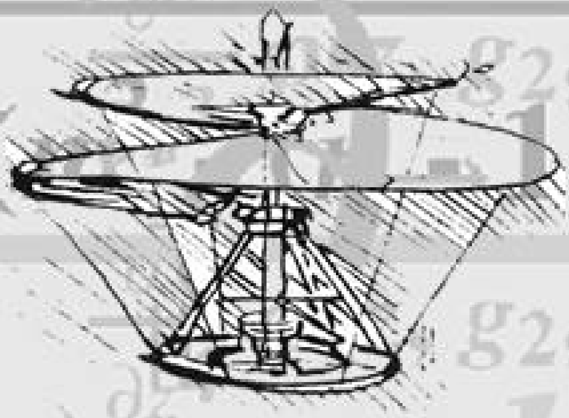
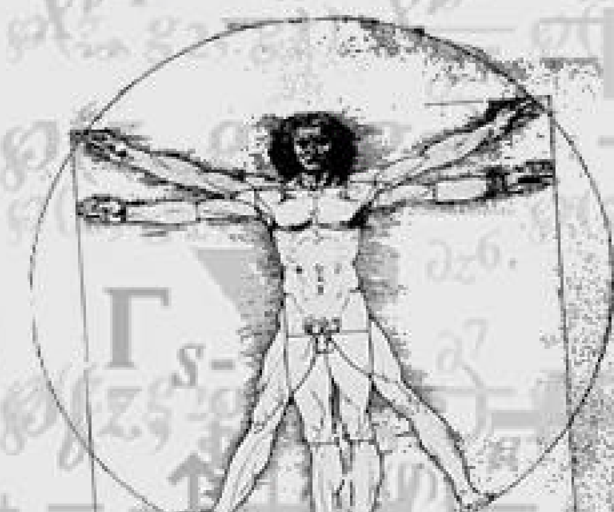


PATTERNS OF KNOWLEDGE

Knowledge As A Complex Evolutionary System
An Educational Imperative



by Derek Cabrera

PATTERNS OF KNOWLEDGE:

KNOWLEDGE AS A COMPLEX EVOLUTIONARY SYSTEM,

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ABSTRACT

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Paulo Freire (2000) proposes that education is about liberation. David Perkins (1992) proposes that education is about knowledge. The author proposes that Freire and Perkins are in total agreement. When a student can adeptly create, retain, understand and use knowledge they are also able to liberate themselves from the bondage of ignorance as well as from the oppression of the "knowledgeable." Knowledge has been the focus of a great deal of research in the cognitive sciences and in educational practice. Yet, most of this research (e.g., cognition, intelligence, transfer, or understanding research) perceives knowledge as merely the output of cognitive inputs. The author argues that a different, but equally important, approach to the phenomenon of knowledge is needed. Drawing upon complexity science and evolutionary theory, the author proposes that knowledge must be viewed as a complex, evolutionary system. An extensive literature review corroborates the existence of isomorphic elemental pairs called, *Patterns of Knowledge.* The patterns are foundational to the two-steps of the evolution of knowledge—creation and selection—which are analogous to the Darwinist processes that occur in the evolution of species. The "first-step" involves a massively parallel integration of the isomorphic elements that leads to an explosion of potential knowledge. The "second-step" imposes logic and reason as a selection filter. Finally, the author reviews the educational implications of the *Patterns of Knowledge* on cognition, transfer and analogical reasoning, breakthrough thinking and insight, interdisciplinarity, learnable and multiple intelligences, testing and assessment, and general pedagogy.

Chapter 1

BACKGROUND

Establishing Normative Goals of Education

Much has been written about the "goals" of education. From John Dewey to Paulo Freire, scholars have proposed what education is and what education should be. It is important to the discussion of education to sift through these various proposals and to identify a sufficiently general definition of the goal of education that encompasses most, if not all, of these proposals. Such a definition would be called a "normative goal of education"—a statement of the goal of education that sufficiently encompasses the *norm*. Harvard professor, David Perkins, proposes three goals of education that "almost no one can disagree with." Perkins goals are (Perkins 1992):

1. Retention of knowledge
2. Understanding of knowledge
3. Active use of knowledge

Perkins' three goals of education are general enough to encompass a number of more specific definitions of education. These normative goals of education provide a backdrop for further discussion about education and learning that is as relevant to scholars, educational theorists, practitioners and teachers. The common denominator of each of Perkins' goals is knowledge. Of course, the crux of Perkins' statement is how we define the term, *knowledge*. Here again, Perkins does a good job of providing a sufficiently broad and inclusive definition for knowledge. (Perkins, page 5). He includes as "knowledge" any of the various processes such as cognition, transfer, intelligence, and memory and any of the manifestations of knowledge such as in the brain, in books, on the internet, etc. Here again, Perkins' definition of knowledge is broad enough to include all of the various processes and manifestations that we think of when we think of knowledge.

Knowledge as Cognitive Processes versus Knowledge As Complex Evolutionary System

There is an abundance of research on knowledge. Yet, no studies focus on knowledge as both a complex, evolutionary system and an educational phenomenon. The research that focuses on knowledge comes in several flavors:

- Knowledge as it relates to knowledge management in business
- Knowledge as it relates to philosophy
- Knowledge as it relates to the processes of the cognitive and learning sciences

The research on knowledge management does not directly contribute to the development of educational ideas regarding knowledge. As it relates to philosophy, knowledge is likely one of the oldest ideas in Western inquiry, yet the heady philosophical debate is of little benefit to the development of better educational practices. The single exception to this rule is in the area of logic which is the birth child of philosophy but which prevails throughout the disciplines. The third area focuses on the "knowledge as cognitive processes." The cognitive-process approach does provide a worthwhile backdrop for the discussion of knowledge as a complex-evolutionary-system approach. In the same way that the study of ecology is different than the study of biology, approaching knowledge as a complex, evolutionary phenomenon is different than approaching it as a cognitive process. Both approaches are intimately related and can co-confirm each other's findings, but they are not the same.

It is the purpose of this paper to subject knowledge to the same scientific scrutiny that various cognitive processes have received and to situate this inquiry within the contexts of complexity, evolution, and educational practice.

Knowledge As It Relates to Philosophy

From the time of Aristotle (and likely long before him), knowledge has been a well-debated concept. A central thread in the philosophy of knowledge is based in deduction and induction, logic and rationale (Schope 1983). In fact, philosophical thinking about knowledge has been predominantly biased by the tyranny of logic. To a large extent, in the philosophical debate, knowledge has become synonymous with logic. While it is clear that the tenets of logic are instrumental to the emergence of knowledge, it is also clear that more is going on. As evidence to this fact, consider that much of the knowledge used in everyday situations is neither logically deducible nor rational.

People regularly use knowledge that is neither rational nor logical, sometimes with positive results. As a recent example, President Bush, and a deluge of bipartisan Senators and Congressman rushed to the microphones to express their disgust with a recent 9th U.S. Circuit Court of Appeals decision that the phrase, "One nation, under God" is unconstitutional because it endorses religion. President Bush called the ruling "ridiculous," and the Senate voted 99 to 0 to reaffirm its support for the phrase "under

God" in the pledge and to call on an appeals court to reverse the ruling (Williams 2002). Why did these politicians feel this way? There is no logical argument that can be deduced from the Constitution or from case law. In fact, the founding fathers carefully omitted references to God in an attempt to keep separation between Church and State. Congress added the words "under God" to the pledge in 1954. Yet, given the political power of the President and the Legislative Branch, it is likely that the 9th Circuit ruling will be overturned. Perhaps it is ironic that the legal system that Aristotle helped to create often neglects to use Aristotelian logic. More often than not, logic and deduction are absent from the knowledge we use on a daily basis. Later in this paper we will see that Aristotelian logic is merely one step in the process of knowledge creation.

Philosophical discussions of knowledge are only generally helpful to the application of knowledge in the professional setting of education. Berkeley cognitive scientist, George Lakoff states, "It is a startling thing to realize that most of Western philosophy is inconsistent with fundamental results from the science of the mind" (Lakoff 2002).

Knowledge As It Relates to Cognitive Processes

As examples of "cognitive process research," there is an abundance of research on transfer (Brown 1989, Dienes 1970, Larkin 1989, Singley 1989, Throndike 1949), cognition (Hauser 2001, Bransford 1999, Singley 1989, Sternberg 1995), learnable intelligence (Gardner 1995, Nickerson 1985), memory (Larkin 1989, Bransford 1999), critical thinking (Levy 1997, Nickerson 1985), insight, (Davidson 1995, Sternberg 1995, Simonton, 1995), understanding (Gelman 1989, Poly 1962), motivation (Wlodkowski 1998, Pintrich and Schunk 1995), communities of practice (Brown 1990, Brown 1989), and learning (Bransford 1999, Resnick 1989, Freire 2000, Dewey 1997). These ideas will be revisited throughout the discussion that follows.

Knowledge As Design

There is one unique approach that sits in between the knowledge-as-a-cognitive-process and knowledge-as-a-complex-evolutionary-system approaches. In Knowledge as Design, Perkins (1986) suggests that one might perceive knowledge as a design problem much like an engineer or an architect would design a bridge or a building. In other words, Perkins' proposes that there is value in seeing knowledge as something to be designed and built rather than as the output of cognitive inputs. Perkins writes, "A hammer has a basic structure, but it also has an abstract structure-a shoe or a brick or a rock can serve as a hammer in a pinch because it is-like a hammer-abstractly weighted with an available striking surface that is more hardened than the object to be struck and a holding apparatus." Perkins' attempt to view knowledge as a phenomenon in its own right—knowledge as a mechanistic structure of design—provides a stepping-stone in the direction of knowledge-as-complex-system.

Evolving the Master Metaphor

It makes sense to think of knowledge as an abstract something one could design and engineer. It is especially appropriate given the trend that science seems to follow that parallels current social trends and beliefs. In the pre-religious age, man's explanations of the world where predominantly based on a natural world. Evidence of this can be seen in current day tribes of the Philippines and Brazil who view the forest as a form of God. As the ideological basis for Taoism (Tzu 1989), nature was the overarching metaphor for man's knowledge. Mayans worshiped the sun god. Even the childhood life of Abraham—the father of three of the world's most dominant religions—was influenced by pagan (natural) gods (Szulc 2001). As religion began to dominate the ideologies of mankind, so too did religious metaphor. During the period of religious reign, it was believed that a pack of angels pushed the planets through their orbits. The logic of the Church, not the logic of nature, ruled man's thoughts and influenced his creation of knowledge. Unseated by Descartes, the religious metaphor was replaced with a grid and a clock. A Cartesian grid could overlay the universe and the fundamental properties of time and space. During this mechanical age, physics took on mechanistic overtones; the master metaphor for science was that of the clock (Capra 1988). Seeing knowledge as a mechanistic tool that meets a prescribed or adaptable purpose is fitting for such a mechanistic age. Yet, as society enters into the computational age (also called the information or digital age), the metaphor will need to change again to meet (and to some extent lead) the times. It is important to note that much of the cognitive process research already embraces the informational and computational paradigm. New thinking that views knowledge as a complex system will contribute to this research.

Knowledge As a Complex System

It is the aim of this paper to consider knowledge not in a mechanistic paradigm or metaphor, as did Perkins, but to evolve our paradigm of knowledge-as-complex-system. This will be done not from the discipline of philosophy but in the context of the profession of education. Viewing knowledge-as-a-complex-system from an educator's perch, one might ask: What can be learned about how to better manage a classroom, a curriculum or an entire educational system? In order to answer this question it is necessary first to review the basis for complexity science.

Instead of a mechanistic view of knowledge that highlights the aspects of knowledge that are logical and rational; instead of a mechanistic view of knowledge that approaches knowledge as design and engineering; we will approach knowledge as a complex, adaptive system. We will view knowledge as a computational "program" of sorts that runs on simple underlying rules and is capable of generating massive complexity. This shift will require that knowledge is viewed as an evolutionary program—its complexity evolving over time from the iteration of simple rules.

Drawing on Complexity Science

Nobel Prize winning physicist, Murray Gell-Mann, writes insightfully on the topic of complexity theory. Gell-Mann's wisdom on complexity is derived from the simple Greek and Latin roots of the word, complexity:

> It is important, in my opinion, for the name to connect with both simplicity and complexity. What is most exciting about our work is that it illuminates the chain of connections between, on the one hand, the simple

> underlying laws that govern the behavior of all matter in the universe and, on the other hand, the complex fabric that we see around us, exhibiting diversity, individuality, and evolution. The interplay between simplicity and complexity is the heart of our subject.
>
> It is interesting to note, therefore, that the two words are related. The Indo-European root **plek-* gives rise to the Latin verb *plicare*, to fold, which yields *simplex*, literally once folded, from which our English word "simple" derives. But **plek-* likewise gives the Latin past participle *plexus*, braided or entwined, from which is derived *complexus*, literally braided together, responsible for the English word "complex." The Greek equivalent to *plexus* is ??????? (*plektos*), yielding the mathematical term "symplectic," which also has the literal meaning braided together, but comes to English from Greek rather than Latin. (Gell-Mann 1995)

It is apropos that Gell-Mann's profound understanding of complexity science should be based on such a simplistic analysis of Latin and Greek roots. Indeed, Gell-Mann not only describes complexity quite well, he also demonstrates the very nature of the complexity paradigm: that underlying the veil of complexity are simple rules. So too, Gell-Mann demonstrates that simplicity is often far more complex than it appears.

If Gell-Mann's philosophical wisdom provides a Zen-like description of the relationship between complexity and simplicity, Stephen Wolfram adds an obsessive-compulsive *tour de force* in his 1200 page, A New Kind of Science.

Wolfram's analysis is founded on three tenets (Wolfram 2001). First, the existence of complex phenomenon need not imply the existence of complex underlying explanations. The complex, as Gell-Mann points out, often rises like a Phoenix from simple ash. Second, Wolfram views the universe not as a jumble of quarks or atoms but as computational information. Viewing the universe from an information paradigm is a novel concept—one that coincides with the social trend toward the computational age.

Ray Kurzweil (2002) quotes Robert Wright who quotes the renowned computer scientist, Edward Fredkin, as saying,

> There are three great philosophical questions. What is life? What is consciousness and thinking and memory and all that? And how does the Universe work? The informational viewpoint encompasses all three. . . . What I'm saying is that at the most basic level of complexity an information process runs what we think of as physics. At the much higher level of complexity, life, DNA - you know, the biochemical functions - are controlled by a digital information process. Then, at another level, our thought processes are basically information processing.

Wolfram believes that the universe and everything in it is merely a computational program that processes information. The rules that these computers follow are simple and complexity emerges from the interaction of these simple rules over the programs "runtime" (computational time period).

Finally, Wolfram gives us his magnum opus—the theory of computational equivalence. In brief, the theory states that all phenomenon of sufficient complexity are equally complex. In other words, a human society, the stock market and a colony of ants, are equally complex. This idea will be discussed in greater depth later on.

Complexity science is a new and emerging tool that can uncover many phenomena that have evaded human understanding. There are thousands of techniques, tools, models, and emerging insights that make up the field of complexity science. However, more important than any specific instrument of complexity science is the paradigm itself. Complexity science is an epistemology of sorts—a way of creating and understanding knowledge. The complexity paradigm is as different from the Cartesian paradigm as Descartes was different from the Pope. It is from this complexity paradigm that one must approach the phenomenon of knowledge-as-complex-system, as it relates to normative educational goals.

There are some good examples that underscore the complexity paradigm and provide insight into how one might go about perceiving knowledge as a complex system. Each of these examples is abstractly made up of 1) a complex adaptive system, 2) underlying rules that are local and simple, 3) a "runtime"—a time variable during which the local rules are applied to independent variables.

Boids, Schools, and Flocks

In 1986 Craig Reynolds (2001) made a "computer model of coordinated animal motion such as bird flocks and fish schools." Reynolds called the simulated flocking creatures, "boids." The basic flocking model consisted of three simple "steering behaviors":

Separation: steer to avoid crowding local flockmates:

Alignment: steer towards the average heading of local flockmates

Cohesion: steer to move toward the average position of local flockmates

Each Boid reacts "only to flockmates within a certain small neighborhood." This means that the Boids are only interacting with neighbors. Flockmates that lie outside of the individual Boid's neighborhood are ignored. Reynolds writes, "the neighborhood could be considered a model of limited perception (as by fish or murky water) but is probably more correct to think of it as defining the region in which flockmates influence boids steering" (Reynolds 2001).

Reynolds' computational experiment models the complex flocking behavior of boids, fish, and birds using simple local rules acting on independent variables. The result is emergent complexity—a collection of individual organisms that act like a single super-organism. Since his 1986 experiment, Reynolds' model has been used to make realistic looking flocking bats in the 1992 Tim Burton film, *Batman Returns* (Reynolds 2001).

An even simpler example of the complex behavior of super-organisms based on simple rules can be found at national sporting events. The stadium wave—where fans simulate an undulating elliptical blanket around the stadium—is based on a single, simple, local rule: if your left neighbor stands up, then stand up. The initial starting condition for this complex phenomenon is a single line of standing people.

At its core, complexity science is the science of patterns. Patterns determine the extent to which phenomena exhibit regularity, complexity, chaos or total randomness. The more regularity a phenomenon exhibits, the simpler it is considered to be; the greater the complexity, the lesser the regularity. Knowledge is a complex system, its underlying patterns are difficult to identify and even then, the elements and rules that underlie these patterns hide from our view.

From the examples of complex systems, one can begin to question how knowledge-as-complex-system might behave:

What are the patterns of knowledge?

What might the simple local rules of knowledge look like? What are the simple rules of underlying knowledge?

How could these simple rules interact to create what amounts to an infinite amount of potential knowledge?

Knowledge As Evolutionary and Adaptive

It was pointed out earlier that while logic plays an important role in the selection of knowledge, it does not render the whole picture. A great deal of people's daily decisions about important events and trivial activities alike are neither logical nor deducible. Therefore, we must conclude that, to a large extent, the creation of knowledge involves significantly more than Aristotelian rules of logic. "According to Aristotle, a proof, or rational argument, or logical argument, consists of a series of assertions, each one following logically from the previous ones in a series, according to some logical rules. Of course, this description can't be quite right, since it doesn't provide any means for the proof to begin: the first assertion in an argument cannot follow from any previous assertions, since in its case there are no previous assertions!" (Devlin 1998). How do the assertions of knowledge begin? Clearly, there is more to the picture.

Charles Darwin's evolutionary theory may provide the missing pieces of the picture. Dean Keith Simonton provides a good synthesis of the connection between Darwinist theory and creativity in *Foresight in Insight? A Darwinian Answer* (Simonton 1995). Simonton writes (p. 467), "Many distinguished psychologists have recognized that this Darwinian process describes more than just the origin of species. The same process operates in creativity, so well. Thus, William James (1818, p.456) proposed:

> The new conceptions, emotions and active tendencies which evolve are originally *produced* in the shape of random images, fancies, accidental outbirths of spontaneous variation in the functional activity of the excessively unstable human brain, which the outer environment simply confirms or refutes, adopts or rejects, preserves or destroys--selects, in short, just as it selects morphological and social variations due to molecular accidents of an analogous sort.

Simonton continues, "B.F. Skinner (1972) argued that creativity involved a trial-and-error process in which creative behaviors are shaped by the reinforcements dispensed by the environment." "It is Donald Campbell's 1960 model of creative thought that holds the most promise. He actually called his scheme the *blind variation* and *selective retention theory*. According to this model, ideas undergo haphazard recombinations in the mind. The resulting blind combinations then pass through a selective filter" (Simonton, p 467).

Simonton's own chance configuration theory of creative genius states that, "creativity begins with the chance combination of mental elements. The latter includes ideas, concepts, recollections, emotions, sensations, or any other basic components of mental functioning. Most of the permutations are too unstable to enjoy anything more than an extremely ephemeral existence in the fancy. Nonetheless, from time to time, a specific combination of elements coalesces to form a cohesive whole, or a conception Gestalt. This chance configuration represents the insight that transfers to more deliberate and elaborate processing at later stages in the creative process " (p.467).

It appears that the evolution of knowledge may parallel similar processes to the evolution of species. It appears that Aristotelian forces (logic, rationale, deduction and induction) "select" from a creative explosion of knowledge in an analogous way that natural selection identifies the viable species from a maladroit circus. If the evolution of knowledge, like that of the evolution of species, is a two-step process, and logic is the second step, what is the first step? Creative geniuses reporting on the thought processes behind their discoveries have noted two steps (Simonton 1995):

1. coming up with massive numbers of ideas/prethoughts
2. consciously and subconsciously sorting through and connecting those prethoughts and making coherent ideas

"Once these intuitive insights emerge, the conscious mind often must do the real work, verifying the hunch, elaborating the details, or providing the logical justifications (Simonton p.475)." From the discussion of evolution as it relates to creativity and insight, we can develop a two-step model for the evolution of knowledge:

First Step: Creation of Knowledge. A diversified explosion of concepts and connections.

Second Step: Selection of Knowledge. A logical filtering of viable concepts and connections.

Haphazard and Unconscious or Ordered and Conscious?

Albert Einstein said, "combinatory play seems to be the essential feature in productive thought, this 'vague play' taking place before there is any connection with logical construction in words or other kinds of signs which can be communicated to others." The topologist, Henri Poincare, said "Ideas arose in crowds; I felt them collide until pairs interlocked so to speak, making a stable combination. By the next morning I had established the existence of a class of Fuchsian functions." Simonton relays that Poincare "compares these colliding images to the 'hooked atoms of Epicurus' that jiggle and bump 'like the molecules of gas in the kinematic theory of gasses' so 'their mutual impacts may produce new combinations.'" Simonton comments, "this represents an explicit and vivid statement of how free variation yield chance configurations" (p 468).

When using phrases such as, "random images, fancies, accidental outbirths," "trial-and-error process," "haphazard recombinations," and "chance configuration," Simonton, et. al., imply that the first-step in knowledge evolution is a mysterious, random process. There is also a tendency for scholars to identify the *elements* of the "first-step" in vague general terms such as, "ideas, concepts, recollections, emotions, sensations, or any other basic components of mental functioning." Consider the following three quotes:

> *Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most abrupt cross-cuts and transitions from one idea to another, the most rarefied abstractions and discriminations, the most unheard of combination of elements, the subtlest associations of analogy; in a word, we seem suddenly introduced into a seething cauldron of ideas, where everything is fizzling and bobling about in a state of bewildering activity, where partnerships can be joined or loosened in an instant, treadmill routine is unknown, and the unexpected seems only law. —William James 1880* (Simonton 1995)

> *Problem solving becomes more nearly a random process, in the sense that the free-associative procedure must come into play. Only by falling back on this less disciplines resource can the creator arrive at insights that are genuinely profound.* (Simonton 1995)

> *The cornerstone of creativity is bisociation—the congruence between two sets of ideas that originate in unrelated domains of experience, and probably the only way two irrelevant realms can be brought together is by*

> *the crazy confluence of rather haphazard and whimsical trains of association.* (Koestler 1964)

The implication is that some kind of process is going on and that some kinds of elements exist, but that the whole affair can be explained only in vague, general terms. At best, one is left with a cloudy understanding of what is going on in the first-step of the knowledge evolution.

Is the first-step an *inherently* unconscious, vague, haphazard, or illogical process? Nobel Laureate and psychologist, Herbert Simon doesn't think so. In his 1973, *Does Scientific Discovery Have a Logic?* Simon argues that the random, haphazard, accidental insights that lead to scientific discovery are logical.

But, where the term logical is used, and it is used often, it becomes increasingly difficult to differentiate what "logic" means. Terminology that is often affiliated with logic (e.g., ordered, systematic, conscious) is used in some cases where antonyms are used in others (e.g., mystical, whimsical, chaos, haphazard, disordered). Soon, using the term logic to identify the second-step has little meaning because one realizes that the first-step can be just as logical. Many writers (present company included) use the term, *logic*, somewhat irresponsibly. But, it is also difficult not to misuse the term because *logic* has common and scientific meanings that are not the same. In common use, *logic* is thought of as something akin to a stale legal trial—something that feels more like a forced march than dancing through fields. But modern logic includes far more than Aristotelian or legalistic logic—logic is the study of patterns of reasoning, but is also injected throughout modern mathematics, which includes irrational notions. Therefore, if the term must be used, then it is helpful to make a distinction between a *logical product* and a *logical process*. If Simon is right, and there is reason to believe that he is, then both steps are logical processes. The first-step, however, often leads to products of knowledge that one would not identify as "logical" despite the systematic and logical process that was used to generate them. Terms such as logic both elucidate and obfuscate the discussion. Still, one can get a gestalt for what others are saying about the two-step process. And a good deal of the commentary about the first-step feels strikingly different from the logical –leaning of scholars such as Simon.

Is the first-step an inherently mysterious process or is it merely a misunderstood process? Is it haphazard or systematic? Simonton writes, "Too often persons fail to make significant insights because they exclude whole domains of elements from entering into the combinative hopper. Yet what appears logically irrelevant may actually provide the missing piece of the puzzle" (p. 473). Simonton's "combinative hopper" may in fact rely on a systematic process that leads to an oft-illogical diversity explosion. Cabrera (2002) writes, "There may be a logical path toward illogical conclusions. For example, if A equals B and B equals C but A does not equal C, we say that this is an illogical statement. It defies the laws of syllogistic logic. Yet, we can logically understand how a person fails to make A equal C based on his or her beliefs. It makes logical sense not to steal from people, but it also makes logical sense why people steal. The product may not be logical, but the process is."

Indeed, terms such as logic both elucidate and obfuscate the discussion. Perhaps different terminology is needed. Rather than frame the debate in logical or illogical terms, it is more accurate to use notions of mathematical or non-mathematical. The common notion is that mathematics is the science of numbers, but this definition is only suited for mathematics as it existed two and a half centuries ago. Within the past thirty years a definition of mathematics has emerged with which most mathematicians can agree—mathematics is the science of patterns (Devlin 1998). The first- and second-steps of the evolution of knowledge should be differentiated by *patterns* rather than by *logic*.

In the previous section, it was proposed that knowledge is a complex system. It was proposed that patterns within knowledge exist in the form of elements and rules. In this section, it is proposed that knowledge is evolutionary and adaptive. Specifically, that the evolution of knowledge is a two-step process. Like the second-step, the first step is logical and appears to exhibit order and regularity. If order exists, patterns exist. The way to differentiate between the first-step and the second-step is to identify the kind of order—the kind of patterns—that exist.

> Are there patterns that underlie the first-step or is it disordered?
>
> Do these patterns have genralizeable elements and rules that could lead to emergent knowledge complexity?

Neither the vague "mental elements" proposed by Simonton, Koestler, James, Skinner, and Poncaire, nor the logical elements proposed by Aristotle are enough to explain the first-step process that produces a diversified ecology of knowledge. Although the first-step is often described in *mystical* terms such as *intuition* or *insight*, the author proposes instead, that the first-step is a complex emergent phenomenon caused by the combinatorial play of simple mental elements and rules. In other words, the first-step is as patterned and ordered as the second-step, only different.

Once the diverse explosion of knowledge occurs, the second-step in the evolution of knowledge imposes different patterns (of reason and deduction) as a selection filter. Currently, the patterns of the first-step appear to be subconscious, haphazard, or intuitive. But, like any insight, once revealed, it can be learned and consciously practiced.

Chapter 2

KNOWLEDGE AS COMPLEX EVOLUTIONARY SYSTEM

Patterns of Knowledge

The patterns of the first-step exist within what might be analogically called, "the genetic code of knowledge." Rather than a chance bisociation of two disparate ideas separated by vastly different disciplines, the first-step process is in fact, an association of similar abstract universal elements. This is a critical point that deserves repetition. The first-step process may not be what many have claimed—a process of random bisociations between totally different ideas. Instead, the first-step is a process of systematic associations between abstractly similar universal elements. *Bisociation* implies that different concepts are being related, whereas, *association* implies that similar constructs are being related. It is the elemental similarity between all concepts that allows connections to be made.

These elements undergo, as Einstein put it, "a combinatorial play" in which unpredictable combinations can be created. An example of the use of abstract elements can be seen in terms of a simple analogy. Comparing one person's western-style house to a tribal villager's mudhut is not a direct comparison between the actual concepts, home and mudhut. Instead, abstracted elements are being used such as the *relationship* between person and domicile that allow the comparison to be made. The same process occurs in the first-step of the evolution of knowledge, only the number of abstractions is far greater than a simple analogy.

Cabrera (2001) proposed that there are a set of elements and rules derived from abstract patterns that exist within the structure and function of knowledge itself. He calls these elements and rules, *Patterns of Knowledge* (Cabrera 2002). The following table of equivalencies defines the basic elements in terms of larger patterns:

	Structural Patterns				*Functional Patterns*			
Patterns	Distinctions		Systems		Relationships		Perspectives	
Elements	Thing	Not-thing	Part	Whole	Cause	Effect	Content	Context

The table above explains that any conceptual "chunk," such as, *green,* has 12 *basic* inferential structures and functions: the four patterns and eight elements. For example:

1. Green is a *distinction* based on its greenness and because it is not red or blue or yellow, etc.
2. Green is a *system* of different hues of green.
3. Green *is* a *relationship* between yellow and blue.
4. Green *is* a *perspective* to which other concepts are compared (e.g., red is to the left of green on the light spectrum).

1. Green is a *thing* defined by its greenness.
2. Green *is* a *not-thing* (e.g., it is not-red).
3. Green is a *part* of the color spectrum.
4. *Green* is a *whole* that includes various hue-parts.
5. Green *causes* surrounding colors to look different.
6. Green is the *effect* of a certain wavelength.
7. Green is *content* within the color spectrum.
8. Green acts as *context* for other colors.

The Three Rules of the Patterns of Knowledge

There are three rules that are derived from the four patterns and eight elements:

The Rule of Equality: Each pattern is equal to two opposing elements.

The Rule of Inference: Each element infers its opposing element.

> *The Rule of Interchangeability*: Any pattern or element is interchangeable with any other pattern or element.

The *Rule of Equality* is based on the nature of knowledge to expand and contract. Knowledge is created through reduction of concepts into smaller concepts and through production of concepts into larger ones. Cabrera (2001) calls this the "reduction-production" cycle. The nature of knowledge is the ebb and flow of reduction and reproduction, expanding and reducing ideas, generalization and specialization. It is said that there are two kinds of scientists—*splitters* and *lumpers*. Splitters reduce concepts until they are infinitesimally small and detailed while lumpers produce large, generally applicable concepts. Each of the patterns is equal to an element pair that reflects this ebb and flow of knowledge. Thus, the Rule of Equality provides:

1. Distinction = thing + not-thing
2. System = part + whole
3. Relationship = cause + effect
4. Perspective = content + context

The *Rule of Inference* parallels Aristotle's A/not-A and Lao Tzu's yin-yang, where one element infers the existence of its opposite. The elemental pairs are entangled in such a way that the conceptualization of one "infers the other." For example, part infers whole, cause infers effect, thing infers not-thing, content infers context, and vice versa. Cabrera contends that the form "A infers not-A" is implicate within the structure of knowledge because, "this form of knowledge appears in the beginnings of both Western (Aristotle) and Eastern (Tzu) thought" (Cabrera 2002). The Rule of Inference provides: (the form, x ß à y, reads, "x infers y and y infers x")

1. thing ß à not-thing
2. part ß à whole
3. cause ß à effect
4. content ß à context

The *Rule of Interchangeability* is based on the fact that any of the elements and patterns are interchangeable because they are isomorphs of each other. The Rule states that: *Any element or pattern is interchangeable with any other element or pattern.* The Rule of Interchangeability leads to the following possibility-space, or what I call, Conceptual Space*:

n chunks	1's	2's	3's	4's	5's	6's	7's	8's	9's	10's	**Conceptual Space**
0	1										**12**
1	1										**12**
2	2	1									**36**
3	3	3	1								**84**
4	4	6	4	1							**180**
5	5	10	10	5	1						**372**
6	6	15	20	15	6	1					**756**
7	7	21	35	35	21	7	1				**1524**
8	8	28	56	70	56	28	8	1			**3060**
9	9	36	84	126	126	84	36	9	1		**6132**
10	10	45	120	210	252	210	120	45	10	1	**12276**

**The basic equation used in each field is* $\frac{n!}{(n-r)!r!}$ *which explains the number of subsets that can be derived from n-set without regard to the order of selection; n is equal to the number of n-chunks; r is equal to the range within n chunks, recursive; the Conceptual Space is calculated by the sum of each row multiplied by the 12 possible states.*

It is not important that one follows the mathematics of how many possibility-states exist. It is more important to recognize that the massively parallel process of knowledge creation requires a massively parallel model to explain it. Each one of the abstract interchanges of "green" adds to an ever-expanding network of concepts. One quickly realizes that, if each of the possibility-states is itself a chunk, the growth pattern is exponential. Because concepts can be thought about in an infinite number of directions, it is impossible to predict which direction one will take and therefore how many combinations will be made.

The Rules of Equality and Inference are logical: a *thing* and a *not-thing* form a *distinction*, a *part* and a *whole* form a *system*, a *cause* and an *effect* form a *relationship*, *content* and *context* form a *perspective*. But is it logical that a part can *become* a whole or that a cause can *become* an effect or that content can *become* context and vice versa? In order for the Rule of Interchangeability to play out as it has been described—where both patterns and elements swap roles in a combinatorial play—this will need to be true. But is it logical?

In Fuzzy Thinking: The New Science of Fuzzy Logic, author Bart Kosko introduces the new science of fuzzy logic. As opposed to the bivalent logic (two state) of Aristotle, fuzzy logic is multivalent (multi state) in nature (Kosko 1993). Fuzzy logic is intimately tied to set theory—a significant contribution to the field of mathematics. Fuzzy logic is also the kind of logic that runs thermostats in cars and houses and a new class of intelligent computers. And, fuzzy logic supports the conventionally illogical idea that the "whole is in the part." In other words, fuzzy logic provides a model that corroborates the Rule of Interchangeability:

> But what about the presence of the whole in the part? In classical logic this is meaningless, but this is actually probability! If we consider the whole as the available state space, then if the whole is the same as the part the probability is 1, if the whole is infinite around the part then the probability is 0. Thus the whole in relation to the part is the probability (called the 'Subsethood Theorem') But the range of values for probability and fuzzy truth are the same! Thus we can say that the two are just alternative perspectives of the same thing, orthogonal views of reality, one concentrating on bottom up (fuzzy occupancy) and one on top down (probabilistic existence). This holistic view of fuzziness ties in nicely with the complexity perspective of downwards causation (the whole constraining the part) and upwards causation (the part forming the whole). More generally, both fuzzy logic and probability form part of Generalized Information Theory (GIT), which also contains other formalisms such as possibility theory and random sets." (CalResCo Website 2002).

Associative, bisociative, metaphorical and analogical connections are made between surface and deep similarities of abstract form (the elements). In this way, an infinite landscape of knowledge variations can emerge. This is an important point that was made earlier. It implies that the reason that "mysterious" connections between different concepts are so often made is because of *similarity* rather than *dissimilarity.* In other words, even dramatically different ideas are made up of the same stuff. For example, every idea is compatible with other ideas to form bigger ideas *because* every part is compatible with other parts to form new wholes. Of course, many of these first-step combinations are not viable. For example, one might imagine the head of a man placed on the body of a horse to create a new kind of creature. This is possible in the first-step because a horse head is abstractly similar (part to whole) to a human head. Using the selective filters of reason and deduction in the second-step, the man-headed horse will likely not survive. That is, unless the *context* is changed to be “otherworldly” to include mythological beasts.

Each new idea can be abstractly configured in a number of ways based on the rules. The further one gets into the runtime of the knowledge-creation program, the more staggering are the number of abstracted elements. This perhaps explains why the human mind leaves such a process to the processing power of unconscious thought. Yet, like any insight revealed, no matter how complex, this unconscious process can be consciously practiced and may someday become sub-conscious habit—what some might call creative genius.

In the past, knowledge creation—along with myriad complex phenomena—has eluded scientific scrutiny. Now, using the paradigm of complexity science, many complex phenomena are revealing their simple underbelly. The *Patterns of Knowledge* do not give us a picture perfect understanding of knowledge creation; only the runtime program of an actual knowledge-creation event can do that. But, the *Patterns of Knowledge* do provide an explicit model that elucidates the simple elements and rules that underlie knowledge creation.

Does Research Corroborate Cabrera’s Universal Patterns of Knowledge?

Are Cabrera’s *Patterns of Knowledge* corroborated by other thinkers or by research? While none of the literature explicitly endorses Cabrera’s Patterns, an array of writings, crossing a number of disciplines, endorse them in concept.

Renowned computer scientist, Edward Fredkin, explains his fascination and frustration with "seeing his ideas everywhere." Fredkin said the following about some of his new and unsubstantiated (since substantiated) ideas on information theory:

> I find the supporting evidence for my beliefs in ten thousand different places, and to me it's just totally overwhelming. It's like there's an animal I want to find. I've found his footprints. I've found his droppings. I've found the half-chewed food. I find pieces of his fur, and so on. In every case it fits one kind of animal, and it's not like any animal anyone's ever seen. People say, where is this animal? I say, Well he was here, he's about this big, this that, and the other. And I know a thousand things about him. I don't have him in hand, but I know he's there. . . . What I see is so compelling that it can't be a creature of my imagination. (Edward Fredkin, as quoted in Did the Universe Just Happen by Robert Wright (Kurzweil 2002))

Fredkin's thoughts on information theory give a good description of the nature of insight and the evolution of knowledge. His sentiment is one in a chorus of great thinkers who have felt similar frustration when required to provide evidence for the obvious.

Perhaps the oldest, Western-world endorsement for Cabrera's *Patterns of Knowledge* can be found at the very basis of Aristotelian logic—the relationship between A and not-A. Aristotelian logic asserts that the conceptualization of A also requires the conceptualization of not-A. This (A begets not-A) is called, bivalent logic. Bivalent logic is the cornerstone of modern science (Kosko 1993). Bivalent logic underlies the following relationships, which in turn underlie Western science:

0 = false = no

1 = true = yes

The philosophical premise that "one cannot conceptualize A without also conceptualizing not-A" is a logical and *a priori* premise. A, or any object for that matter, does not exist in a vacuum: when one conceptualizes, A, one must also consider that which is not A. This simple but profound logic is the foundation of the Western thinking. And, in many regards, it has served the evolution of science and technology quite well.

Conceptually, the ancient Eastern notion of yin-yang parallels both Aristotelian bivalent logic and Cabrera's *Patterns of Knowledge.* While these specific ideas (bivalent logic and yin-yang) may be worlds apart, they are conceptually the same. As a poignant example, Gottfried Wilhelm von Leibniz's binary system chart and Zhu Xi's diagram of the *I Ching* hexagrams are identical (Moran and Yu 2002). Aristotle's A/not-A and Lao Tzu's yin-yang are synonymous with Cabrera's *Distinctions* (thing/not-thing) and are also the conceptual basis for the interaction of all of Cabrera's elemental pairs. For example, part begets whole, cause begets effect, content begets context, and vice versa.

A number of credible thinkers, both old and new, confirm the notion of underlying mental elements in combinatorial play. "Whenever nature has created systems that seem to be open-ended and generative, they've used some kind of system with a discrete set of recombinable elements" (Hauser 2002). Knowledge is clearly an open ended and generative system. The *Patterns of Knowledge* provide the "discrete set of recombinable elements" for knowledge.

From what is now referred to as the "old Chomskyan tradition," (Lakoff 2002) MIT Linguist, Noam Chomsky, pointed to the universality of many linguistic features and suggested that an innate computational mechanism must be at play. This insight revolutionized the field of linguistics, and set much of the cognitive sciences in motion (Hauser 2002). Because linguistics is so central to knowledge creation, it seems plausible that similar "innate computational mechanisms" are also playing out in the evolution of knowledge.

In his recent book, Philosophy In The Flesh, UC Berkeley cognitive scientist, George Lakoff explains how conceptual metaphors underlie mathematics (and all forms of thought) and make it possible for people to use conceptually mathematical thinking even though it may not be recognizably mathematical:

> These metaphors for numbers are part of the mathematics, and you make a choice each time depending on the kind of mathematics you want to be doing. The moral is simple: Conceptual metaphor is central to conceptualization of number in mathematics of any complexity at all. It's a perfectly sensible idea. Conceptual metaphors are cross-domain mappings that preserve inferential structure. Mathematical metaphors are what provide the links across different branches of mathematics. One of our most interesting results concerns the conceptualization of infinity. There are many concepts that involve infinity: points at infinity in projective and inversive geometry, infinite sets, infinite unions, mathematical induction, transfinite numbers, infinite sequences, infinite decimals, infinite sums, limits, least upper bounds, and infinitesimals. Núñez and I have found that all of these concepts can be conceptualized as special cases of one simple Basic Metaphor of Infinity. The idea of "actual infinity"-of infinity not just as going on and on, but as a thing- is metaphorical, but the metaphor, as we show turns out to quite simple and exists outside of mathematics. What mathematicians have done is to provide elaborate carefully devised special cases of this basic metaphorical idea" (Lakoff 2002)

Lakoff's reference to "inferential structure" endorses the idea that all concepts retain such a structure. The fact that the "Basic Metaphor of Infinity" underlies so many mathematical concepts indicates that similar metaphors exist throughout the disciplines. For example, because all concepts *interrelate* with and are organized into *systems* of other concepts, it follows logically that all concepts retain inferential structure. In this example, the inferential structure is [the metaphor of] *Relationships* and *Systems.*

Even early on in the study of the mind and transfer, researchers referred to underlying elements, although most of this thinking appears to have been highly biased by the traditional logic. In 1901, Thorndike (1930) completed what is widely considered the first study of learning transfer. "This [Thorndike's] doctrine viewed the mind as a collection of general faculties, including observation, discrimination, and reasoning." In light of what we know today, it is clear that Thorndike's logical elements serve as the second-step in the evolution of knowledge. But, Throndike's leaning toward elemental structure and massively parallel integration need not be lost.

Kurzweil (2002), speaking about Wolfram and Minsky, offers a good description of the new kind of thinking and how such mental elements might interact,

> I do appreciate Wolfram's strong argument, however, that nature is not as complex as it often appears to be. Some of the key features of the paradigm of biological systems, which differ from much of our contemporary designed technology, are that it is massively parallel, and that apparently complex behavior can result from the intermingling of a vast number of simpler systems. One example that comes to mind is Marvin Minsky's theory of intelligence as a 'Society of Mind' in which intelligence may result from a hierarchy of simpler intelligences with simple agents not unlike cellular automata at the base (Kurzweil 2002).

The elemental pairs of Cabrera's *Patterns of Knowledge* are not unlike the binary pairs of cellular automata (e.g., the black and white squares). It is important to note that complexity emerges not because the elemental pairs *exist*, but because the elements *interact* over time. Cabrera's element pairs, like binary digits, are simple. The massively parallel interaction between and among these pairs, over time, is complex.

Ann Brown, in her studies of transfer and learning found that there are some ideas that are more fundamental than others. Brown called these ideas, "big ideas" and found that big ideas aided learning and transfer (Bransford 1999). Like a physicist who continually attempts to find the more fundamental elements, one wonders if there is a limit to the elemental nature of these big ideas? Are there ideas—like physical elements—that are so pervasive that they underlie all of knowledge? The *Patterns of Knowledge* explain how such ideas might work. If transfer between two tasks or disciplines yields "big ideas" (for example, that Lakoff's Basic Metaphor of Infinity underlies numerous mathematical concepts or that differentiation and integration is the basis for both calculus and ecology) then the *Patterns of Knowledge* are "huge" elemental ideas.

In a 1999 landmark study sponsored by the National Academy of Sciences (NAS) entitled, <u>How People Learn: Brain, Mind, Experience, and School</u> (Bransford, Brown and Cocking 1999), aspects of Cabrera's *Patterns of Knowledge* are endorsed in concept. For example, the authors endorse the importance of all of the *Patterns of Knowledge* and especially *systems* made up of *parts* and *wholes*, by stating:

> Perhaps the most pervasive strategy used to improve memory performance is clustering: organizing disparate pieces of information into meaningful units. Clustering is a strategy that depends on organizing knowledge. In a classic paper, Miller (1956) described the persistence of a phenomenon he called the "magical number 7 ± 2" in human mental processing. Given a list of numbers to remember, sounds (phonemes) to distinguish from one another, or a set of unrelated facts to recall, there is a critical change in performance at around seven items. Up to seven items (between five and nine, actually, hence Miller's title), people can readily handle a variety of tasks; with more than seven, they simply cannot process them handily. People have developed ways around this memory constraint by organizing

> information, such as grouping together or "chunking" disparate elements into sets of letters, numbers, or pictures that make sense to them.

Patterns are widely considered to lie at the basis of human thinking (Perkins 1992). The NAS study concurs, “An ever-increasing body of evidence shows that the human mind is endowed with an implicit mental ability that facilitates attention to and use of representations of the number of items in a visual array, sequence of drumbeats, jumps of a toy bunny, numerical values represented in arrays, etc.” The NAS Study also describes distinction making (as a contrast between the distinction being made and proximal stimuli) at length, “Infants have to be able to distinguish linguistic information from nonlinguistic stimuli: they attribute meaning and linguistic function to words and not to dog barks or telephone rings. By 4 months of age, infants clearly show a preference for listening to words over other sounds.” The study continues, “Young infants learn to pay attention to the features of speech, such as intonation and rhythm, that help them obtain critical information about language and meaning. As they get older, they concentrate on utterances that share a structure that corresponds to their maternal language, and they neglect utterances that do not.” The study indicates that distinction making is acculturated, “Like the development of the visual system, parallel processes occur in human language development for the capacity to perceive phonemes, the "atoms" of speech. A phoneme is defined as the smallest meaningful unit of speech sound. Human beings discriminate the "b" sound from the "p" sound largely by perceiving the time of the onset of the voice relative to the time the lips part; there is a boundary that separates "b" from "p" that helps to distinguish "bet" from "pet."

Boundaries of this sort exist among closely related phonemes, and in adults these boundaries reflect language experience. Very young children discriminate many more phonemic boundaries than adults, but they lose their discriminatory powers when certain boundaries are not supported by experience with spoken language (Kuhl 1993). Native Japanese speakers, for example, typically do not discriminate the "r" from the "l" sounds that are evident to English speakers, and this ability is lost in early childhood because it is not in the speech that they hear. It is not known whether synapse overproduction and elimination underlies this process, but it certainly seems plausible."

Again, while no source explicitly refers to the collection of patterns, elements and rules that Cabrera proposes, many sources taken from a broad spectrum of the sciences confirm the importance of one pattern or another. In The Evolving Self, Mihaly Csikszentmihalyi (1994) argues that the very survival of human society is based on evolving our ability to think more complexly. In concept, Csikszentmihalyi (1994) endorses *Relationships* and *cause* and *effect* when he states,

> Perhaps the most urgent task facing us is to create a new educational curriculum that will make each child aware, from the first grade on, that life in the universe is interdependent. It should be an education that trains the mind to perceive the network of causes and effects in which our actions are embedded, and trains the emotions and the imagination to respond appropriately to the consequences of those actions.

In a very different field from information theory, education, psychology or general science, management icon, Peter F. Drucker, eludes to a number of Cabrera's Patterns when he says:

> 'Only connect' was the constant admonition of the great English novelist, E.AM. Forster. It has always been the hallmark of the artist, not equally of

> the great scientist—of a Darwin, a Bohr, an Einstein. At their level, the capacity to connect may be inborn and part of that mystery we call 'genius.' But to a large extent, the ability to connect and thus to raise the yield of existing knowledge (whether for an individual, for a team, or for the entire organization) is learnable. Eventually, it should become teachable. It requires a methodology for problem definition - even more urgently perhaps than it requires the currently fashionable methodology for 'problem solving.' It requires systematic analysis of the kind of knowledge and information a given problem requires, and a methodology for organizing the stages in which a given problem can be tackled - the methodology which underlies what we now call 'systems research.' It requires what might be called 'Organizing Ignorance' -and there is always so much more ignorance around than there is knowledge.

Harvard professor of Education, Howard Gardner, created the popular Theory of Multiple Intelligences (Gardner 1995). Contrary to popular belief, the multiple intelligence types did not rise to the surface from one of Gardner's research projects; the intelligences cannot be found in the conclusion section of one of Gardner's research papers. Instead, Gardner deduced and gave names to these intelligence types based on numerous disjointed research projects in areas ranging from music learning to the study of psychological anomalies. Gardner's Multiple Intelligences Theory is widely used by educators and has contributed tremendous value to the educational debate, but no one can point to a study that verifies the actual existence of the intelligences. Does this mean that multiple intelligences do or don't exist? What it means is that Gardner has provided a viable model from which to frame and base our thinking and our future research. Gardner's model advances our ability to understand, and to put into words, what is going on in a classroom of different intelligences. At some point in the future we may discover that a better model exists and replace Gardner's model. The moral of this story is that models such as Gardner's Multiple Intelligence Theory are often not derived from a single research effort. Like the evolution of knowledge itself, sometimes these models emerge from patterns that traverse the intellectual landscape. Cabrera's *Patterns of Knowledge* reflect isomorphisms in the inferential structure of knowledge. Likewise, much of the current support for Cabrera's *Patterns of Knowledge* is inferential.

Across the disciplinary landscape, from physics to business management, great thinkers and credible research points to a number of these conceptual isomorphs. These isomorphs cross-disciplinary boundaries and act as conceptual least common denominators. Sometimes the words that are used are slightly different, but the underlying meaning is the same:

Knowledge is Patterns

Knowledge is Distinctions

Knowledge is Systems

Knowledge is Relationships

Knowledge is Perspectives

Underlying these Patterns are the elemental pairs such as cause and effect, part and whole, thing and not-thing and content and context. When one stops looking so intently and relaxes the eyes, one realizes that the "animal" that Fredkin refers to is really neither rare nor elusive. The *Patterns of Knowledge* are pervasive.

Chapter 3

EDUCATIONAL IMPLICATIONS OF KNOWLEDGE AS A COMPLEX EVOLUTIONARY SYSTEM

Important Research Areas

Our discussion in this paper began with normative goals of education; goals that provide a backdrop for more technical discussion of knowledge as a complex, evolutionary system. Cabrera's *Patterns of Knowledge* provide a model that supports the normative educational goal in terms of knowledge creation. Now it is time to come full circle and connect some of the educational topics facing teachers in the classroom with the *Patterns of Knowledge.* Out of a long list of research areas, a handful of important topics have been chosen. This section relates some of the research in each area to the *Patterns of Knowledge* and knowledge as a complex, evolutionary system.

Implications for Cognition, Transfer and Analogical Reasoning

The central argument in the transfer research is between those who believe that transfer occurs merely by surface associations of shape, size, and form and those who believe that there are deeper, more "essential" associations that cause transfer. The warring camps might be called, "essential elements" and "deep principles." But Medin and Oteney (Brown 1989, p 180) wisely float in both camps, "In this discussion, we consider the implications of the distinction between the more accessible, surface, aspects of representations and the less accessible, deeper, aspects for the nature of similarity and its role in cognition." They continue, "Central to the position that we advocate, which we we'll call psychological essentialism, is the idea that these surface features are frequently constrained by, and sometimes generated by, the deeper, more central parts of concepts."

Another thread of research on transfer is in the realm of analogy making. Specifically, there is a great deal of discussion as to the structures and functions of knowledge. Brown (1989) refers to “isomorphs.” Isomorphs in transfer are concepts that are similar or identical in form, shape or structure. In her seminal research on transfer, Brown shows (p384-5) that children choose underlying conceptual structure over surficial patterns in a task associated with pulling objects using sticks and canes.

To a large extent, transfer has either been dealt with in broad strokes in a way that leaves transfer a mysterious process, or in the kind of fine detail that seems to miss the forest for the trees. But, throughout the transfer research there are references to pattern recognition, part-whole thinking, causal relations, distinction making, and context. "The main types where the stimulus-response-outcome models” (Dienes and Jeeves 1970). “The other type of model, the role (whole, role) model, suggested that the subject was learning to associate role to a certain part of the structure" (Dienes and Jeeves 1970). Brown (1989) makes frequent reference to causal relations and the importance of context in transfer but fails to point out that causal relations require abstract part-whole structures and that shifts in context require reciprocal shifts in content. Perkins (2000) explains that the recognition of patterns is the basis for thinking, transfer and intelligence. The *Patterns of Knowledge* are the universal isomorphs that are so important to transfer.

As teachers, it is critical that we provide our students with tools for learning. Clearly, transfer and analogical reasoning are central to learning. When students are made aware of the isomorphic patterns of knowledge, they will be better able to accomplish the normative goals of education.

Implications for Breakthrough Thinking (insight)

The following excerpt is taken from an article in the New York Times entitled, *Here He Comes to Save the Día: Super Rico Is Born* (Medina 2002):

> After they heard the roar of Flight 11 over their classroom and watched on television as the World Trade Center crumbled, the students in Nina Anastasia's class at Public School 721 on the Lower East Side wondered if the people would have been saved if Superman had swooped in from above or Catwoman had scampered up the towers.
>
> Then, in April, when the promotion of "Spider-Man" also spilled into her classroom, Ms. Anastasia moved to capitalize on her sixth and seventh graders' fascination with superheroes. She decided to have the students create their own comic book superhero, one that might give them a lesson or two in writing and grammar and along the way help them work out some of the feelings lingering from Sept. 11.
>
> After considering Spiderboy or Superboy, the class of nine sixth and seventh graders came up with Super Rico, an all-powerful Puerto Rican tree frog, or *coqui*, who wears blue briefs and a red cape and can leap tall buildings and hurl razor-edged lily pads. No other comic book character has his compassion, Puerto Rican street argot or incredibly sticky tongue, the students say.

How does a class of sixth graders evolve their knowledge from Spiderman to Super Rico the lily-pad hurling tree-frog superhero? The same way that a pack of street kids improvises a basketball net out of a dumpster and a shopping cart.

Kevin Cannon / Las Vegas Review-Journal

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Is this kind of breakthrough thinking a mystery of the human mind or a logical art form? Harvard professor of education and MIT trained mathematician, David Perkins (2000) coined the term "breakthrough thinking" in his book, The Eureka Effect: The Art and Logic of Breakthrough Thinking. In it, Perkins describes a number of processes that lead to breakthrough thinking where he uses complexity, chaos and evolutionary theory. Perkins explains that breakthrough thinking occurs in a two-step process, "first infinite possibility states and Klondike factors, then logic and reason" (Perkins 2000). Perkins does a good job of providing general strategies that lead to breakthrough thinking. For example, "generating good bets," "brainstorming," "looking for generativity," and "pursuing promise." Yet, these strategies are too general in nature to offer anything but a starting point. Finer detail is needed in order to turn these strategies into a learning science. Such detail, combined with Perkins' strategies would provide an ample model from which to teach. For example, a teacher might instruct students to "brainstorm" and then continue the lesson in greater detail: "Ashleigh, consider two different systems and then combine their parts" or "Kevin, what would you get if you took what you are saying and applied a different context?"

Super Rico and the shopping cart basketball net are not mystical or haphazard innovations of the human spirit. Nor are they merely, as Perkins suggests, semi-conscious adherence to general strategies of breakthrough thinking. These innovations are logical out births of a complex emergent process originating from simple elements and rules.

> Need a Super Hero…Superhero's throw stuff…We are Puerto Rican…What is Puerto Rico known for?…Rain forest…What lives in the

> rainforest?…Tree frogs…What could a tree frog throw?…Lilly pads…But that wouldn't hurt?…Put razor edges on them.

Underlying this logical flow of questions is an elemental structure: What are the parts of the distinction Superhero? What are the parts of the distinction Puerto Rico? What are the parts of a frog's environment? Tree frog is a part of the group *frogs*, the frogs I've seen live in ponds, and ponds have lily pads. Lily pads are round. What else is round that is also lethal? Circular saw blades. And so on.

It is illogical that Super Rico—a Puerto Rican *tree* frog—would throw lily pads, but it is also wildly creative. The students of Ms. Anastasia's class, created new knowledge by combining the abstract elements of various distinctions, systems, relationships and perspectives. What they ended up with wasn't logical, but it was extremely creative. And it solved the classes' particular problem—the needed a Super Hero. Their solution was creative enough to be a Super Hero. It was creative enough to be reviewed in the New York Times. Someday, this kind of thinking will be creative enough for the student's in Ms. Anastasia's class to get a promotion, solve a family problem, or develop a cure for cancer.

Similarly, the street kids are not mysteriously bisociating dissimilar constructs of *shopping cart* and a *dumpster* with *basketball net* and *pole*. The shopping cart likely began as a moving basket but moved around too much to be used in a game. The children needed a stationary pole like the NBA. The dumpster is a part of the system: "things in the environment at the right 'dunking' height." As an abstract shape, the dumpster, is no different than a supporting pole but better serves the relationship required by the "hooked" undercarriage of the shopping cart. The street kids are using the abstract form and function of the constructs in their environment and manipulating distinctions, systems, relationships and perspectives to meet their needs.

The majority of school hours are spent learning knowledge that has already been created, knowledge that has already been exposed to the logical forces of the second-step. This knowledge has already been selected for viability in the logicscape. This kind of knowledge is extremely important. Indeed, it is the basis for evolving human societies who build upon ancestral learning. Yet, we now know that there is another important step in the knowledge evolution, which involves the creation of knowledge —the first-step. In our schools, this first-step is largely ignored. Yet, in our society, the individuals who complete both steps—creation and selection—are rewarded for their insight, creativity, innovation and problem solving skills. The *Patterns of Knowledge* provide an elemental curriculum for the full process of knowledge creation and selection.

Implications for Interdisciplinarity

The research and practice on interdisciplinarity ranges from combining a course in English and African American Studies to larger attempts to organize best practices of interdisciplinarity from a viewpoint that knowledge, in and of itself, is a single discipline. For example, it is common practice in colleges to create departments of interdisciplinarity that serve the needs of students who's interests do not fit neatly into the boundaries of the academic disciplines. It is also popular to combine courses in which students learn a skill through the study of an otherwise different content area. For example, learning to write (what was once called Freshman Writing) through semiotic analysis of contemporary media such as the television show, *The Simpsons*. Recently, numerous hybrid disciplines such as eco-physiology or socio-biology have emerged as leading fields in the sciences. These are interdisciplinary sciences, but should there be a Science of Interdisciplinarity?

The study of interdisciplinarity (also related to and/or synonymous with Transdisciplinary or Integrated Studies) must mature into a credible science of connectionism (something akin to Peter Drucker's advice, "Only Connect"). In other words, the field of Interdisciplinarity must develop—similar to the fields of Physics, Mathematics or Chemistry—its own unique ideological frameworks, methods, and best practices (Conversation with Bill Newell 2001). Such a Science of Interdisciplinarity would itself become a discipline, rather than the combination of disciplines. Complexity science provides a good framework for the science of interdisciplinarity. Because the study of complex phenomenon is inherently multidisciplinary, complexity science crosses many disciplines of science. Yet, complexity science is much more than a smorgasbord of connections between the disciplines. Complexity science is itself a discipline that embraces sundry ideologies, terminologies, methodologies, technologies and best practices.

I propose that the assumptions that underlie the *Patterns of Knowledge* and the notion that knowledge is a complex evolutionary system provides a disciplined framework for a new kind of Science of Interdisciplinary that is marked by greater *discipline*. This paradigmatic framework provides the desperately needed parameters for

Interdisciplinary research that will lead to better understanding and practices of how we should develop interdisciplinary thinkers.

It turns out that developing better interdisciplinary thinkers is not only relevant to a new kind of Interdisciplinary Science, it is also a critical step in creating better schools that prepare students for life. In other words, the new science of interdisciplinarity is also a critical educational imperative. As society becomes globalized, so do its problems. Even more so than traditional problems, globalized problems are decidedly cross-disciplinary. Global problems have a knack for disrespecting disciplinary boundaries. The result is that interdisciplinary thinking, interdisciplinary problem solving, interdisciplinary teams and specialists who function well as a member of an interdisciplinary team, will be in increasingly high demand. In his book, Consilience, E.O. Wilson (1998) writes, "The ongoing fragmentation of knowledge and resulting chaos in philosophy are not reflections of the real world but artifacts of scholarship."

Thus, the future of interdisciplinary pursuit is also the future of educational curriculum as well as the future of the workplace. The ideal interdisciplinarian is also the ideal contributing member of society. Interdisciplinarians have far more to do than to merely combine English and African American Studies courses into a unified curriculum. Interdisciplinarians are the future problem solvers in a global society where problems are increasingly complex and cross-disciplinary.

Implications for Learnable Intelligence and Multiple Intelligences

An important implication of Cabrera's *Patterns of Knowledge* is that they may underlie each one of the intelligences proposed by Gardner in his *Theory of Multiple Intelligences*.

Of course, research that confirms this hypothesis is needed, but it seems at least plausible that there may be a more *universal intelligence* underlying Gardner's multiple intelligences. Because the *Patterns of Knowledge* are conceptual (verses merely linguistic) isomorphs they are capable of underlying the knowledge creation abilities of a wide range of intelligence styles including those styles that deal with non-linguistic or perceptual constructs (Cabrera 2002). For example, an individual of musical intelligence uses the same A/not-A distinction making to identify and differentiate notes in the ear and in the mind. The table below offers a brief overview of Gardner's Multiple Intelligences in relation to Cabrera's *Patterns of Knowledge:*

Linguistic	Makes distinctions, antonyms and synonyms, organizes distinctions into words, words into, phrases, phrases into sentences (systems), plays with words to create different relationships and perspectives (poetry)
Musical	Makes aural distinctions, organizes systems of notes into symphonies of sound, relates notes in different ways and develops consonance and dissonance
Logical-mathematical	Makes distinctions of number and symbol, organizes systems such as equations, relates variables and creates perspectives based on certain rules, unit of analysis.
Spatial	Makes object-oriented distinctions, relates objects in various ways, creates systems of objects and alters space to form various perspectives
Bodily-kinesthetic	Feels distinctions of relationships and systems in the body. Is in tune with various perspectives of the body such as feeling the back muscles through leg extension, etc.

Interpersonal	Awareness of the feeling, goals, motivations of other's and their competing interests. Is able to see different perspectives and relate them in a systemic way.
Intrapersonal	Easily differentiates one feeling from another and has awareness of systems and relationships and various perspectives.
Naturalist	Classifies natural objects into distinctive systems based on relationships and environment (perspective)

The hidden *Patterns of Knowledge* are really not hidden at all. They have been in use by all archetypical intelligences for centuries. The task at hand is to bring these implicate patterns to the surface. Underlying the various forms of intelligence is a universal intelligence, a conceptual intelligence, a learnable intelligence. We must teach these patterns.

Implications for Testing and Assessment

As discussed in Chapter 2, Stephen Wolfram makes three important points in his controversial book, A New Kind of Science. Wolfram's (2001) third point is his magnum opus of sorts—the *Law of Computational Equivalence*. Wolfram's idea of computational equivalence serves as a backdrop for an idea about educational testing and assessment that will likely be equally or more controversial than Wolfram's book. But first, an explanation is needed of Wolfram's computational equivalence.

The gist of Wolfram's computational equivalence is that all phenomenon of "sufficient complexity" are equally complex. In other words, because complex systems are based on simple rules and a runtime program (a time series in which the simple rules combine and create emergent patterns) one cannot adequately predict the complexity of a "sufficiently complex" system without somehow (impossibly) out running the runtime of the complex program. It is not necessary that one understand the full extent of Wolfram's computational equivalence, only that one grasps the basic idea. As an analogy, Wolfram's idea is similar to stating that it is impossible to know whether a particular child will turn out "good" or not. Just because a child behaves badly, even criminally, does not preclude the possibility that sometime in the complex runtime of that child's life, a pattern of social conformity, human compassion or self-actualization cannot or will not emerge. Likewise, based on what we know about learning today, it turns out that it is impossible to truly measure learning.

So little is known about learning and how it occurs that an attempt to measure learning to any degree of certainty demonstrates bias and hubris. This is *not* an argument against assessment. Instead, it is a proposal that testing should occur only to get better at testing, and that biased and ill-informed tests should not be used as criteria for the placement or advancement of human beings. Does this mean that assessment should not be used in classrooms? No, it doesn't. Assessment can be a valuable tool as a part of the learning process when it is used as a feedback mechanism for the learner. In other words, assessment should be used as an instrument of learning but not as an instrument of placement and advancement.

Children are "sufficiently complex" phenomenon that one must respect the possibility that there is far more occurring than meets our scientific eye. Therefore, instead of testing for the purpose of placement and advancement, it should be used to develop better knowledge of testing. If this sounds like a circular argument, it is. But it is a logically and scientifically valid circular argument. First, it is common scientific practice not to blindly accept one set of research data as truth. Truth is only established when *enough* data supports it. Reproducibility is a cornerstone of the scientific method. The underlying assumption in the idea of reproducibility is that one must have enough scientific data before one reaches scientific conclusions. Second, it is scientifically unethical to test human subjects with potentially dangerous drugs or to subject them to harmful social experiments. The ethical standards of pharmaceutical research ensure that potentially harmful side effects are controlled in non-human tests before FDA approval is given for human consumption. The same principles should apply to educational testing and assessment. Exposing human subjects to the potentially harmful side effects of testing instruments that have not been sufficiently validated on non-human subjects is unethical. Some educators and presidents will argue vehemently with the notion that current testing is unethical. The common argument is, "well then, how do you plan on assessing learning for advancement, for college acceptance, for degree completion?" This argument is based on two fallacies: 1) the fallacy that current testing adequately serves these needs and, 2) the fallacy that *something* is better than *nothing*. Imagine if pharmaceutical researchers used this same kind of argument for providing bogus cancer-drugs to cancer victims; "Well then, if you don't use this [placebo] Xeripitinol® then how do you plan on saving people from cancer?" To people whom want a better answer for testing in education, the answer is: *there is no answer*. The test, like the cure-all for cancer, does not yet exist. In science, no answer is better than an unreliable answer.

It is a reasonable argument that assessment, in and of itself, does no inherent harm to students. However, when testing is used to advance or place students it clearly has the potential to do harm. It is acceptable then, to test students in order to refine our testing abilities. And, it is acceptable to assess students as feedback in the learning process. But, when testing is used as a mechanism for placement or advancement, an incorrect assumption is made that the runtime program of a complex system (a student's learning) can be outrun. Wolfram's *Theory of Computational Equivalence* points out that a student's learning is as complex as the teacher's testing. It seems scientifically obvious that one cannot measure learning until one knows what it is one is measuring.

It may be that no test will ever adequately measure learning. If science can adequately describe how learning occurs, how the brain makes connections, how transfer, intelligence, cognition, understanding, and knowledge work, then perhaps testing can be used for placement and advancement. Even then, as Wolfram points out, it may be difficult or impossible to sufficiently judge the complexities of the runtime program. In the meantime, assessment is a valuable feedback tool in the learning process as long as it is not used for placement and advancement. The *Patterns of Knowledge* can help teachers to more accurately understand and assess the complexities of the learning process and of the learner.

Implications for Pedagogy

It is said that education should not be about filling buckets but lighting fires. This parallels Freire's thoughts on the "banking concept" of education, where teachers make deposits of information into students, versus his more advanced *dialogics*, the highest form of dialogue (Freire 2000). From Friere to Dewey to Piaget to Perkins, great thinkers on education have concluded that education was about liberation, experience, development, or knowledge. None of our great educational thinkers have argued that education is about memorization, regurgitation, facts and content. Yet, the “Content King” drives so much of the education complex. Teachers are trained to be experts in content. Students must master content. Courses are framed around content. Tests and grades are determined by how much content can be memorized. Courses are structured by textbooks, which are designed around content. All of this, despite the fact that few 30 year olds can remember any of the content they learned, say, in freshman year chemistry. It appears that our system of education is nearly antithetical to the thinking of society’s greatest educational thinkers.

There is no doubt that our current educational paradigm is based on the notion that a teacher knows stuff that the student needs to know. Given the enormous complexity of the human mind and the infinite potential for knowledge evolution described thus far in this paper, it seems imbecilic to exist in such a paradigm. Our methods of teaching are akin to Darwin making a futile attempt to *direct* the entire complex evolutionary process rather than merely to *describe* it.

It is clear to many teachers and administrators that we must move away from the Content King paradigm where content reigns over the curriculum and he who holds the content rules the learning process. The question is not whether or not to revolt against the Content King, but what kind of system replaces him? The replacement for the Content

King, is a new paradigm where the teacher acts as "Facilitator of Transfer." In this paradigm the teacher need not be an expert in the topic of discussion because the teacher merely deals with abstractions of content. This allows for many new developments in the classroom and in pedagogy.

First, the content "bottleneck" that is caused by the teacher-is-expert paradigm is removed. In the vernacular of the dotcom era, "the classroom has more bandwidth." Because the Content King paradigm is based on the idea that the teacher knows the content and the students do not, it is clear that anytime discussion expands beyond the boundaries of the teacher's knowledge, it must be herded back within the parameters of what the teacher knows. When teacher is facilitator of transfer, students may engage in complex *dialogics* in which the teacher facilitates important ideas throughout of the conversation. The teacher need not know anymore than the students about a subject in order to perform his or her new duty as transfer expert.

Second, students actively engage in learning by thinking and through dialogics. Students struggle with problems and solutions. Students gain practice in creating new knowledge rather than memorizing existing knowledge. When memorization is required, students recollect the information because they have created meaningful structures into which facts are distributed rather than laundry lists of meaningless data.

Third, when Content King is dethroned, articles such as textbooks and curriculum no longer act as an oppressive king's attorney where chapters and facts impose their structure upon learning. Instead, textbooks and curriculum are utilized as resources of distributed intelligence. Students learn how and where to find the information they need rather than learning information that the teacher believes is important to the student. This practice leads to the development of skills that lead to lifelong learners. In addition, poorer schools will not be faced with the financial liability of content such as textbooks. Poorer school districts will invest money into long-term information sources such as internet access rather than industry-driven textbooks sales.

It is one thing to advise that a change in the pedagogical paradigm is needed. It is yet another to provide useful models that allow teachers to turn paradigm into practice. The *Patterns of Knowledge* will help teachers to 1) bring out the natural processes of knowledge evolution in themselves and their students and, 2) be capable of tracking and facilitating the complex and infinite number of connections students will make when they are allowed to. There are of course countless other methods and technologies that will serve the teacher as facilitator of transfer. The *Patterns of Knowledge* provide a solid foundation.

Chapter 4

CONCLUSION

Knowledge and Liberation

The evolution of knowledge—whether for whole societies or a single individual—is a two-step process. The first-step exists as a kind of explosive algae bloom of diverse knowledge. The second-step uses logic as a kind of Darwinian razor, cutting through the fluff, selecting irrational conclusions for annihilation, and leaving viable concepts to adapt and survive. The beauty of the human existence is its tendency toward self-creativity combined with logical precision. The complexity of knowledge is bewildering enough that we have the tendency to mystify it. Yet, simple patterns underlie the mystifying complexity of knowledge evolution. The evolution of knowledge, like the evolution of species, will likely always be a complex. But, the simple underlying *Patterns of Knowledge* can be taught, learned and practiced.

Paulo Freire (2000) proposes that education is about liberation. David Perkins (1992) proposes that education is about knowledge. The author proposes that Freire and Perkins are in total agreement. When a student can adeptly create, retain, understand and use knowledge they are also able to liberate themselves from the bondage of ignorance as well as from the oppression of the "knowledgeable."

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