explain development and demonstrations of intelligence during Piaget's sensorimotor stage (birth to 2 years old). We do not explain to children how to walk or how to develop a sensorimotor scheme that permits them to obtain a cookie out of a box located on a shelf.

In similar fashion, Piaget’s imposition of the paradigmatic assumption that development proceeds toward the accumulation and formulation of logical mathematical structures in the mind, creates limitations. Within this context, Piaget would be at a loss to explain the finding of cognitive scientists that human reasoning does not reflect underlying logical mathematical structure; it reflects the relational structure or semantic content within the individual’s concept schemas.

The discussion above illuminates the value of the perspective of curriculum theorists such as Patrick Slattery (2006), William Pinar (2004) and Sharon Reynolds (2008). Explicit within curriculum theory is the idea that all systems of knowledge proceed from a context and are expressed in language systems that embed the meaning constructions and values (as well as biases) of a society. As discussed above, the context imposed and the language system employed will impact the meanings that are constructed. Also explicit within curriculum theory is the notion that absolute truth and absolute values elude our grasp. In summary, the strategies advocated by curriculum theorists are intended to be a critical re-examination of contexts and language systems with full acknowledgment of their directive power.

A strategy advocated by curriculum theorists, such as de-construction, seeks to examine contradictions, omissions, ambiguities, and injustices in texts and knowledge systems by devolving (deconstructing) them back to the paradigmatic framework or context from which they were built. It involves discovering the origins or predicates for these frameworks and the complex forces that shaped and influenced the evolution of the text or knowledge system (Slattery, 2006). A closely related strategy involves developing hermeneutic understanding of an evolved knowledge system. Hermeneutic inquiry acknowledges that, at any point in history, the creation of text unavoidably expresses the confluence of history, culture, social forces, political forces and the specific intentionality of the writer. For example, I have always felt that Descartes' bifurcation of body and mind was in no small measure influenced by the political need to create a niche for science that did not threaten the province of the Church. If not subconsciously a part of Descartes' thought process, this bifurcation at least explains why Descartes' philosophy prevailed over that of his contemporaries.

William Pinar's (2004) concept of currere articulates a similar epistemic. In this strategy, the individual re-conceptualizes his or her autobiography. It is a rethinking of the past in the context of the present. In a manner analogous to psychoanalysis, the concept is that our currently richer and more elaborated understandings will allow us to rethink events of the past that may have been seminal in forming who we presently are. Our original processing of these events was predicated on our knowledge systems at that time. This rethinking of the past, in the context of our more fully formed knowledge systems of the present, can change us and create possible different directions for our future.

The above strategies represent **revolutionary** changes in systems of thought. As such, they represent extremely powerful methods for the construction of improved contexts for understanding and the creation of meaning. Many great discoveries, including Einstein's theory of relativity, involved a deconstruction of pre-existing contexts, as was discussed previously in this Dissertation. The schema modification process of Piaget (1985) describes an **evolutionary** change in thinking. It begins with disequilibrium between our current schemas and the evidence or circumstance with which we are currently presented. Our current schemas (mental organizations) cannot assimilate this evidence or circumstance. In order to accommodate this new information, we must reconstruct the schema. The process typically involves recognition that another dimension is involved, such as additional characteristics or attributes, and the recognition that this additional dimension requires a different relationship to be constructed between the elements characterizing the event or circumstance. As discussed previously, Piaget (1985) characterizes this process as expanding the referential (increasing the dimension of characterization) and relativizing the notion (changing the relationship between elements). A consequence of this process is, more often than not, the emergence of a generalization at a higher logical level.

We can see in Plato's (1952) dialogues many illustrations of this process. In the beginning of *The Republic,* Socrates asks Cephalus, an elderly man facing his mortality, to review his life and offer the conversants in the dialogue a definition of justice. Cephalus responds: "… I do not say to every man, but to a good man, is, that he has no occasion to deceive or defraud others, either intentionally or unintentionally; and when he departs to the world below he is not in any apprehension about offerings due to the gods or debts which he owes to men" (p.35). Socrates then summarizes Cephalus statement, and we have our first definition of justice: to speak the truth and to repay one's debts. Socrates then proceeds to produce a contradiction which results from this theory of justice. Socrates states, "Suppose that a friend when in his right mind has deposited arms with me and he asks for them when he is not in his right mind, ought I to give them back to him? No one would say that I ought or that I might be right in doing so, any more than they would say that I ought always to speak the truth to someone who is in his condition" (p.37). Cephalus agrees with Socrates, excuses himself and turns the debate over to his son, Polemarchus. Polemarchus allows that Simonides (not present, but apparently a respected figure) shares the same definition of justice. After some discussion, it is concluded that truth and repayment of debt, while constituents of just behavior, do not constitute a comprehensive definition of justice because of the cited exception. The next conclusion is that what Simonides may have meant to say is that justice gives to friends what is good and to enemies what is evil. We have now our next, more comprehensive definition which will, of course, be subsequently dismantled in the dialogue.

As seen above, the initial theory of justice failed to assimilate the case of a friend not in his right mind. The schema had to be altered in order to accommodate this circumstance. The manner in which this was done was to first differentiate the two circumstances: a person in his right mind and a person not in his right mind. The original schema was retained (truth and debt repayment) since all agreed that it was a part of just behavior. A generalization at a higher logical level, which encompassed both the original concept and the contradiction as subsets, was constructed. Note that this was done by determining a generality in which both of these behaviors possess a **similarity**. The similarity is that both of these subsets or cases are instances of doing what is good for friends. Another way to state this is: The task is to find a more general principle under which the elements express a similarity. What is the same in these differentiated elements if we view them as exemplars of a theory or concept at a higher logical level? Note the widening of referential (the addition of the differentiated circumstance to the schema) and the relativization of the notion (subsuming the original schema as a subordinate of a higher level ordinate).

The immediately ensuing conversation in the dialogue is a wonderful example of Piaget's (1985) concept of reflective abstraction. Socrates cites a number of concrete relationships with which the conversants are familiar. He then generalizes or abstracts the form of relationship which each of these concrete examples exemplify (note, a similarity construct is again involved). His generalization flies in the face of their current beliefs, but they reluctantly accept it because they perceive the logic of his argument to be sound. This leads us directly to the next linchpin in our epistemological model: equilibrated relationships.

Relationships and equilibration

When juxtaposing **all** of the knowledge systems investigated, a consistent structure appears: M**eaning is derived through and determined by relationship**. We saw innumerable examples of this in the Dissertation. We can add to this by also stating that not all relationships create meaning. Meaning emerges from **relationships that are stable equilibrations within the context of the individual's existing mental structures (schemas, organizations, knowledge systems)**. To use Maturana and Varela's (1998) terminology, the relationship must be a structural coupling that conserves the autopoietic organization of the unities (current structures). To use the language of nonlinear dynamics, a stable structure or organization results from a state of dynamic equilibrium between driving force, the relationships within the system and environmental circumstance. In the prior sentence, we can abstract driving force as goal, organization as relationship and environmental conditions as context. The sentence would then read: **Meaning results from a state of dynamic equilibrium between goal, relationship and context.**

Piaget (Gruber & Voneche, 1995) envisioned the ultimate goal of development to be the evolution of mental structures that enable a capacity for planning, strategy development and the mental representation of intended action prior to execution. It immediately follows that these **mental structures or organizations necessarily express the relational constancies (invariance) that exist in the universe of the individual.** There can be no planning or strategy development in a universe devoid of regularity. It therefore follows that **similarity or what remains after differentiation (an act of distinction), is the fundamental mental construct.** As Piaget (1952) noted, all mental operations (organizations) contain the supposition that something is conserved. As Taylor (1995) demonstrates, unless there is a terminal speed in the universe (the speed of light), there can be no causality. The lack of a terminal speed creates the possibility that effects could precede causes.

The cognitive function of the individual can then be summarized as the creation of relationships that express the constancies or invariants in the individual's experiences. These constancies or invariants can be sensory derived physical characteristics, as expressed in concrete relationships, or they can be relational constancies, as expressed in abstract relationships. In fact, they can even be a sequence of actions that constitute the means for attaining an end, as is expressed in sensory motor or procedural relationships. **The above suggests a characterization of human cognitive function as ultimately a rule- (concept, theory, and schema) building activity.** As the text of the Dissertation illustrates, it is a rule builder connected to an associational structure.

Terrence Deacon's (1997) theory concerning the evolution of words as symbolic representations provides a clear illustration of this process. Words begin through a process of iconization. The mind performs an act of distinction or differentiation when representing the features of the events and circumstances of experience. Through this process, certain attributes and characteristics of objects and events become iconic or representative. These icons are subsequently associated (indexed) between related or similar events and thus connected through this association. This is the mechanism by which words take on their representational character. For example, given the experience of multiple fire events, the mind will iconize characteristics such as heat, flame, smoke and other attributes that are similar (iconic) across the events. These icons are associated with the word fire. It is when these representations (words) are relationally connected (to other words) that they stabilize, take on meaning and emerge as symbolic representations or concepts. As Vygotsky (1986) illustrates, it is when the words are connected through relationships that express judgments concerning the **nature** of the connecting relationships: **space** (under, over, within), **time** (before, after, presently), **causality** (because of, despite of, as a result of), **substance** (is, has, belongs to) that words emerge as concepts or abstractions. Deacon (1997) states that once relationally connected (as described above), word meanings are stabilized and defined through these relational connections to other words. The word is then freed from dependence on its direct associational connection or index and can take on a symbolic character or abstract nature. Again, **it is through relationship that the word takes on a meaning or semantic structure and can**

symbolically or abstractly represent a category. I would add that it can represent a category of things and a category of relational types or transformations of state. This latter category would characterize words such as equilibration, adaptation and quantification: words that categorize a process, transformation or type of relationship.

An additional structure that emerges from a connection of the knowledge systems investigated in this Dissertation is that of an **associational network connected to a rule-based system**, **all of which operates on mental representations.** Certainly the process that is described above implies such a structural configuration. As discussed in the Cognitive Science chapter, the associative system seems to work by encoding statistical information from the environment: frequencies, distributions, and correlations. The system appears to divide perceptions into clusters on the basis of statistical regularity. This would appear to be precisely the iconization and indexing process described by Deacon (1997). In the Neuroscience chapter, I described how this could be performed through long-term potentiation of neuronal connections.

The degree to which an association is made is proportional to the **similarity** between a current stimulus and associated prior stimuli. The system does not rely on causal structures. Inferences are based on statistical structures such as similarity and co-variation. Through the process of indexing or connecting things iconic across events, the associative system has the capacity for inferential judgments such as, "Where there is smoke, there is fire." Another way to visualize the associative system is as a mechanism for matching patterns. Since the system organizes according to features (icons), it is a productive system. Features can participate in many patterns and concept constructions. For example, wings can participate in airplane, bird, or even automobile patterns. Please recall that features are the form of neurologic representation of information supplied by the senses. The associative system facilitates the operation of the rule-based system through a capacity to enable generalization with feature overlap (patterns of similar features).

As stated previously, the basic nature of the process of long-term potentiation of synaptic connections between neurons will give neuronal representations and their connections a statistical character. The process of long-term potentiation creates what is, in effect, a frequency distribution. Dehaene (2007) describes recent research that further illustrates a statistical nature for certain types of mental processing. The depiction below (Dehaene, 2007) illustrates the response of neurons in the parietal lobe of macaque monkeys to different numbers of objects. As shown below, an individual neuron does not respond to or encode a specific number. The neuron exhibits a preference for a particular number, but its rate of firing shows a Gaussian profile (on a logarithmic scale) centered about this preference. The figure below also shows that analogous areas in the human and macaque monkey brain are involved in numerical processing. The implication here is that neurons in the human brain perform similarly.

The same response patterns have been measured in neurons controlling the direction of motor movement (Bear, et al., 2007). A single motor neuron involved with directing the motion of an extremity is most strongly activated for a specific direction but shows some level of activation for a range of directions proximal to this principal direction. The direction of movement appears to be determined by a summation or, effectively, an averaging of activity registered in the population of neurons involved in directing the motion. One can surmise, perhaps, that this permits motion to be smooth rather than a series of jerky digital-like movements.

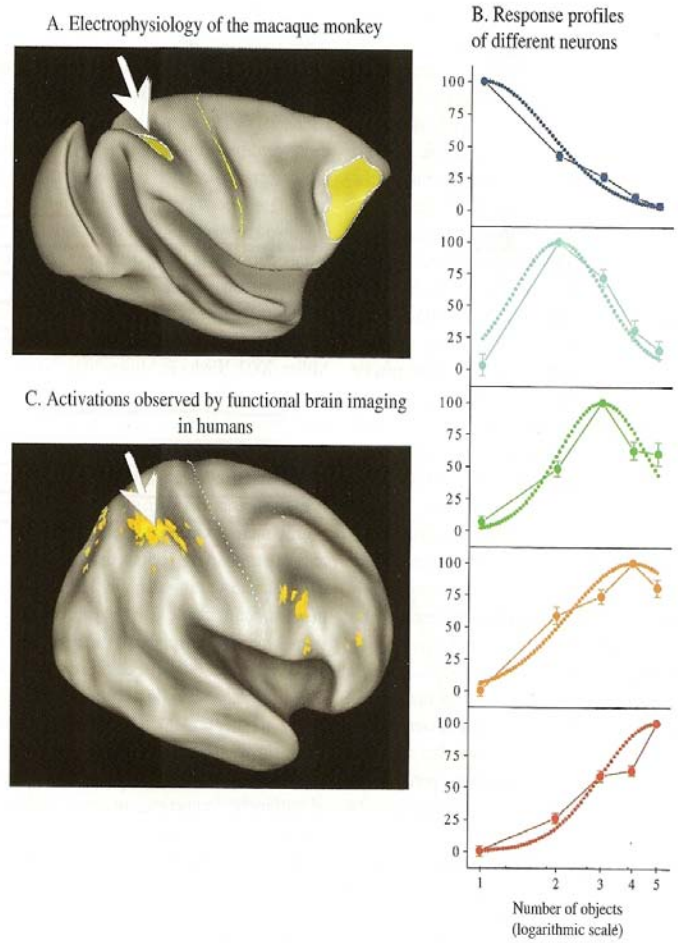
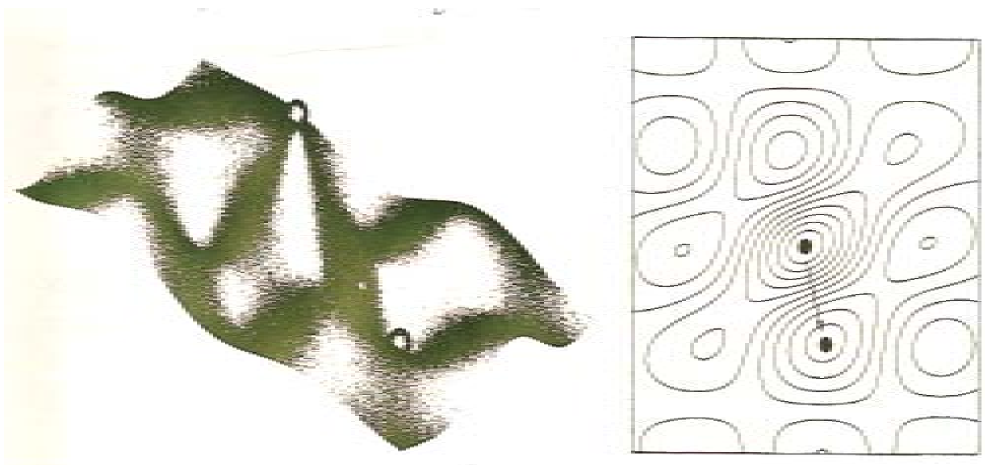


Fig. 4. Number-coding neurons in the macaque monkey (after Nieder & Miller, 2002, 2003, 2004). Neurons have been identified in the depth of the intraparietal sulcus (A) whose response profiles correspond to the predictions of psychophysical theory: each neuron prefers a particular number, and its rate of firing shows a Gaussian profile on a logarithmic scale (B). The deep intraparietal region wherein these neurons have been identified shows a plausible homology with the horizontal segment of the human intraparietal sulcus, where brain imaging shows activations linked to mental calculation and to the processing of quantities (C).

Dehaene (2007) discusses research by Wong and Wang (2006) that has shown how a statistical decision process could occur through the dynamic activity of a network of neurons with feedback loops, where each decision is represented by a group of neurons. Such a connection is a nonlinear system with a landscape of stabilities and instabilities. The instabilities can be considered saddle points that separate the basins of attraction corresponding to different choices. The illustration below, taken from Haken (2006), shows a nonlinear landscape with basins of attraction (toward points of stability) separated by saddle points (points of instability). As discussed in the nonlinear dynamics chapter, the various states that a nonlinear system can take on can be represented as a landscape consisting of valleys that lead to points of stability, separated by ridges (saddles) or peaks that are the points of instability for the system.

Resolving Instability



Using the illustration above, we can, for example, qualitatively think of the ball at the top of the peak as representing an initial state of ambiguity or uncertainty after an individual first senses an object streaking across the sky. Is it a bird, is it a plane, or is it Superman? The person focuses his senses more closely and sees that it is larger than a bird. His next piece of information is the sight of a vapor trail. He then hears a distinctive roar. With this piece of information, he moves from the initial state (ambiguity/instability) and descends into the valley of a stable inferential conclusion: The object is a jet airplane.

Dehaene (2007) also discusses Turing's algorithm which constitutes an optimal mechanism for sequential statistical inference. Turing's algorithm allowed the British to crack the German enigma code during World War II. In this algorithm, the weight of information (I) in favor of a hypothesis (A) is defined as the logarithm of its likelihood, given that the hypothesis is true, divided by its likelihood given that the hypothesis is false:

$$I = Log\left[\frac{P\langle I|A\rangle}{P(I|\sim A)}\right]$$

Bayes law states that the weights of independent pieces of information can be added.

$$\sum I = initial\ bias + I_1 + I_2 + I_3 + \ \ldots.$$

A decision is made when a certain threshold of weight for a hypothesis is reached. We saw from our previous qualitative description how a nonlinear system could implement this algorithm. I would also like to point out that given the known properties of neuronal systems, a biological implementation is also quite feasible. Currently, however, such models of human reasoning are still hypothetical.

The above line of reasoning, I believe, sheds some light on the success achieved by researchers modeling human reasoning with Bayes Nets (Gopnik et al., 2004; Sloman, 2005). Bayesian networks are powerful enough to model both probabilistic inferences and deterministic (rule-based) deductions (Sloman, 2005). As such, this mathematical framework has generated considerable interest in the field of cognitive science and drawn some researchers away from what Sloman (2005) refers to as the High Church Doctrine of Cognitive Science: the computer/information processing metaphor of the mind.

As the Cognitive Science chapter discusses in detail, an associationist system falls short of explaining the complete range of human reasoning capability. Pinker (2007) provides an interesting discussion of the limitations of a connectionist (associationist) computer model devised by McClelland and

Kawamoto. Models of this type associate "features with features" rather than manipulate structured representations (rules). They have a dense array of connections between neuron-like units, each representing a feature of the meaning of different words (subject is soft, verb implies intense action). There is a training phase in which thousands of sentences are input, and word-meaning features are strengthened so that the model can "learn" what kinds of events tend to be done by what kinds of objects. The model, using its connective structure, renders an interpretation of a sentence. A way to think of the model is as a device that performs the iconization and indexing functions described in Deacon's (1997) theory.

Pinker (2007) reports that the model correctly forced the word *with, as* in, "Eat pasta *with* a fork," to mean "using" since it had learned that hard things tend to be used as instruments (fork). It also correctly forced the "*with"* in eat pasta with clam sauce to mean "accompaniment" since it had learned that soft things tend to be used as food. When the model encountered a sentence that was in any way out of the ordinary, however, it forced its meaning into conformity with the most frequently occurring stereotype it had developed from its training. For example, when given *the wolf ate a chicken* it interpreted the meal as cooked chicken meat because that's what chicken usually refers to when it comes after the verb eat. When told that John touched Mary, the computer interpreted touch to mean hit. Pinker (2007) states:

> And when given *the bat broke the window* which is ambiguous between an animal flying into it and an object being swung against it, it bred a chimera that meant "a bat [the animal] broke the window using a baseball bat" - the one interpretation that people *don't* make. That's what you can get when meanings are molded by expectations and context rather than being assembled from **rules** and entries: an affectionate man falsely accused of beating his wife, and a club wielding Vespertilio pipistrellus (p.123).

What the connectionist model is lacking is Deacon's final process in the construction of words as symbolic representations that constitute concepts, theories and rules expressing a semantic. The model simply indexes the features of words. It does not **equilibrate the relationship of words among themselves** in order to create a stable or invariant relationship between the things represented by the words, a relationship congruent with experience. For example, the features of a bat [the animal] do not include extremities (arms) that could hold and swing a bat [the object]. The human mind is also familiar with the causality relationship involved in swinging a bat [the object] with sufficient force to break a window. A human would never create the interpretation that a bat [the animal] would break a window with a bat [the object] because the relationship or semantic implied by this is incongruent with what we know about the representation (what is contained in the representation of) bat [the animal], bat [the object], window [the object], and break [the verb/action]. We would not create this interpretation because it does not equilibrate or produce a stable semantic or meaning congruent with experience and what we know about the things these words represent. We can infer from this the semantic: **The creation of meaning is the equilibration of the relationship of representations congruent with experience.** Human knowledge creation involves:

1) acts of distinction or differentiation according to features (similarity and difference): creating icons;
2) acts of association and the creation of representations according to feature similarity: creating indexical associations; and
3) acts of equilibration of relationships between representations that are congruent with or summarizing of experience (invariant relationships): creation of concepts, theories and rules.

The above model, I believe, constitutes an emergent structure or morphology which includes:

1) Vygotsky's (1986) theory of concept formation and the relationship of language and thought,
2) Piaget's (1985) equilibration of cognitive structures,
3) Deacon's (1997) theory of the evolution of words as symbolic representations,
4) Sloman's (1996) case for two systems of reasoning,
5) Pinker's (2007) insights concerning the origin and nature of grammar,
6) Smolensky's (1988) model of an intuitive (associational) processor connected to a rule or concept-building processor,
7) Dehaene's (2007) account of the statistical nature of mental processing (associational systems),
8) Evidence from neuroscience concerning the nature of neuronal connection and systemic behavior (Hebb's hypothesis, long term potentiation, etc.),
9) Maturana and Varela's (1998) necessary consequences of biologic systems in systemic relationship,
10) Bateson's (2002) epistemological insights and
11) The logically necessary consequences of a nonlinearly connected universe that acts to conserve a fundamental ecology.

I freely admit to the sin of seeking out sources congruent to my thesis as a pattern began to emerge. Had I begun with an existential context, for example, I might have concluded otherwise. As this Dissertation illustrates, absolute truth eludes us. I contend only that when I place the sources of this Dissertation into relationship (non-linear heterarchy), the above conclusions and those to follow are emergent. The "truth" of the conclusions is contingent upon the equilibrations within the reader.

Additional conclusions derived from the synthesis described above are:

1) **The teleos of knowledge construction is rule building, concept formation and theory formulation** ;
2) **The final product of knowledge construction is the semantic or meaning that is consequent from the above constructions**, and
3) **Deductive reasoning processes (prediction, planning, and strategy) that result from these constructions are guided by the semantic or relational structure within the constructions (concepts, rules and theories).**

Conclusion 3 above affirms the deductive reasoning model of Johnson-Laird et al. (1992; 2005)

While I agree with Piaget (Gruber & Voneche, 1995) that the ultimate goal of knowledge creation is the facilitation of deduction, as this Dissertation has shown, there are other forms of thought that prelude deduction:

1) sensorimotor relationship (procedural relationship) or the connection of a sequence of actions that connect **means and ends,**
2) physical relationship and associational inference derived from **representational images** of the external world,
3) concrete relationships derived from the abstraction and inductive generalization of similar or **invariant attributes** of objects and events and
4) abstract relationships derived by abstracting and generalizing the invariant form of **relational structure** among concrete relationships (what remains constant through a sequence of actions or changes in state).

Representations and Thought

The above characterization of forms of thought leads to another conclusion of this Dissertation: **The form of thought an individual undertakes is controlled by the type of representation constructed of**

the objects and events of consideration and the type of relationships enabled by this form of representation. Again, this conclusion, I believe, expresses the confluence of various systems of thought investigated in this Dissertation. As shown in the body of the Dissertation, it is strongly influenced by the juxtaposition of results from neuroscience and Piaget's (Wadworth, 1989) stages of development. The table below summarizes the form of representation, the attribute abstracted, the nature of relationships facilitated by the representation and the problem-solving strategy enabled.

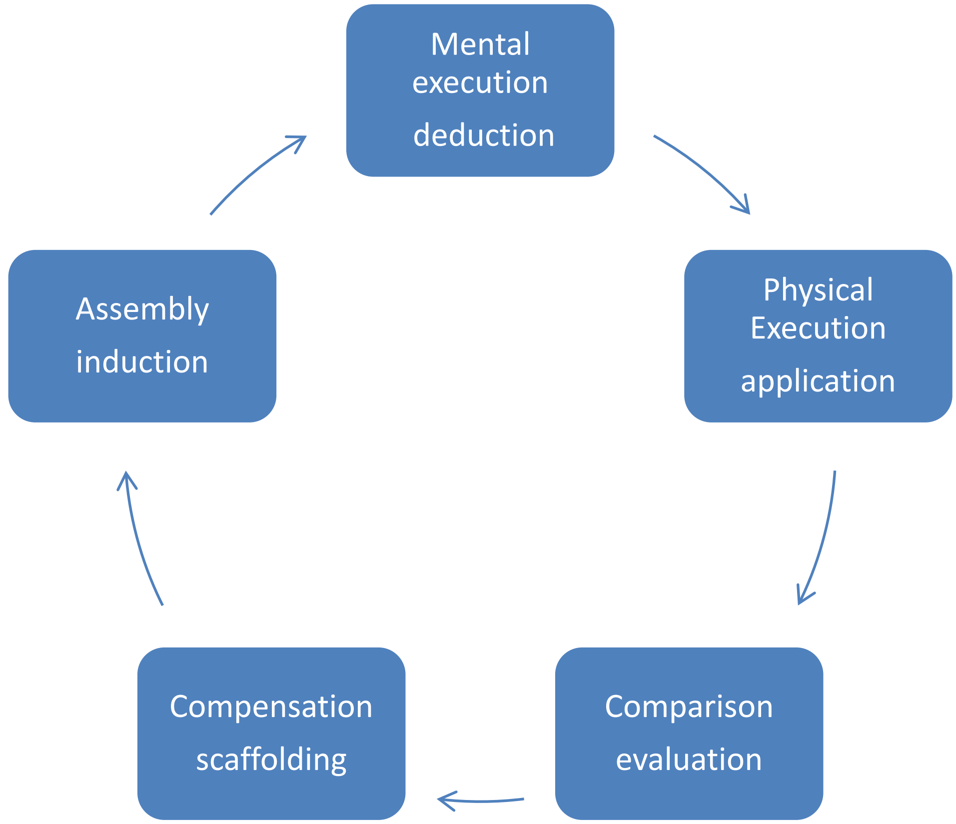
Representation	Abstraction	Relationship	Meaning	Problem solving method
Algorithm	None	Connected series of action steps	Means-ends (procedural meaning)	Trial and error
Image	None	Physical, external	Connections between objects and events	Associational inference
Related series of images	Physical attribute	Invariant physical relationships and/ or transformations	Concrete rule, concept or theory	Induction and generalization to create rule and subsequently concrete deduction
Word	Relationship	Metaphor, analogy, relational consistency	Abstract concept, rule or theory	Abstract rule based thought, analogy, metaphor

As discussed in the body of the Dissertation, these forms of representation, relationship, meaning and problem solving correlate directly with Piaget's (Wadworth, 1989) stages of development. They represent the maximum cognitive ability during these stages. They also correlate with Vygotsky's (1986) stages of concept development. It is a conclusion of this Dissertation that **these knowledge systems persist throughout the life of the individual.** They are variously invoked contingent upon an individual's perception of the cognitive requirements of a task and the individual's prior experience and knowledge. For example, a cognitive task that involves something with which the individual is completely unfamiliar is often addressed with a trial-and-error problem solving strategy. The goal is to put together a series of actions that will lead to a desired end result. The individual has no concept or rule, or perhaps even association, with which to proceed differently. In the course of a day, we solve any number of problems through simple associational inference, without invoking our conscious, attention-driven, rule-guided problem-solving capabilities. We experience a stimulus and instantaneously know what is connected with it through associational inference. For example, we may see a dark cloud and immediately intuit the possibility of rain. This intuition can be strictly associational inference and need not employ any conceptual or theoretical understanding of the causality relationships involved with rain events. The difference between the thought of an adult and that of a child is the child's limitation to the modes of thought which have evolved up to his or her current stage of development. Adults, given sufficient information, can self-scaffold themselves through progressive modes of thought. Unsurprisingly, experiments show that humans will use what they perceive to be the quickest and most efficient form of thought required by a problem (Reisberg, 2006). Inductive inference is a fast, essentially subconscious process. Rule-based thinking is sequential and requires attentional resources and consciousness. As such, it is a considerably slower process. It does offer the advantage of greater accuracy and likelihood for success.

The above has significant implications for teaching and learning. One implication is that students can become tempted to bypass conceptual level understanding if an algorithm can be constructed that achieves the desired ends. In my estimation, this frequently occurs in mathematics instruction. Even taking derivatives, performing integrals and solving certain differential equations can be reduced to an algorithmic operation and accomplished with little or no conceptual understanding of the abstract relational structure that undergirds these operations. Particularly, those students who assume that mathematics will not be a requisite part of their occupational interest can be tempted to bypass a conceptual level understanding, if the teacher's assessments permit success with purely algorithmic operations. I would also point out that many multiple-choice tests, matching tasks and similar forms of assessment can be accomplished using associational inference or an image-based understanding of what goes with what. The reader is referred back to the Piaget section of the dissertation for a fuller discussion and explanation of types of representations and the relationships and types of meaning that can be constructed from these representations. The principal conclusion from this discussion is**: The type of mental representation created of objects and events, controls the type of relationships that are constructed and therefore the meaning and form of knowledge that can be created.**

An instructional model for learning with meaning

Utilizing the foregoing conclusions, I have constructed a proposed model for teaching and learning at the level of conceptual, theoretical or rule-based meaning creation. As discussed previously, this first involves the construction of stable equilibrated relationships among the differentiated features of the objects and events of our experience. The model is a reconstitution of Piaget's (1985) model for the equilibration of cognitive structures. It is reconstituted in order to better accommodate the conclusions of the Dissertation and to more directly suggest curriculum and instruction. Its basic structure is shown below.



The model is a recursive loop. This is intended to communicate that the process steps are repeated until an equilibration or stable conceptual structure results. The lowercase words in the boxes not only describe the process, but are the same words expressed in Bloom's (1956) taxonomy of cognitive activity. Bloom et al. (1956) expressed these terms as a hierarchy of increasingly complex cognitive activity. Please note that I have taken the position that they are, in fact, collateral and are all necessary for the stabilization or equilibration of meaning at the conceptual level. I have used these terms because they are constructs familiar to educators and commonly used to translate cognitive activity into observable and measurable learning activities (Kubiszyn & Borich, 2003).

Let us begin at the assembly point of the process structure. At the level of a concept that would be designated by a noun, what I envision is the process described by Vygotsky (1986) for the formation of genuine concepts. This involves the abstraction of similar or invariant attributes/characteristics among the objects of consideration. It therefore involves an act of distincting or determining similarities and differences among these objects of consideration. In simple terms, we are forming a category or class. Our first goal is to determine the basis for categorization or classification. This involves differentiating the objects and events of experience and grouping according to similarity. As discussed previously, the associative systems in our minds readily facilitate such comparisons. The next step is to fashion a relationship wherein the relational connections are logical, as logical is defined by Vygotsky (1986) - relationships that involve a judgment:

1) Spatial/Motion through space (above, below, rising, falling…)
2) Temporal (before, after, starting….)
3) Causal (because of, since, leads to, is the result of….)
4) Substance/part-whole (is part of, is an example of, has, belongs to….)
5) Logical (and, or, not, some, all, necessary…)

As discussed extensively before, there is a preliminary equilibration that occurs at this point. The initial conceptual structure or elements in relationship must be stable and congruent with respect to what we know about the objects and events of consideration. For example, we could construct the relationship swims through water, but not the relationship swims through rock.

Please note that in using the above five categories of relationship, I have accepted Steven Pinker's (2007) premise that a semantic analysis of language constructions shows that all of the world's languages appear to be organized according to five abstract categories, which Pinker took from philosopher Immanuel Kant (1724-1804). Kant (1781/1982) proposed in *The Critique of Pure Reason* that perception and conception were organized by the mind within these categories. He also postulated that the categories were a-priori and not derived. I have adopted this premise because it is completely congruent with the relational structures that have emerged in this Dissertation. For example, these five categories can express the relational structures in all of the forms representation that I have proposed as the basis for thought. These five categories are also consistent with a biological and evolutionary conception of language and thought. If we think of language as an adaptation of an existing structure, then language should reflect the underlying structure or organization of perceptual systems and subsequently thought systems that rely on associational inference (a capacity demonstrated in all mammals). The information necessary for a mammal to successfully matriculate his environment consists of answers to the following questions: what/who (substance), when (temporal), where (spatial/spatial change) and why (causal). I would therefore submit that these informational categories are not only primal, but fundamental and a necessary consequence of environmental adaptation. In Kantian fashion we can ask ourselves what basic information a mammal needs to survive. I believe Kant's (1791/1982) categories present a good answer to this question. Please note that these categories organize not only relational connectives, like verbs and prepositions, but also nouns and the attributes/characteristics by which we differentiate objects and events.

I have adopted two other premises that I feel are consistent with the emergent epistemic structure of this Dissertation. The first is that the mind treats a changing entity in the same manner metaphorically, that it treats a physically moving entity. It thinks in terms of states of being. "A state is conceived as a location in a space of possible states, and changes are equated with moving from one location to another in that state- space" (Pinker, 2007, p.47).

In abstract concept formation what is generalized is the form of relationship that appears invariant either among events characterized by a concrete relationship or from a transition consisting of sequenced actions. What this generalization produces is a metaphor. The work of MIT linguists Gruber, Lakoff, and Jackendoff (Pinker, 2007) indicates that words used in abstract relationships reveal a physical origin or retain a "semantic skeleton" that relates directly back to physical conception and physical reasoning. This is an attractive premise, not only because of the research and compelling argument of its originators (Lakoff & Johnson, 1980), but also because of its consistency with the idea of a biological, developmentally progressive evolution of thought process. As discussed extensively before, biological entities do not reinvent themselves; they build upon existing structures through adaptation.

Pinker cites as an example of the metaphor theory, the beginning of the Declaration of Independence:

> When in the course of human events it becomes necessary for one people to dissolve the political bands which have connected them with one another and to assume among the powers of the earth the separate and equal station to which the Laws of Nature and of Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

The above expresses an abstract political idea. Pinker (2007) asks us, however, to consider the following. *The course of human events* is a metaphorical expression of history as motion along a pathway. *To dissolve the political bands which have connected them* invokes the physical idea of loosening a connection to effect a separation. [Pinker (2007) points out that dissolve meant to loosen asunder in the 18th century.] The phrases *powers of the earth and causes which impel them to the separation* are metaphors for physical concepts. Pinker (2007) interprets the metaphor involved as: causes of behavior are forces. He points out the ubiquity of metaphor in the abstract use of words such as: impetus, drive, force, push, and pressure. The title of the document itself is metaphorical: declare comes from the Latin word for "make clear," as in clarify.

The above has significant implications for learning and the development of abstract concepts, theories and rules. First, it reveals that **the generalizing or inductive process is one of creating metaphors (abstract forms of relationship) through the use of analogy.** Second, since the student, via prior experience, is familiar with physical relationships, the analogy consists of consistent physical relationships or previously-constructed concrete rules (concrete operations).

Let us return to Plato's (1952) *Republic* for an example of this process. A conversant in the dialogue, Thrasymachus, has put forth the proposition that a Ruler, in so far as he is a Ruler, always commands for his own self-interest. Socrates asks if he means Ruler in the strict (abstract, theoretical) sense or in the popular sense (actual existing Ruler). Thrasymachus replies that he means in the strict sense. Socrates then posits the following argument:

- In the strict sense, is a physician a healer or a maker of money? [all reply healer]
- In the strict sense, is a pilot a captain of sailors or merely a sailor? [all reply captain]
- Every art (medicine, sailing) has an interest for which it has to consider and provide.
- The interest of the art is the perfection of it.
- In the strict sense, the physician considers not his own good but the good of the patient in what he prescribes.
- The pilot or Ruler of sailors provides for the good of the Sail.

____

Therefore: Any Ruler, insofar as he is a Ruler, considers not his own interest, but the interest of his subjects.

What Socrates does in developing his concept or theory is to abstract the <u>form</u> of relationship from concrete relationships (examples, analogies) with which the conversants are familiar and believe to be true. He makes the implicit induction that any practitioner true to the practice of his art will perform in a manner consistent with the intended goal and object of the art. From this induction or rule, he immediately makes the deduction that a Ruler (in the strict sense) will act in the interest of his subject.

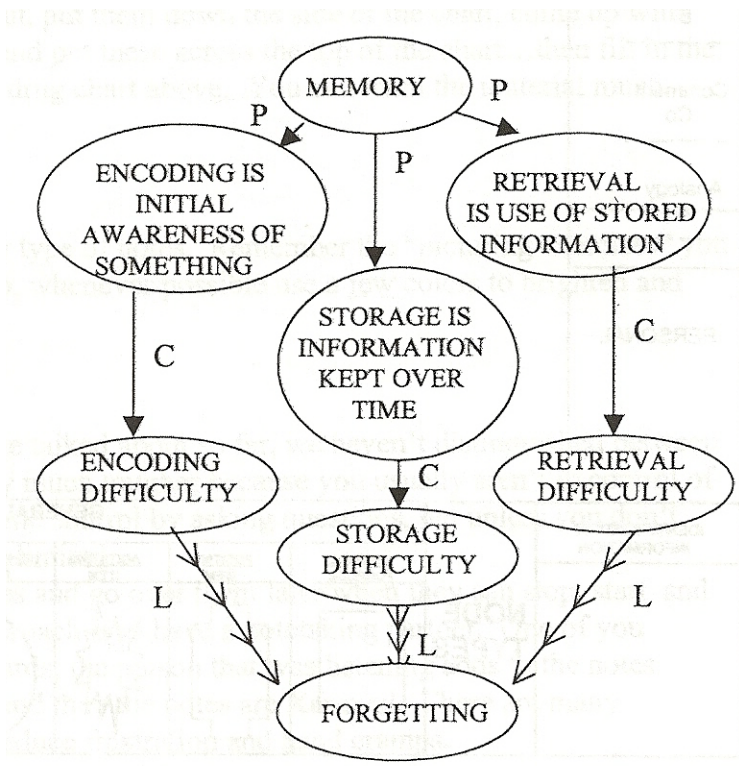
An entire Dissertation can be written around the premise that the human mind organizes around Kant’s (1781/1982) categories: space, time, causality, logic and substance. There is, however, sufficient evidence from psycholinguistics to state that these categories should be extremely useful constructs, both directly and metaphorically, for helping students create relational structures and organizations (concepts, theories, rules). As stated previously, they are applicable to all of the forms of mental representation discussed.

It is of interest to look at a form of advance organizer (shown below) developed by Dansereau, Joe and Simpson (1993). While originally employed in connection with drug abuse counseling, the organizer can be used to summarize any form of mental organization. The authors did not derive the relational connectives utilized in the organizer from Kant, but their connectives can be summarized within Kant's categories as follows:

1) Causality: leads to, influences
2) Time: next
3) Substance: type, part, characteristic, example, analogy

If Kant's categories are the way students will instinctively tend to organize, then pedagogy that is congruent with this premise should more successfully enable students to create mental organizations.

Link Types	
Leads to	L
Next	N
Influences	I
Type	T
Part	P
Characteristic	C
Example	EX
Analogy	A
Comment	CO



Deduction and Application

After the rule, concept or theory has been induced we can use it to deduct the logically necessary consequences that follow from it. As discussed previously, the rule expresses an invariant relationship between elements. As such, it is the construct that enables activities such as prediction, planning and strategy development. When comparing the inductive process of rule formulation with the deductive process of rule application, we find the same inseparability and equilibrating dynamic that we did within induction itself. For example, when students articulate a lack of understanding of a rule or theory they will make statements such as, "I don't see why the theory is necessarily true." These statements reveal that students quickly begin to apply the theory in their minds to the objects and events of their prior experience to determine whether it is consistent with this experience. Students appear to be performing two operations: determining whether the theory equilibrates with their prior understanding and checking to see if the theory produces a consequence that is a contradiction with respect to their prior understanding. The second operation is directly analogous to what Socrates undertook in our first example from Plato's (1952) *Republic*.

We can use the model of Johnson- Laird et al. (1995; 2002) to gain insight as to how the deductive process proceeds. The rule we apply articulates a semantic expressed in the rule's relational structure. Deduction, internal to the individual, is an effort to create a relationship of similarity between a mental representation of the rule and a representation of the verbal premises or perceptual observations of the object of the deductive process, to which rule is being applied. The representation of the rule then renders a necessary conclusion regarding the object of consideration that is not explicitly present (or determinable without the rule) in the object considered. The conclusion will express information not directly expressed in the premises or perceptually observed. The body of the Dissertation illustrates this process in more detail.

The above abstract description of deduction explains a common problem students have in applying theory. When applying theory, the student must create a connection between the abstracted elements and relationships of the theory and real objects and events. **This is not trivial.** In applying a physics principle, for example, the first task is to find the concrete articulations of the abstracted elements of the theory in the statement of the problem or in the actual physical circumstance. The relationships contained within the principal then allow the student to reach conclusions which are not explicit in the physical situation. This is the external manifestation of the internal process of creating representations and affecting a similarity relationship. To successfully apply theory requires a one-to-one mapping between the abstracted elements of the theory and the actual physical attributes of the circumstance to which the theory is applied.

The problem is exacerbated by the fact that any theory is a summarization of a portion of the attributes of objects and events. These objects and events possess other dimensions or attributes not incorporated within the theory. As discussed in the body of the Dissertation, this problem manifests itself in all disciplines, including the interpretation of multiple ententes in literature. In summary, this is a complex process requiring teacher direction and instruction. In my estimation, the single biggest reason why students cannot apply theory successfully is the inability to make the connection between the abstracted elements of theory and the actual properties of the objects/events to which the theory is applied or as they are articulated in verbal premises. **Teaching must impart process and application skills, not merely content and theory.** It is entirely too often the case that when children are asked to summarize, deduct or conclude when processing complex material, they do not have a clue as to how to proceed. This then brings us to the next process steps of our learning model.

Evaluation and Compensations

Initially-learned theory is inevitably incomplete and unstable. Application often results in mistakes or a result that is less than the goal that was originally sought. These results produce a need for compensating activity that facilitates the achievement of goal. It also produces for the teacher, an opportunity for the application of educational interventions collectively referred to as scaffolding. Some educational theorists, such as McConnell (2000), contend that a large percentage of learning actually occurs through the compensatory process of making the inevitable mistakes, effecting a correction and trying again, recursively, until a learning goal is reached.

In my estimation, teaching activities and strategies, such as cooperative learning, portfolios, directed classroom discussion and metacognition fall in the category of compensatory activity. Portfolios require students to create work products meeting specified standards that reflect attainment of specific instructional goals. In its most effective form, there is continuous feedback (compensation) from the teacher during this process (Groulx, 2005). Work products are revised and improved based on student-teacher interaction.

Classroom discussion can take many forms: student presentations with peer and teacher feedback (questions, comments), debates, role-playing and directed discussion (peer-to-peer, teacher-student). All of these activities can perform a compensatory function. An extremely obvious conclusion of this Dissertation is: **Knowledge and meaning are created by and within the student through a teacher-guided and directed process.** As such, we can agree with Bateson (2002) that all initial learning is subjective. A significant part of the learning process, then, must be involved with a public demonstration of one's mental organizations, the receipt of feedback and a compensatory process based on one's evaluation of this feedback. As discussed previously, this is the process by which one's "subjective" understanding comes to be regarded as "objective" knowledge: social concurrence. Political connotations aside, discussion-related activity is invaluable in equilibrating and stabilizing one's mental organizational structures.

Metacognition has received considerable attention as an effective tool for increasing academic success. This term relates to taking consciousness of and exercising regulatory control over one's own cognitive activities. As such, it can be considered self-compensation. It involves activities such as developing a knowledge of one's mental competencies and skills (or deficits), knowledge concerning requirements created by a cognitive task and knowledge of alternative strategies for accomplishing such tasks. Note here, that metacognition involves taking consciousness of and interacting with the brain's executive functions.

Metacognition is self-monitoring and self-regulating. Self-monitoring refers to keeping track of where one stands with regard to his goal of understanding and remembering. Self-regulation refers to planning, directing and evaluating one's behavior (Schneider, 2008). There is a body of research that confirms that meta-cognitive knowledge and the use of self-regulated learning strategies correlate with increased academic performance (Schneider, 2008). In its current (less than fully implemented incarnation) teacher-directed, meta-cognitive activity typically involves:

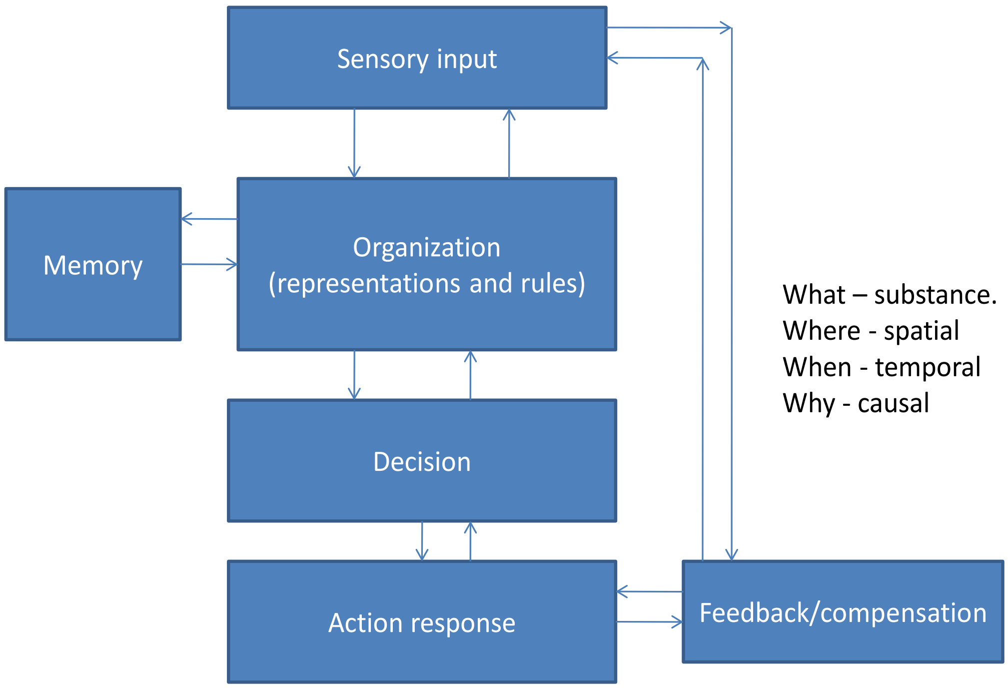
1) having students plan activities (resources, timing, and strategies) that will lead to attainment of instructional goals,
2) asking students to think about what strategies they used in solving problems,
3) asking students to consider alternative strategies that might have solved the problem and
4) having students introspectively review the results of their activities and think about what they would need to improve their performance.

Obviously, the more knowledgeable a teacher is concerning the cognitive functions and requirements posed by various learning tasks, the more successful she will be in directing student meta-cognitive activity. As this is not trivial, it implies extensive teacher training.

Executive Function and Scaffolding

As previously stated, Pinker (1997) summarizes intelligence as the ability to attain goals in the face of obstacles by means of decisions based on rational rules. He adds that this includes specifying a goal, assessing the current situation to see how it differs from the goal and applying a set of operations that reduce the difference. What he has described, in essence, correlates with the tasks undertaken by the brain's executive function. Shown below is a block diagram depicting the components of an intelligent system.

Intelligent system



Human executive function and its implications were extensively discussed in the body of the dissertation. Teacher scaffolding activity can be considered as an augmentation of human executive function as well as a form of compensatory activity. I have therefore placed scaffolding activities in the context of executive function. This confluence is illustrated below.

Executive Function and Scaffolding

- **attention**: helping students focus on and attend to the relevant aspects of the instructional task and the information within it
- **invoking long-term memory**: assisting students in recalling and applying their existing knowledge base or schemas to the task at hand
- **planning and executing**: demonstrating or modeling the process of meaning creation involved in the specific instructional activity
- **scheduling**: helping students plan learning activities (resources,timing, strategies)
- **switching**: learning is a feedback compensation process involving changing tactics (eliminating some and amplifying others) and the stabilization of meaning structures; teacher intervention can help guide this process.
- **decision-making**: helping students choose among courses of action and understand the inferences and deductions implied by their constructed meaning structures

Research

This Dissertation is theoretical in nature and construction. I would, however, like to cite research that I believe supports the conclusions of the Dissertation.

Researchers at Midcontinent Research for Education Laboratory (MCREL) analyzed thousands of quantitative research studies on instructional strategies that could be employed by K-12 educators in classroom settings (Marzano, 1998). The study consisted of a meta-analysis of prior research. In a meta-analysis, the researcher categorizes the results of a given study in terms of effect size. An effect size measures the increase or decrease in achievement of the group receiving the instructional strategy (versus the control group) in standard deviation units. An effect size of one, for example, means that the average score for the students in the experimental group was one standard deviation higher than students in the control group. If student test scores have a normal distribution, this translates into a percentile gain of 34 points. An effect size of one is hence highly significant, indicating that the average student did 34% better on an assessment of learning after experiencing the instructional strategy.

Listed below is a table of instructional strategies that resulted in significant improvements in student achievement (Marzano, 1998).

Instructional Strategies Affecting Student Achievement

Category	Ave. Effect Size (ES)	Percentile Gain	No. of studies	Standard Deviation
Identifying similarities and differences	1.61	45	31	0.31
Summarizing and note taking	1	34	179	0.5
Reinforcing effort and providing recognition	0.8	29	21	0.35
Homework and practice	0.77	28	134	0.36
Nonlinguistic representations	0.75	27	246	0.4
Cooperative learning	0.73	27	122	0.4
Setting objectives and providing feedback	0.61	23	408	0.28
Generating and testing hypotheses	0.61	23	63	0.79
Questions, cues, and advance organizers	0.59	22	1251	0.26

As shown above, the largest average effect size was achieved by having students identify similarities and differences. This involves the activities of comparing, contrasting, categorizing, creating metaphors and creating analogies. Given the conclusions of this Dissertation, this should come as no surprise to the reader; these activities are the fundamental predicates of meaning construction. In one fashion or another, the complete inventory of activity shown above has been addressed in this Dissertation. The above research emboldens me to make the following conclusion: **The most effective instructional strategy will be that strategy most congruent with and supportive of the mind's natural mechanisms for creating meaning from experience.**

Addendum – postmodernism

As a closing observation, I would like to state that this Dissertation turned out to be congruent with Schwartz and Ogilvy's (1979) characterization of the postmodern paradigm:

1) As systems become complex, new properties are emergent. This cannot occur by compounding simple systems.
2) Many systems are characterized by a heterachy of interactive and simultaneous influence. They cannot be expressed as hierarchies.
3) The hologram expressing dynamic interaction, differentiation and interconnection is a more appropriate metaphor for natural systems than a machine or collection of simple actions that combine in linear fashion.
4) The universe demonstrates the confluence of determinism and chance. It is not completely describable, predictable and mathematically determinable.
5) Mutual causality, nonlinear relationship and symbiotic interaction more accurately describe natural phenomena than linear causality.
6) Morphogenesis or the emergence of structure through self-organization in open systems better describes the construction of natural systems than the idea of components assembled according to a plan.
7) No single perspective or context constitutes "the" way of knowing or describing phenomena

In summary, 20th-century innovation and consequent paradigm revision creates the possibility that the 21st century may be one of the most innovative and constructive times in human history. This prognosis extends to the field of Education which is charged with the weighty responsibility of helping individuals create meaning for their lives.

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VITA

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ABSTRACT

AN EPISTEMOLOGICAL FRAMEWORK

FOR CURRICULUM AND INSTRUCTION IN THE 21ST CENTURY

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Many scholars have equated the 20th century with the 17th century as an era that brought forth a new paradigm or pattern of thought and belief. The 17th century saw the emergence of the modern paradigm. It is postulated that placing the innovations and discoveries of the 20th century in proper context results in the emergence of a new framework for thought, understanding and the creation of meaning. This new framework is characterized as the postmodern paradigm.

The goal of this Dissertation is to perform a critical examination of the intellectual innovations of the 20th century and the first decade of the 21st century in order to derive an epistemological basis for the design of learning experiences: curriculum and instruction. The methodology of the Dissertation is influenced by postmodern thought in the sense that it is structured as a heterachy consisting of the analysis of systems of thought in diverse domains, and is relationally connected in the Conclusions chapter in order to create an emergent structure which represents a synthesis of these diverse domains. The methodology also borrows an idea from Einstein of relating not only the conclusions between domains but also relating the frameworks or contexts within which those conclusions were derived. The

domains investigated include psychology, neuroscience, philosophy, linguistics, education, physics and mathematics.

The Dissertation characterizes human activity as the equilibration of a nonlinear systemic relationship between the motivated goals, mental organizations and behavioral actions of the individual. Goal influences the context in which meaning is created. Context, in turn, controls the nature of the metrics employed in the meaning creation process, the type of relationships that can be created, the nature of the meaning that can be constructed, the depth and breadth of the meaning constructed and the logical level of the meaning. Additionally it was found that context is necessary for the creation of meaning, must allow for an unambiguous description of phenomena, cannot possess the quality of logical necessity and does not control the nature of relationships actually existent within the "thing in and of itself." Context is not a static entity. When elements are placed into relationship, a context is emergent. With phylogenetic and ontogenetic progression, a context can be expressed as an emergent pattern with time.

The creation of meaning can be defined as the construction of a stable equilibrated relationship between elements representative of objects and events of consideration. Meaning is imparted by and derived through relationship. Equilibration occurs within the context of the aggregate of an individual's mental organizations. As this is an open system subject to adaptational ontogeny, we can consider these equilibrations as nonlinear self organizations. The structure emergent through the relationship of the aforementioned knowledge domains implies the following:

1) Similarity is the fundamental mental construct.
2) The teleos of human cognitive function is rule (concept, theory) building.
3) The human mind can be characterized as a language-enabled rule builder connected to a statistically driven, associational mechanism.

4) The predicate for human logic and deduction is the semantic expressed in stabilized relational structures.

The Dissertation makes the hypothesis that there are four forms of mental representation: connected actions or motor/procedural sequences (algorithms), physical images, connected physical images summarized through concrete rules and words expressing abstract rules or metaphorical forms of relationship. These representations are an articulation of the neurological structures that enable them. The type of representation determines the form of thought and problem-solving process that can be undertaken. While developmental, these forms of representation persist throughout life. They are variously invoked contingent upon the individual's perception of the requirements of a mental task.

The Dissertation presents a model for the design of rule-based (concept, theory) learning. It affirms the principles of postmodernism and a constructivist paradigm for teaching. Research, which is felt to support the hypotheses of the Dissertation, is cited. The Dissertation also concludes that the most effective instructional strategies will be the ones most congruent with and supportive of the mind's natural and inherent mechanisms for creating meaning from experience.