

THE CHEMISTRY OF EDUCATION: A PERIODIC RELATIONSHIP

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To my daughters, Kaitlyn, Hailey and Madyson who teach me daily;
to my numerous students from whom I continually learn to teach;
and to Leah the most patient and inspiring teacher, mentor, and writer.

ABSTRACT

The purpose and focus of this research is to examine a chemistry of education and to build a metacognitive bridge between the two disciplines, chemistry and education, through autobiographical narrative development of a relational periodic table for education. The *elements* of teaching are integrated using the actual model of the chemical periodic table of elements as a working metaphor to re-understand teaching and education. Through the narrative analysis of the inter- and intra-relationships (the educational *chemical reactions*), this thesis posits a new understanding of the *complex matrical* relationships of education and thus expands this relational knowledge toward developing new and better methods for teachers, students and for all investors of education to engage in and experience the *chemistry of education*.

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PROLOGUE

¹The Call to Teach

"Hello. Is this Michelle?" the voice belonging to the Chairperson of the Department of Chemistry asked.

"Yes." I replied, my heart pounding, echoing in my ears so loudly I was having trouble hearing what he was saying.

"Would you be interested in coming back to teach for us on a full time basis this semester. Your work last semester was exceptional and we need a full-time sessional instructor this term."

Given I had just handed in my resignation a mere few moments before, quitting a job in agricultural research, specifically ruminant biochemistry, a job I detested and could no longer make myself get up for in the mornings, I jumped at the chance. After we discussed the particulars of salary, start date, job description and set a meeting date for the following week, I hung up the phone relieved and elated. At least I would be out of one of the hell-holes I was currently in, although it would still be doing something [teaching] I had intentionally avoided over the years. But anything [working for minimum wage included] was a step up from my current job.

I began teaching five introductory chemistry courses that fall, a heavy load at the best of times, and most particularly for someone new to teaching. Being the only female in an all-male environment, there was little support and acceptance for a young, over-enthusiastic female trying to make a mark and so mentoring from my colleagues was not an option. I relied on my own learning experience, recalling past instructors in my field who had presented and delivered the curriculum to me when I was a student. I taught like I had been taught. After all, I had learned from such a style and it was obviously effective because there I was. Somewhere in such thought processes though I forgot how much I had loathed learning that way, how frustrated I had many times been with my instructors. I forgot the stark contrast between my incredibly positive secondary experience and my often, frustrating, university experience. As I continued to teach that

¹ Tropes and short stories I have written will be presented in italics with one and one-half spacing and a centered title to highlight and separate them from the body of the text.

way for the rest of the semester, I lulled myself into believing things were going smoothly, and for the most part they were. The students learned and passed.

The end of every semester is marked by evaluations, performed on the instructor by the students essentially ranking one's [the instructor's] teaching abilities at the hand of the students' learning experience, the results of which [fair or unfair] are used by department chairpersons and deans when it comes to evaluating performance for meritorious increase. My evaluations for that semester were above average with comments such as; "Michelle is an excellent instructor; Michelle is. . . personable, easy to approach, always listens, always has a smile, never makes anyone feel foolish, never makes anyone feel inadequate or stupid, et cetera". But none spoke to my teaching style, to my ability to teach the curriculum, to my ability to stimulate curiosity, et cetera. I was disappointed. In my enthusiasm I wanted to be that "all-engaging" interesting teacher who stimulated conversation, thought processes, curiosity, much like my grade six English teacher, Mrs. M. What was I doing wrong? And then I read the comments of one student:

Michelle has the potential to be an excellent, even great, teacher but right now she just delivers the curriculum. She teaches like she has been taught, I suspect, and does not put any part of herself, her own ideas, her own passion into her teaching. You see that passion when she engages one-on-one but it is lost when she is teaching to the whole. Michelle should take an Education course or two to really learn how to teach. (Student evaluation, 1991)

At first I was angry at such a judgment. What does this young whipper-snapper-person know? How dare she? I looked at the back of the evaluation form for a clue as to who the originator of such "rude" comments was. The student was an Education student.

"Figures," I thought, and read, re-read and re-read those comments as I remembered the shy, young not so whipper-snapperish girl in the far left, back corner of the classroom, my suspect originator. Was there some truth, some merit to her comments? Ouch!

I took that evaluation personally and was devastated to the point of quitting. "*I knew I wasn't meant to teach!*" was my initial response, but it is not my nature to quit. So I began to look at my teaching as if I were sitting in the student's spot. Would I be engaged? If not, then how was I missing the mark? I came to the conclusion that I was doing what most university professors/instructors did and that was simply "delivering the curriculum" rather than engaging the students into wanting more. I thought about Ms. E., Mrs. S. and Mrs. M. and other teachers who had taught me and who had a significant impact on me. They certainly engaged and I did with them as well. What were the differences? I thought about the periodic table of chemical elements and the inter- and intra/relationships [the chemistry] that exists within and throughout the table and the chemistry involved in those relationships. Reflectively, I looked at my own philosophy of the *chemistry of education* and realized there is considerable difference between the curriculum-as-planned and curriculum-as-lived-experience (Aoki, 1991). I recognized that often my delivery of the curriculum might not be the best of "lived" (van Manen, 1994), for the student.

I am a biochemist and I began to think of teaching as being much like a chemical reaction. The path or reaction mechanism is much like the curriculum in education. Like any reaction, there are specific steps [easy and difficult] and in order to produce the endproduct, the reactants must engage in each of these steps. The reaction of teaching [education] is a re/active process and it is rare to get from the start to the finish [endproduct] without some difficulty.

CHAPTER I

INTRODUCTION

"Such a language would be...one that grows in the middle."
(Ted Aoki, 1993, p. 9)

"A teacher has two jobs, one is to feed the minds with knowledge and the other more important is to give their minds a compass so that the knowledge doesn't go to waste." (*Mr. Holland's Opus*, 1995).

Location of the Researcher

I was *never* going to teach. In fact, when it was repeatedly suggested by many of my university professors who thought I had a natural ability to make the difficult understandable in an interesting and engaging fashion, that teaching would be a good career choice, I very adamantly disagreed, saying, "*There is no way on this earth I will ever teach!*" Part of that came from my innate shyness but mostly the field of education seemed not a place where my analytical, scientific mind could be stimulated such that I would find it sufficiently challenging and engaging. So during and following my undergraduate education, I spent a number of years doing very *interesting* [to me] scientific research in such areas as agricultural, soil, food, water and oil sands chemistry, and finally applying my knowledge and research skills to the very rewarding area of cancer research. Upon relocating to a new city with limited opportunities, the only job I could garner was that of teaching chemistry and biochemistry in a university environment. Thus, I reluctantly began teaching and what was supposed to be a short, interim, two-semester job has turned into a twelve-year career. With continued residence in the teaching field, I have come to realize how difficult it is to teach and that not only is it an art but it is also a science. Such a combination of art and science does, in fact, have

a chemistry that must exist so that the educational experience is a good one for both the teacher and the student.

The impetus for this work was born from not only my desire to understand my own teaching and relational experience, but also to put into context the relationships of teaching at both the theoretical and pedagogical levels as well as at the practical and experiential levels. One of the major problems I have encountered over the years at the tertiary level of education is in the teaching practice itself. There appears to be an underlying assumption that any person with a doctorate is automatically able to teach simply by virtue of holding that piece of paper and being an expert in his or her own discipline. Often an individual is hired into a professorial position [generally one in which research performance is more highly regarded, preferential and expected than teaching performance] and is expected to start teaching the minute he or she begins his or her position. Many new professors have taught very little, some not at all, during their academic training and post-doctoral positions. To be *tossed to the wolves* without any sort of training or coaching can lead to the rude awakening that "not anyone can teach," the result of which is *teaching difficulty*.

The second underlying, prevalent, and somewhat arrogant assumption, seen most often in the sciences, is that the professor is the expert [all-knower] and the student is the [empty-headed] learner (Miller and Seller, 1991). This is a philosophy that can result in polar and intimidating relationships of power between the teacher and the student. The results of such dynamics often leave the student feeling overwhelmed by negative feelings that interfere with the cognitive acquisition and development of knowledge, skills, and attitudes resulting in a less-than-favourable learning experience.

There is also the indoctrinated personal philosophy of *payback* (Grumet, 1988) the adage of, "*Because I had to do it that way so should everyone else following. After all, look at me...I made it [somewhat scathed I think] but I am successful.*" This is so particularly true of the physical sciences at the tertiary level but as a parent I have also experienced this philosophy at the elementary, intermediate, and secondary levels in my own interactions with my children's teachers. There is often little room for flexibility or differing approaches to teaching, particularly when one [the teacher] is out of her comfort zone. As a parent I find this frustrating and as a teaching instructor at the tertiary level, infuriating because it thwarts the learning enterprises.

I see these issues as pivotal teaching and learning problems and have always felt that there has to be more to teaching than just the "delivery" of curriculum. The traditional content and framework are essential to education, but this traditional approach should be looked at in light of new data about contemporary events and the feelings, ideas, and conceptual learning needs of teachers and students who are living current, institutional curricula. Not only should there be an acquisition of information [knowledge], but there should also be some sort of transformation that makes it a meaningful process so that it becomes part of the learner's constructed knowledge. As well, there needs to be some evaluation of the education enterprise in terms of the breadth and depth of content and relevancy to the learner (Bruner, 1960; Pinar, 1997) rather than, again, the mere presentation of the curriculum.

My position as a university laboratory and course instructor has given me an advantage in that I see teaching, and the role of the teacher/instructor, as a carefully planned intervention with the goal of facilitating a change in behaviour and

understanding (the learning process). Alfred North Whitehead, according to Sherburne (1966), theorized the mere presentation of information will not necessarily result in assimilation [obtaining the information]. Rather, there has to be some means of engagement whereby that instruction gets metamorphosed to learning as the acquisition of knowledge, skills, and attributes. Even at the tertiary level, and even in such disciplines as the sciences that apparently, although not rightly, seem to be removed from philosophies of grounded teaching practices, it is possible to pay holistic attention to the curriculum, the program, the course, and the experience of the students. The responsibility lies at the hands and minds of those designing, developing, and implementing the curriculum and those facilitating the acquisition of the knowledge and the integration of the curriculum to relevant, applicable experience. How that is done, is the responsibility of the teacher/instructor/facilitator and is also a product of the environment in which the learning takes place, all of which involve a particular chemistry. Education at all levels, is a complex matrix of the *inter-* and *intra-*relationships of the teaching of the curriculum and the experience of such teaching from the point of view of both the student and the teacher.

My “ideals” about teaching, the integration of imparting and constructing knowledge in a fashion that also provides meaningful experience, is not a philosophy well-recognized or practised at the tertiary level, particularly within my own discipline. I teach in an all-male department, one that has never had a female colleague and one that is very much inculcated within its traditional patriarchal philosophies and practices of teaching. I often suffer criticisms that I am “*too nice*”, “*too concerned*”, “*too sensitive and caring*” and my teaching style and way of engagement is “*just a woman’s way of*

doing it'. These criticisms have been a source of personal conflict for me and have led to such polar feelings ranging from extreme anger and outrage at the injustice of the stereotype, to feelings of inadequacy at my more relational approach to teaching.

Devaluation of the student experience in favour of assumed efficiency in delivering the curriculum at any cost, criticisms of my teaching style, as well as several difficult incidents and unfair practices over my teaching career, particularly in the past five years, have not only elevated my level of frustration as an instructor but have resulted in a deepened concern for quality teaching and learning experiences. Thus, disillusioned, I began reflecting on my own teaching practice and my philosophies, as well as the whole paradigm of teaching: *What is education? What is it we are doing in education? What is the purpose of education?* These were just some of the questions that began to plague me.

Education Versus Training

"The first duty of an education is to stir up life, but leave it free to develop."
²(Maria Montessori-1870-1952).

I watched as he released his pup from the end of its leash, a dark chocolate brown lab with huge bear-paw like feet and knees that seemed to bend in non-normal directions so that his feet swung like pendulum weights hanging from the bottom of chocolate chains and seemingly having no ability to provide a stable support for the enthusiastic body atop. Those feet really didn't know where they should be, certainly not on the shoulders of his owner where he placed them giving him the ability to stand human-like and kiss his face in gratitude for the chance to run free. He was scolded sharply for that affectionate action and made to sit properly until set free with a gesture known to both dog and master. And off he took at breakneck speed, freedom from the restriction of the leash,

² Quotes from Maria Montessori (1870-1952) are taken from the website "Montessori Wise Words-Quotes (<http://members.tripod.com/~junejuno2/words.html>) and thus will be only referenced by her name where ever they are used throughout the paper.

bounding, leaping, racing back to his master, circling, nipping at his heels, and off again, ears laying flat back against his head making him into an aerodynamic bullet slicing through the cold, crisp, winter air, his tongue, scarf-like, flapping behind.

What is the penchant we have with training/educating our animals, our dogs in particular, and our young? I have often wondered why we make them conform to our way of being. Is it that we want them to be more like us? Why do we insist on taking away that bit of carefree zest for life, that enthusiasm, and constrain it into some ritualistic pattern of sit, jump, stay, roll over, play dead. Why play dead? That point is reached soon enough; is it really necessary to practice for it? Some people go through life, passionless, afraid to live, live a dying life. Maybe playing dead makes dying easier? The young, dogs and children alike, know how to live, have a natural born curiosity, zest, enthusiasm for life, for learning. Why do we insist on squelching that? Most likely as adults we lose that, and become lost in the ritual of daily living. Possibly in adults we should cultivate more spirit than mechanical living as a scientist (Maria Montessori). As educators we need to notice the leashes we use in teaching as well as the "liberations" (Freire, 1970).

Vast literatures explore the difference between education and training but I began to consider my own assumptions about such differences. As one whose work it is to educate others, a teacher in the finest sense of labels and a supposed specialist in the theories, methodologies, and pedagogies of the process of education, I have difficulty with the boundary between *education*, the process of training and developing the knowledge, mind, and character by formal schooling or teaching (Webster's Dictionary, 1976, p. 444), and *training*, the action or method that leads to the process or experience of having been trained (Webster's Dictionary, 1976, p.1508). To me training reduces education: it makes robots, de-individualizes, makes persons who can sit, jump, roll over, and play dead, but it does nothing for providing the tools for individuality, providing the compass to navigate in the world, to "think outside the box." I feel my role as an

educator, particularly lately and especially at the post-secondary level, is to do exactly that: train students to perform some set of tasks [rituals] set by society or industry for financial remuneration only but never for the sheer curiosity of answering the question on the lips of all five-year-olds: "*Why?*" I am often discouraged by the loss of the passion, desire, and curiosity for learning I now see in the eyes of my five-year-old, which is still present in my nine-year-old, but that is beginning to be lost in my nearly thirteen-year-old and that is certainly lost by the time the eighteen-year-olds enter my courses. What happens to that desire and passion, to know *why*? As educators, why do we lose our curiosity, lose our desire to understand, why do we conform?

Herbert Spencer suggested, "before there can be a rational curriculum, we must settle which things it most concerns us to know...we must determine the relative value of knowledge." The question of questions for Spencer was "What knowledge is of most worth?" (Spencer, 1909, p.11). In Spencer's naturalistic-evolutionary analysis of human affairs, he concluded that *science* [the broader version of social and practical science as well as the physical and life sciences] is the knowledge of most worth. Knowing what knowledge is required can shape curriculum thinking and will help assess the relative value of various curriculum items. The question *What is the curriculum and how is that curriculum taught?* is a perpetual one that must be asked every day. Mark Van Doren (1959) stated, "the college is meaningless without a curriculum, but it is more so when it has one that is meaningless." (p.108)

So then, what does it mean to educate? The word *educate* originates from the Latin word *educatus*, of *educare*, meaning to bring up, rear or train, or develop the knowledge, skill, mind, or character of, especially by formal schooling, study, teaching or

instruction (Webster's Dictionary, 1976, p. 444). In order to educate, there must be a curriculum. Authentic and viable curricula must be designed and developed, consistent with our presuppositions about what is necessary. Different philosophical approaches will produce different curricula. What is the chemistry that maintains that passion? In the words of Maria Montessori, "the training of the teacher who is to help life is something far more than the learning of ideas. It includes the training of character; it is a preparation of the spirit."

With these persistent questions about curricula, I began examining more broadly the *inter-* and *intra-*relationships of teaching, of my own teaching of chemistry, of education. I began to examine the idea of a chemistry of education. I began to think that my knowledge of chemistry and of chemical relationships could extend to education at all levels, to a complementarity between the structural foundation and the practice of how that foundation is taught, received and perceived. What do we know? What do we need to know? What knowledge is of most worth? What is the patternicity (Fowler, 1997) and periodicity? I knew my own tertiary chemistry-teaching experiences were not unique but were just one set of stories from one educator. What were the other stories, the counter-narratives? If, we as researchers of education look at the stories and their patterns, how can we reframe or develop a new set of patterns and relationships, a new paradigm, so that we get the best and most effective results and experiences in both teaching and learning? The obvious place to look for answers to such deep, difficult, and complicated questions was to the discipline of education. Thus began my serious study of a chemistry of education and the building of a bridge between the disciplines of chemistry and education.

Purpose and Focus of the Research

"What would happen if we looked at the world beyond the garden this way, regarded our place in nature from the same upside-down perspective?" (Michael Pollan, 2001, *The Botany of Desire*, p. xvi).

The purpose of this research is to explore, develop, construct, and explicate a periodic table of the elements of teaching using the actual model of the *chemical periodic table of elements* as a working metaphor to focus our understanding and to help re-understand teaching and "relational education" (Fowler, 1997).

Chemistry is the elemental science that deals with the composition and properties of substances and with the reactions by which substances are produced from or converted into other substances and includes the chemical properties, composition, reactions, and uses of the substances (Brown, 2000). All aspects of the physical world are tied to chemistry and chemistry, being an extremely practical science having a very influential impact on our daily living, provides an important understanding of the workings of our world. Such essential questions as: What is the nature and structure of matter? What is the composition of the physical components? What are their properties and how do these influence their action, interactions, and reactions? as well as, How and why do they undergo change? are raised about the chemistry of our interactions with the physical or material world. Chemistry by its universality of language and ideas allows us not only to describe and understand matter, but the universality of its language and ideas allows us to understand the multitude of complex reactions that take place and exist in other systems.

Similar questions of education can also be asked: What is the composition of the physical components of education? What are their properties? How do they undergo change? Chemical principles apply to all aspects of our daily life and in general all

chemistry can be explained by the behavior of the chemical elements that make up matter.

Why the Periodic Table?

For me too, the periodic table was a passion. . . . As a boy, I stood in front of the display for hours, thinking how wonderful it was that each of these metal foils and jars of gas had its own distinct personality. (Freeman Dyson in Oliver Sacks, 2001, *Uncle Tungsten*, p. 203)

"Design in nature is but a concatenation of accidents, culled by natural selection until the result is so beautiful or effective as to seem a miracle of purpose."
(Michael Pollan, 2001, *The Botany of Desire*, p. xxi)

At the tertiary level in particular, knowledge is often fragmented as each individual teaches in her area of expertise with little extension out of a habitual comfort zone. This often leads to a piece-meal or smorgasbord effect of education rather than a clear connected picture and it is often difficult to see how the individual realms fit the schemata of the whole subject area. Scholars at all levels of education, for many reasons stemming from professional jealousy to simply lack of time, have lost the ability to communicate with one another and often operate in a singular disconnected practice [particularly at the tertiary level]. This lack of communication and correlation results in the inability to relate one's subject matter or area of expertise to other areas of knowledge. I find this to be so true of the field of science as researchers and educators concentrate their efforts only in the field, resulting in a relatively narrow view or perception and little applicability. I believe there needs to be coherent patterns into which we can fit the various subjects of the curriculum such that their inter- and intra-relationships become more visible and accessible for study and thought.

The periodic table of elements, developed by the Russian chemist Mendeleev in the years 1868-1870, is a graphical schematic means of understanding such a complex subject as chemistry by fitting all the facts, the elements, into a simple logical pattern. It

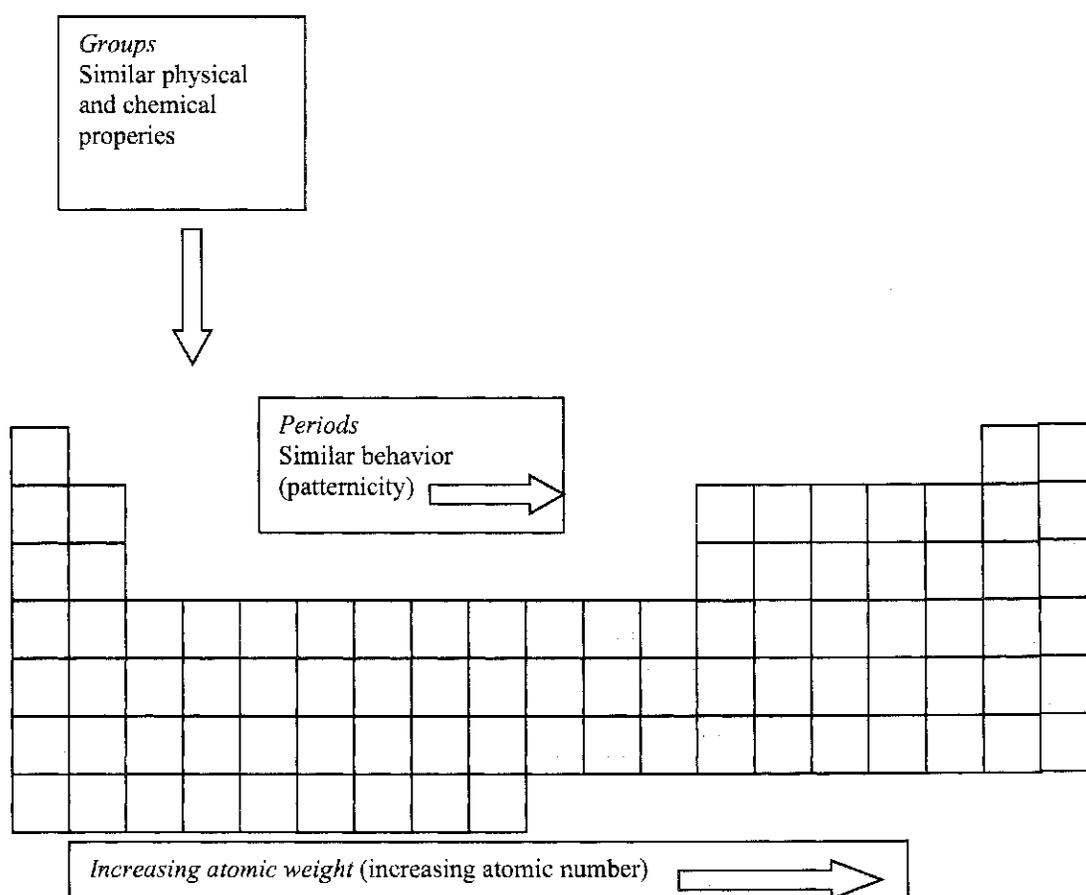


Figure 1. The basic structure of the Chemical Periodic Table of Elements.

systematizes the properties of the elements and such a systemization provides a logical, accurate, descriptive, framework for explaining and predicting the *periodicity* and *patternicity* of the elemental properties and their compounds as well as their interactions and reactions.

The elements of the periodic table are arranged in order of increasing atomic weight with the *groups* being the vertical columns and the *periods* being the horizontal rows. Those elements in the same periodic group or family possess similar chemical properties while the relational behavior can be explained by the periods [trends across the table]. The periodic table is full of repeating patterns and this patternicity enables us to determine the relational behavior of the elements within the periodic table and also the concrete world of matter. Each grouping and patternicity allows for the unique opportunity to predict the behavior of an element or the outcome of a reaction relative to the position of the given element within the table. Thus the physical principles of chemistry are explained by the structure or framework of the periodic table, while the actual chemistry is explained by the relational patternicity [reactions between the elements] of the periodic table.

Just as Michael Pollan (2001, p. xiii) in *The Botany of Desire* wondered "what existential difference is there between the human being's role in this (or any) garden and the bumblebee's?" I too wonder what is the existential difference between chemistry and education and what is the chemistry involved in education? Like the comparison of human beings to bumblebees in the garden, it is really not a stretch of the imagination, nor laughable (Pollan, 2001, p.xiii) that chemistry has a profound effect on education.

Much like the garden or a ³temenos, the construct of the ⁴periodic table, and its

³ A temenos is a sacred grove or garden created as a place for meditation. A literary temenos is a structure created out of language and just as a garden has an overall design, the literary temenos is a whole that is greater than the language and images that form its building blocks thus holding the whole of the language. A temenos is also a crucible to contain hot and dangerous elements in chemical reactions.

⁴ The periodic table is a structure or an arrangement of its elements [basic components] into a pattern and can therefore be considered the temenos of chemistry. A periodic table developed for education would hold the whole of education, the reactions of which can be described through narrative, the arrangement of experiences [the elements and their reactions] into patterns and stories.

general application to the language and ideas of chemistry, can offer an engaging metaphor for thinking about the complex elements, patterns, reactions, and interactions of teaching. Education is the process of developing the knowledge, mind, character et cetera, especially by formal schooling, teaching, or training that, in its most formal setting, takes place at an institution of learning. The systematic study of the methods and theories of teaching and learning leads to, or should lead to, the attainment of knowledge and ability. To educate is to teach and/or instruct, to train or develop knowledge, skill, mind or character (Webster's Dictionary, 1976, p. 444). Such a formal, denotative definition of education is very simplistic in that it describes its functionality but does nothing to describe its the breadth and depth, the dynamics of education, the actions, reactions and interactions – *its chemistry*. I purpose that the discipline of education does have its own chemistry, its own patternicity and periodicity. It is grounded in fundamental principles or pedagogies that provide its structure and framework. The elemental basis or content of that framework is essentially the curriculum (Pinar, 1995), which although it varies, does have an enduring and fundamental, core position within the frame of education. How that curriculum is taught by the teacher and experienced by the student involves a fundamental chemistry, the relational experience of coming to know, understand, and apply that understanding in life. What is the chemistry of education? How can the complex relational matrices of education be represented in a schematic and symbolic form? What is the nature and meaning of the chemistry of education? What are the intra- [within] and inter- [between] relationships that lead to effective or non-effective teaching? To achieve a thorough understanding of such a complex, dynamic and living discipline as education, it is

tempting to find a metaphoric structure that fits all the elements of education into a logical pattern much like the periodic table of chemistry. As educators, we look at the construct of a periodic table as the "*temenos*" (Fowler, 1997, p. 2) that holds all the philosophies, pedagogies, principles et cetera and how they are translated and experienced through chemical reactions/engaged pedagogy (Hooks, 1998). If we believe there is a chemistry to education, both in terms of its content as well as in how it is taught and experienced, then there is a definite inter-connection or bridge between chemistry and education. It is possible to conceptualize education in terms of a periodic table and then look at the periodicity, patternicity, and predictability of such a "chemistry of education."

The focus of this research is to examine the chemistry of education with the purpose of building a bridge between the two disciplines through the development of a periodic table for education in order to provide a new understanding of the complex matrical relationships of education and thus expand this relational knowledge to developing new and better methods of engaging in and experiencing the "chemistry of education."

I call this the chemistry of education because there is a particular chemistry, many reactions and inter/actions, which occur in the teaching and learning of the curriculum of education at all levels. Relationships of all sorts can be viewed from a structural, elemental, or fundamental vantage point. I am interested in exploring the question: what are the elemental components of the teaching and learning reactions? Related questions ensue: How do those components of the educational reactions inter-relate? What affects that inter-relationship? What are the subsequent educational outcomes? What causes such

inter-relationships to fail? What happens when they do fail? How can we maximize such inter- and intra-relationships to get the most and the best products without jeopardizing the reactants (teachers, students, and curriculum) or the products (knowledge)? What are the key relationships and reactions in the chemistry of education? These are all questions to be considered when we are looking at the science of effective and non-effective teaching.

I propose that the chemistry of the reactions in the fundamental framework of the periodic table of elements could provide an analogous blueprint to education and could foster understanding of not only the mechanics of the inter- and intra-relationships but also the chemistry of those relationships. The mechanics are grounded in the fundamentals of the graphic frame of chemistry, the periodic table, while the experience is grounded in the chemical reactions. Experience can be shared narratively through the lab notebook and experimental observations in chemistry, and through narrative knowing (Polkinghorne, 1988) in the form of narratives in education.

In this research, I work inductively to construct a periodic table for education using the conceptual frames and historical development of the chemical periodic table to theorize and analyze the structure and relationships of education. The principles behind the chemical reactions will be used to develop analogous “educational” reactions that can then be used to theorize the relational matrix that leads to effective and/or non-effective teaching. The fundamental frame for the educational periodic table will be constructed from grounded theory, pedagogies, and philosophies of education. The specific chemistry [the relational reactions] will be substantiated by personal narrative [literary] data, in the form of narratives from the field of education. The resultant educational periodic table

may then be used to think about, explain, predict, and to possibly theorize and suggest avenues for future educational practices.

CHAPTER II

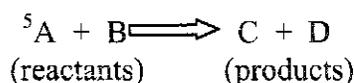
LITERATURE REVIEW

The periodic table is more than just the structure or framework for the chemical elements of the physical world. It is also a creative, aesthetic artifact that shows the historical development of the philosophy, epistemology, and original discoveries of chemistry. Oliver Sacks said of the periodic table;

...I found myself looking at the table in almost geographic terms, as a realm, a kingdom, with different territories and boundaries. Seeing the table as a geographic realm allowed me to rise above the individual elements, and see certain general gradients and trends. (Sacks, 2001, p. 191)

...I could mentally trace its paths in every direction, going up a group, then turning right on a period, stopping, going down one, yet always knowing where I was. It was like a garden, the garden of numbers I had loved as a child--but unlike this, it was real, a key to the universe. I spent hours now, enchanted, totally absorbed, wandering, making discoveries in the enchanted garden of Mendeleev. (Sacks, 2001, p. 194).

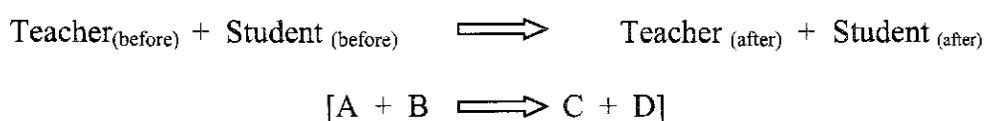
How the elements relate to each other, their reactions, are based on fundamental theoretical principles of chemistry, but the actual observable outcome of the reactions provides the most significant information; the *what* [the product]. It is one thing to *say* reactants A plus B produce products C plus D, a basic reaction description that is illustrated as such,



How the reactants A plus B produce the products C plus D, the *how* that is experienced by the components of the reaction, by the surrounding environment, the system in which

⁵Throughout the document, A and B will be used in formulas to generically represent reactants while C and D will be used to generically represent products, both in chemical and educational reactions.

the reaction takes place, and other elements within the system or environment is the *what* that leads to the quality and experience of the reaction. The *why* is the story [the purpose of the research] and embedded within it are the far-reaching effects and implications of such a reaction. An analogous reaction can be used to describe teaching; the engagement of the teacher and student [the reactants] at any or all levels,



forming the *what* [the products of "changed" (after) teacher and student]. The *how* is the experience of the teacher and student during and in that engagement [reaction] and how and why that takes place and is experienced leads to the quality of the experience and effective or ineffective teaching and/or learning. Robin Williams said in the film *Awakenings* (1991), the periodic table is the "universe at its essence... every element has its place in the order, secure, no matter what". The periodic table, and the chemistry housed within it, can not only be used to explain relationships within the chemical world but it can also be transposed to metaphorically explain teaching relationships and experiences in the educational world. Such a metaphor can be used to bridge the disciplines of chemistry and education.

William Doll in *A post-modern perspective on curriculum* (1993) used the concept of frames to metaphorically represent education in terms of mini-paradigms from both a personal (qualitative) and situational (quantitative or physical/countable) point. His concept was based on the work of Donald Schon (1983) who suggested that frames are ways in which we construct reality, as well as the work of Jacques Derrida (1978), who claimed that frames provide a representation, a way of encapsulating *what is* and

what is not. The (chemical) periodic table can serve as a frame for education, but I suggest that it has broader and more far-reaching depth of purpose, it is a *temenos* (see page 15), a container, which holds the whole of education. Even more so, it contains within it a *vision* of education. As Immanuel Kant and his followers did, Doll not only draws on the science of philosophy as "*the frame for analysis*" (Doll, 1993, p.12) but he uses philosophy even one step further and as a means of "edifying" (Doll, 1993, p.12) practical and situational problems.

In looking to chemistry as a means of understanding education, such analytical and edifying principles are built directly into the reactions and inter/actions of the elements [the chemistry] within the periodic table. The outcomes of the reactions themselves, the products, provide that means of analysis and edification. The qualitative experience, the actual chemistry of the reactions and interactions of the elements of the periodic table, is further substantiated by hermeneutic and phenomenological narrative methods of documenting experience, the data in the form of the lab notebook, the observational results of the experimenter. Doll (1993) himself, uses continental thought, "-hermeneutic and phenomenological-" (p. 12), as a means of establishing "a sense of community, dialogue, historical interpretation, and exploration of paradox" (p. 12). Such thought is critical to understanding the educational experience from the vantage points of both the teacher and the student [the reactants], the reaction of which leads to the formation of the products [changed teacher and student].

Although, as Doll (1993) suggests, other fields or disciplines such as "art, architecture, literary theory, literature, management, mathematics, music, philosophy, political theory, the sciences and theology" (p. 12) should not be used as models for

curricular development in education [an error commonly made by imitation curricularists]. Looking to the assumptions and methods used within these disciplines is a heuristic tool of analysis and explanation for curriculum theorists and designers. He states, "there is a need to study other disciplines and to abstract metaphorically not literally, those ideas and ideals which have pedagogical potential" (Doll, 1993, p.13). Such pedagogical potential can occur naturally with the use of the chemical periodic table of elements as a metaphor for the understanding of the elements [the principles] and the chemistry of the interactions and reactions of the elements [the pedagogies] of education.

Paradigms

The etymology of the word *paradigm* stems from the Greek word *paradeigma*, meaning to show an example, and is defined, according to Webster's dictionary (1976, p. 1028), as an example, a pattern, or a model. In Thomas Kuhn's definition, "a paradigm controls the 'methods, problems and standards' (Kuhn, 1970, p. 48) a community uses as well as the broader 'constellation of beliefs, values, techniques', (Kuhn, 1970, p. 175) it cherishes" (Doll, 1993, p. 1). Such a definition serves to bridge both chemistry and education.

Paradigms exist within all fields and some, like many of those found in chemistry, are entrenched in their doctrines and difficult to change. Others undergo a metamorphosis on a relatively regular basis and some are continually transforming and shape-shifting. If one looks at science, probably the greatest and most easily understood paradigm is that of natural selection and Darwin's theory of evolution (Darwin, 1964). Such a theory has stood the test of time and is entrenched within the fabric of biological science. The periodic table too, is a paradigm, a pattern, or model for chemical reactivity.

In both science [chemistry] and education, the respective paradigms can be divided into modernism and post-modernism. Modern science had its beginnings with such pioneer scientists as Nicholas Copernicus, Galileo Galilee, Albert Einstein, Neils Bohr, and Werner Heisenberg whose work led to the paradigm of *scientism*, which in essence was grounded in procedure-based dogmas. There was little room for a philosophical view of the workings of science but rather it was a production type of science with the end-result being a quantifiable product. Herbert Spencer [Spencerianism], Isaac Newton [Empericism] and Rene Descartes [Rationalism] brought to science a "new" more philosophical view or paradigm that eventually served as a base for the social sciences, education included (Doll, 1993; Smith, 1982).

Science in the *modernist* era moved quickly making great leaps and bounds. Discoveries were continually taking place largely because the "wheel" was being invented with each new discovery, not re-invented, so science was viewed as the "knowledge of most worth" (Doll, 1993; Smith, 1982). Education though had been around forever and so curriculum reform, changes in paradigms and philosophies, was a matter of *re-inventing the wheel*; finding a way of reforming the curriculum such that education was a positive, stimulating experience both for the teacher and the student, something new.

Disenchantment with science and its lack of ability to *save all* occurred as curriculum reform began to take place and the philosophies of Isaac Newton, Rene Descartes, and Herbert Spencer were set aside as the the transition from modernism to post-modernism began. It was the beginning of a "new" more philosophical, less dogmatic, still practical science [physics, chemistry, biology, mathematics]. The impact

of this "new" science in post-modernism lead to the *Enlightenment* rationality of the past two centuries (Doll, 1993). The era of post-modernism, everything after modernism, is far reaching and spans all disciplines from the sciences to the social sciences. Unlike modern thought, indoctrinated in rigid, black and white, philosophies and principles of *doing* rather than understanding the doing and the outcomes of doing, post-modern thought relaxes the rigidity of the dichotomies that exist between the doing and the experience. It is less rigid in practice and thought and allows for flexibility of the experience. Where modern science was grounded in organized theory, structure, balance, stature, and complexity, the new science based on these foundational principles is governed by self-organization, having a flexible, changing, and even dissipative structure and qualitative thought processes. Like the chemical reaction of above, this new post-modern science allows us to experience the formation of the products from the interaction and reactions of the reactants. It allows us to look at what happens when the reaction fails rather than just the fact that the products were not produced because the reaction failed. As Doll quotes Waters, "it allows us to remove the Cartesian straightjacket we have imposed" (Waters, 1986, p. 113, in Doll, 1993, p. 5). Being a synthesis of the traditions of modernism, post-modernism is "eclectic" (Doll, 1983, p. 8) in nature and thus it allows for choice and creation.

By the very nature of the above characteristics, post-modernism is multi-layered, and if one looks at it, as Jencks (1987) does, as a matrix, much like the periodic table, one can see it is a "paradoxical, dialectical, challenging: a play of ideas"...a "double-coded" (Doll, 1983, p.8), mix of the past and present. In comparison to the closed, bounded system of modernism, post-modernism is an "open system," having no top or bottom or

limiting boundaries and is more readily represented by chemical reactions. Because chemical reactions are subject to the surrounding environment, the system in which they take place, be it a biological system or a physical/chemical system, they are subject to challenge and will adapt accordingly [and are capable of transformation]. The use of the periodic table as a rubric for education fits perfectly into post-modern philosophy and possibly even better because it has dimensionality; the frame or structure [foundation and basic principles, the curriculum], the reactions [interaction and reaction of the elements within the structure] and the experience [narratives, qualitative observations] are all embedded within its three dimensional structure not only giving flexibility but depth and transformability. It is highly complex, more indeterminate and more interactive, much like the "new" science and education of post-modernism.

The curriculum, the structure, should not be defined as the "course-to-be-run" (Doll, 1993, p.13) or the course-to-be delivered but rather it should be defined as a process much like the running of a race or a marathon. Like any race, the course is just the frame, the path, the currere (Pinar, 1995, p. 414), the means to the end. The actual race however, the process, establishing one's personal best, is the learning or the transformation from the start to the finish. The periodic table therefore, could be viewed as the course of chemistry, containing the content, and the reactions between the elements is the process. Together, the content and process form the curriculum (what and how) integrated with the experience. Hermeneutics [the interpretive analysis of text] and phenomenology [the attentive and philosophical study of literal phenomena] are a useful means of interpreting or analyzing the data of those qualitative, experiential narratives necessary for understanding in the post-modern disciplines.

I do believe modern thought and experience are the foundation and backbone, the principles and paradigms critical to post-modernism. However, because the works of the contributors to modernism, for both science and education, are too voluminous to present in this thesis, I will concentrate on those from the post modern era whose work I feel most relevant to my research.

Cognitive Constructivist Theories

In bridging the disciplines of chemistry and education, one must consider the philosophies and pedagogies that exist within both disciplines and develop a strategy that pays attention to both. The physical sciences have the image of being a "hands on" or a "doing" way of learning where specific skills and techniques are developed that require considerable cognitive skills that translate the theory into the practical. The teaching of the physical sciences is most logically governed by philosophies of cognitive constructivism. Cognitive structures are the brain patterns of physical or mental action that underlie specific acts of intelligence and correspond to stages of cognitive development or understanding. Knowledge of the cognitive processes used in learning, on the part of the teacher/instructor, such as a) the processes or methods utilized by competent learners b) the initial state of the learners prior to instruction and c) how the learner moves from the initial state to the end state during the learning process are a significant part of post modern thought and cognitive constructivist theory. Constructivist approaches to teaching and learning have emerged from the works of early psychologists and educators such as Jean Piaget, John Dewey, Jerome Bruner, Alfred North Whitehead and Lev Vygotsky. These thinkers, although not in the post-modern era in that they were alive before the popularity of the movement in the 1980s, were "ahead of their time" and

their way of thinking and being has had a significant impact on post-modern thought. These researchers significantly contributed to the evolution of the understanding of education and shape my own assumptions and underlying beliefs as I develop my periodic table of education.

Theory of Jean Piaget

The pioneer of cognitive constructivism, Jean Piaget, theorized that children evolve through specific chronological stages in which their cognitive structures become more progressively complex. Piaget describes individuals as active participants, rather than passive receivers of knowledge and the differences observed in the intellectual function among individuals can be attributed to chronological age, content knowledge, experience, interest, and their social milieu (Flavell, 1963; von Glaserfeld, 1998). Although his theories apply more directly to pre-school and early school-age children, two key principles do emerge which are more broadly applicable and which can be applied to all learning (Flavell, 1963).

1. Learning is an active process where direct experience such as allowing students to make errors and to look for solutions is imperative to the assimilation and accommodation of information.
2. Learning is a whole, authentic and real experience where understanding meaning comes from allowing the learner to interact in meaningful ways with the world around him/her.

Jean Piaget [Piagetism] based his theories on a biological model where humans interact with their living systems such that the reaction is a compensatory one. The equilibrium that exists between the reactants and the products [human or chemical] can

be interrupted by an external force or a challenge to the system so that re-equilibrium is established, this time at a new, higher level of more knowledge or experience. If one looks at this in terms of a chemical reaction then,

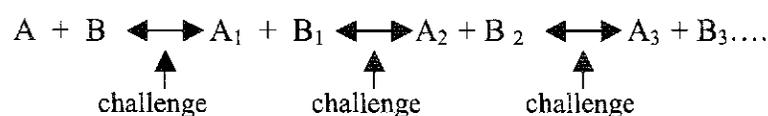


Figure 2. A chemical reaction depicting Piagetism. The reactants, A and B, establish an equilibrium with products A₁ and B₁ such that the forward reaction is equivalent to the reverse reaction until the system is challenged. This causes a shift in the equilibrium and a new equilibrium is eventually re-established at a higher [depicted by the subscripts] level (2). Each time this happens a higher level of knowledge [1 → 2 → 3] or experience, a new understanding, way of being or a higher standard is attained.

Such a philosophy can be directly applied to the *hands-on* learning environment of the chemistry laboratory if the students are allowed leeway to make and correct mistakes [failed experiments] as well as draw relevant and meaningful worth from their work. It also applies to all levels of cognitive education in that learning is a step-wise process and is often best learned and retained by the experience of our mistakes.

Theory of Jerome Bruner

Jerome Bruner (1960), considered to be more of a behaviorist with cognitive constructivist theories, suggested there exist two modes of cognitive functioning, or ordering of experience in meaning making, both of which complement one another but function differently. In his book, *The process of education* (1960) and his later book, *Actual minds; possible worlds* (1986), Bruner theorized that learning is an active and social process whereby the student selects information, originates her own hypothesis and makes decisions that are based on her own experience, past and present, all of which are a

part of the development of her existing mental constructs. Learning is facilitated by a variety of teaching methods which allow students many choices and opportunities to discover principles by themselves. The teacher/instructor is a facilitator whose purpose is to translate information to the learner in a format appropriate to the learner's current state of understanding. Bruner (1973) believed in going beyond what is given in the information, extrapolating what we know to what we do not know. Thus, the curriculum should be organized in such a fashion that students continually build upon what they have already learned (Bruner, 1973; 1986).

Bruner's theories are based on the importance of social interaction as a means of both teaching and learning. We teach others by how we are in the social milieu and we learn from others through social interaction. He calls this "social reciprocity" or "learning from others" (Bruner, 1986, p. 138). In his social reciprocity philosophy, he suggests that in our interactions with others we learn about ourselves and our community, important concepts that are better learned through experience rather than sitting in a seat in a classroom in an isolated environment. Science labs are highly social requiring that one interact with one's partner or partners in order to do the work and carry out the experiment carefully. In other words, one learns from one's peers and one has to find ways of working with others. He believes that humans are by nature active and searching and such characteristics are broader in nature and enable one to learn through sheer curiosity and looking for the answers. Such looking requires one to interact socially, and such social learning is critical to one's development and way of being. He believed too, that learners are constructors whose constructions improve through their own repeated practice, learning from others [seeing how they do it] and reflecting on the how, what,

and why of what they have done (Bruner, 1986). The extent of their constructions are directly dependent on how they reconfigure the information from such interactions and incorporate the information as "learned" knowledge, transforming the learner from a copier to a generator or a builder of the construction. Bruner recognized this did not apply well to new or very young learners but even they could take social learning and apply it to the self.

Bruner, like Piaget, believed in pushing oneself beyond the limit of stasis, disrupting the equilibrium so that newer and higher levels of learning could be achieved and applied such a philosophy to the concept of challenging or pushing personal structures such that in doing so a higher level of construction [organization] is attained. Even in the younger grades, Bruner believed that children could learn that it is possible to change their limits and they could incorporate other patterns into their thoughts (Bruner, 1986).

In contrast to Piaget who thought more developmentally, Bruner was more concerned with individuals and thought more intra-speculatively with significantly more emphasis on the self and self-reflection. Bruner further applied such a philosophy to the curriculum in that the curriculum should be turned onto itself, be taught and reflected on, changed and this process repeated. According to Doll (1993, p. 124), Bruner is famous for his "spiral curriculum" where the curriculum is studied over a number of years at increasing complexity such that the knowledge distils down to a perfection of the material, a depth of understanding [added layers of purity, density, complexity, richness].

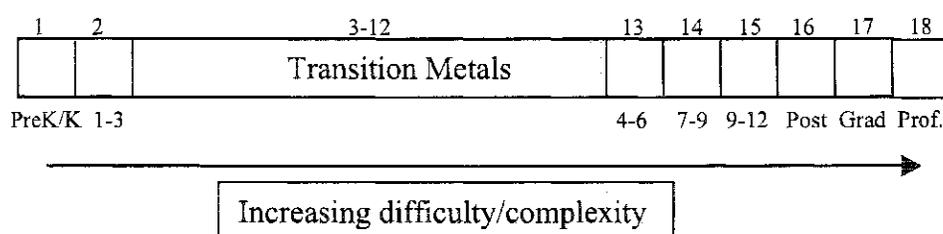


Figure 3. The increasing complexity [spiral curriculum] of a given subject or course across the periodic table. The degree of complexity increases because the ability of the individuals at the different levels increases and they have more ability draw on other resources, such as social interaction and learning from others. The diagram depicts one row of the periodic table [any row] as a subject or area of study, the numbers at the top of the diagram represent the vertical columns [groups or grade levels] and the numbers at the bottom of the diagram represent the levels represented by the groups.

In looking at the periodic table as a metaphor for education, if one thinks of the groups [vertical columns] of the periodic table as the different levels of complexity of education (i.e. grades 1-3, 4-6, 7-9, 9-12) and one looks at a particular subject, say math or English, as one proceeds horizontally across the table [through the grades] the degree of complexity with each level increases.

Like other post-modern theorists, Bruner also believed that knowledge or learning was not built solely of logic, but also through hermeneutics and "other" forms of knowing. Knowledge, according to Bruner, is developed through *multiple perspectives* [looking at something from different viewpoints], *presuppositions* [making hypotheses or assumptions about what might take place based on prior knowledge or experience], and *subjectifications* [subjecting or challenging the boundaries of one's knowledge to go beyond subjecting one's learning to scrutiny] (Bruner, 1986; Doll, 1993).

If one thinks like Bruner, then hermeneutics, the interpretive analysis of texts and returning to questions of original difficulty and subtext, applies to all disciplines,

including the sciences. In science one tries to get an experiment to work from many approaches, varying the parameters of the system little by little until the reaction works [multiple perspectives]. These variations of parameters can be numerous and time consuming and often we look to resources, including others' experience, for a hint as to how to make the reaction [the experiment] work. We make presuppositions based on previous self-experience and other's experience, presuppositions which in science are generally called hypotheses. We continually challenge the boundaries of our knowledge. For example, if we know this [something] now, what happens when we change some parameter or provide a challenge? How does what we know apply somewhere else? If we were to change this variable, what would happen? These are only a few of the representative questions that fuel many scientific curiosities. Bruner's cognitive constructivist philosophies fit well with science and education and the construction of a bridging periodic table.

Theory of John Dewey

John Dewey, commonly referred to as the "*Father of Progressive Education*," rejected rote learning in contrast to the more developmentally progressive "*directed living*" whereby the students learn by working on large more relevant projects in a workshop-type setting. Such a philosophy is conducive to a skills-type learning. His ideas, which are at the heart of constructivist curriculum, imply that students need to be engaged in meaningful and relevant activity in order to allow them to apply the concepts they are endeavouring to learn (Dewey, 1938). Students who do not see relevance to what they are learning, or who do not get the opportunity to apply their learned concepts at an appropriate time, are often very frustrated and become stilted in their learning. He

believed that simple, linear thinking and learning did not allow for the explanation of *complex* human behavior (Doll, 1993).

Dewey himself did not believe in dichotomies *per se*, because dichotomous entities are very polar or opposite, distinct in their separate characteristics. He believed that there was a transformation that occurred between dichotomous entities such that a short-lived intermediate was developed (Dewey, 1933/1971; Doll, 1993) that served as a temporary stopping place, a partial conclusion or an "*ends-in-view*" (Doll, p. 138) for the process.

Most chemical reactions involve one or more short-lived intermediates that are often unobserved simply because the reaction takes place so quickly. Such an intermediate is important because it acts as a moment of rest, a means of gathering energy or transforming energy for the rest of the reaction; "*the means-to-the end.*" Such intermediates exist at all levels of education as well. It is rare that there is a complete transformation from one way of being, one understanding or one form to another, particularly if the other is very polar to the original, without some form of intermediate or rest occurring [accommodation and assimilation (see Piaget's work) of the knowledge]. In educational thought, this can be a place of reflection. Figure 4 summarizes Dewey's philosophy.

transaction and such an analysis allows for change. Experience, in both chemistry and education involves the meshing of reflection, interaction and transaction in order to understand the phenomenon that took place in its entirety.

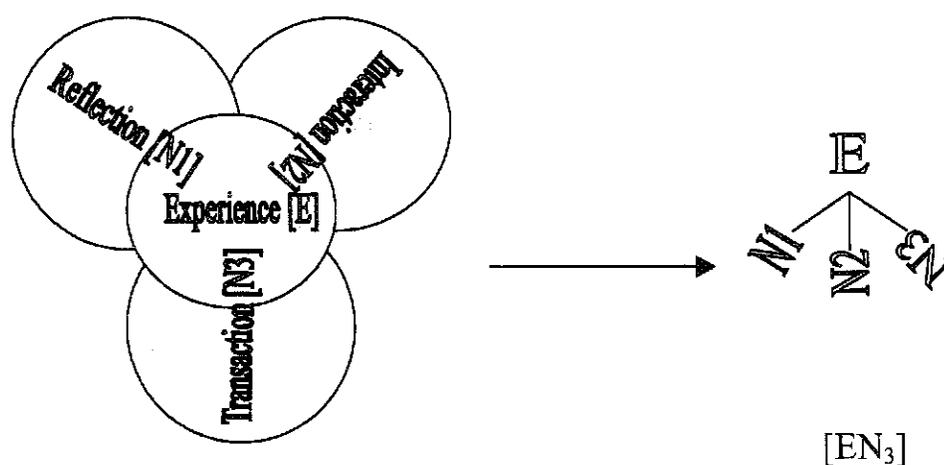


Figure 5. Dewey's concept of the hermeneutic experience involves the interconnection of reflection, interaction and transaction. Such a relationship can be represented also by a chemical structure where the central atom is the experience [E] and attached are the three elements reflection [N1], interaction [N2] and transaction [N3]. The general formula for the educational and chemical relationships can be depicted as EN_3 with the overall structural shape being pyramidal, the experience being the peak of the pyramid [the ultimate point].

According to Dewey, this leads to what he terms as a new experiential epistemology or root of understanding. A hermeneutical representation for education is given in Figure 5 above and this can be extended to an analogous chemical structure. In both structures, the experience is the ultimate goal or product with reflection (N_1), interaction (N_2) and transaction (N_3), as the path to achieving that goal.

Theory of Alfred North Whitehead

Alfred North Whitehead published *The Aims of Education* in 1929 (Whitehead, 1967a), a set of essays that were initially composed as lectures with the purpose of

protesting against *dead knowledge*. Whitehead believed all things were best understood as a "drop of experience" (Whitehead, 1969, p. 23) in a period of time and that all drops of experience converged to become larger and larger experiences to become, finally, the whole [epoch] of the experience as illustrated in Figure 6.

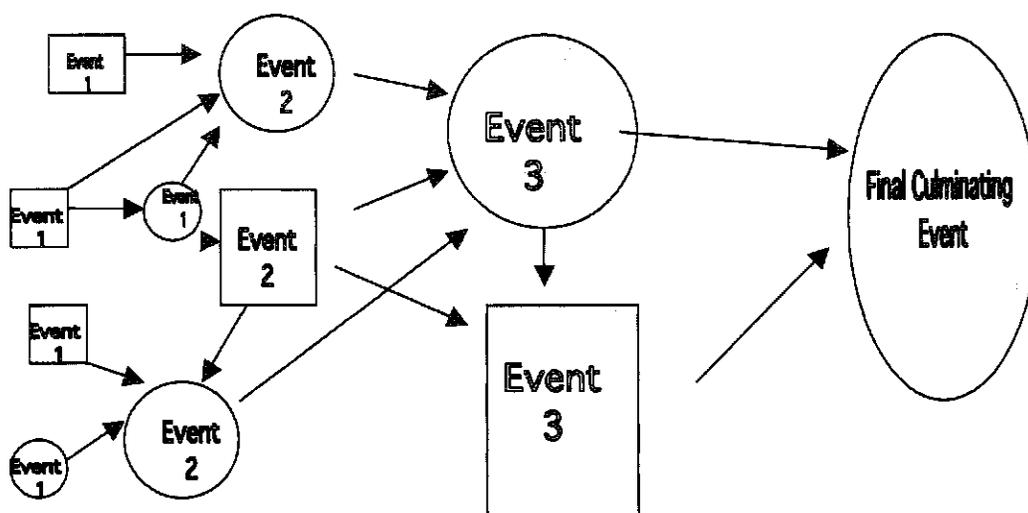
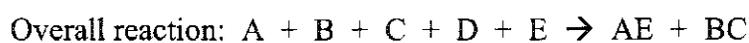
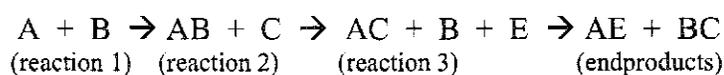


Figure 6. Summary of Alfred North Whitehead's philosophy that every "drop of experience" (Whitehead, 1969, p. 23) or every event is comprised of smaller events and every event is the precursor or data for a larger event. All events lead to the final culminating event.

Such a philosophy applies directly to chemistry in that many reactions are comprised of many smaller reactions or intermediate reactions, often unseen by the rapidity of the reaction such that the overall reaction appears to be only one reaction.



In scientific research the final product, is the result of much experimentation [many experiments] that often takes place over several years. Each experiment contributes more

information [provides data] towards the final answer, but at the same time as contributing one answer, it might be the source of further questions.

Alfred North Whitehead (1969) introduced the term *prehension* (p. 244), meaning to grasp or take hold of an object, for example, a subject. The process of defining prehension, according to Whitehead is that of *concrecence* [the coming or growing together] and is the process by which a person emerges from her inheritances and experiences; the real internal constitution of the actual "occasion" (p. 244) in question. Prehension, therefore, cannot be experienced in the same manner by all and involves the selection of data, either positively or negatively, and such selection is generally based on subjective forms such as that of wisdom. Wisdom, he believed, is the way in which knowledge is held and wisdom aids in selection from competing data.

Freedom and limitation, although generally considered antithetical concepts, are involved in the process of selection in prehending in order to determine what is relevant to add value to the experience or to create a new event (Whitehead, 1967a). Limitation implies discipline for Whitehead and freedom and discipline are complementary, each requiring the other for positive and negative prehensions and each being incomplete without the other. Freedom is the openness to possibilities and the capability of the selection of those possibilities but also it is the positive selection of data. The richness of the experience is related to the breadth and depth of the data used to prehend that experience. Limitation or discipline allows us to select data from the negative in that it allows us to put limitations or set criteria such that we can add more finite value (Whitehead, 1967b) to the data we are using in prehending.

Concrescence, according to Whitehead (1969) occurs in three phases: the *responsive* phase or the "phase of pure reception of the actual world in its guise of an objective datum" (p. 245); the *transformation* into unity and satisfaction, and the *entity* or *end-product*, the ultimate product or goal. These phases are the blueprint of analysis in which the actual entity is seen as a process.

In his theory of intellectual progress, Alfred North Whitehead (1969) postulated that freedom and discipline were part of a rhythm to a student's intellectual journey comprised of three stages: romance, precision, and generalization. It is imperative that every educational event begins with romance, the stage where the student is introduced through novelty to engagement or active involvement in a learning situation. Interest in the curriculum is developed as one is excited by the possibility of pleasurable activity and an emotional connection and curiosity takes place. The learner/student sees relevance and judges or believes that she has something to contribute.

The romance stage occurs in science as well. General curiosity initiates many experiments. What happens if we mix A with B? How do we make a desired product? What happens when we change variables to a system? Such questions spark the initiation of many experiments, both at the scientific as well as the social science level. Thus the romance of the question, invites relationship. The general curiosity of *why* and *how* preside in the romance stage of any educational event, be it in chemistry, in one's social learning or in some other discipline.

Once the novelty of romance ebbs, it is replaced by desire for more precise knowledge as the craving for more answers grows. At this stage discipline is critical as one learns the right and wrong ways to do something, to find more precise results. In

chemistry, as one learns how a chemical reaction works or the outcomes of a particular experiment, one wants to refine it in such a manner as to get the maximum yield of product, find the most economical way of carrying out the reaction, and have the reaction proceed with the greatest efficiency. At this stage, freedom is critical as it gives rise to the positive acceptance of truths for the learner.

The final stage, that of generalization, is a synthesis of the first two stages, romance and precision, and it looks at ways to apply the learned knowledge to other more far-reaching systems. Some of the questions asked at this stage are: How can we apply this to the bigger picture? What other implications for other things do our results have? The emphasis at this stage switches to the future as the educational events contribute data to the future. How can we apply this knowledge to what we anticipate for the future [make predictions]?

This also applies to chemistry and to science in general and Mendeleeev in fact did this when he developed the periodic table of elements. Based on group characteristics and prior knowledge of chemistry or chemical reactions and the patternicity of the table, he was able to place elements into the table, based largely on their atomic weight, without having knowledge of their reactivity and even before their actual discovery. This prior knowledge allowed him to correctly generalize about new materials. Such learned information becomes incorporated as wisdom. Alfred North Whitehead stated, "An education which does not begin by evoking initiative and ends by encouraging it, must be wrong" (1967a, p. 37).

As well as being specific in his writings on education, Alfred North Whitehead extended his quality of generalization to nature. Education, he believed like Dewey,

should be life-long and self-generated in learning and extend to every event in life and to the final outcome of the culmination of events. Education is universal and his philosophies apply to all ages, all situations and all institutional settings. Such learning involves a balance of freedom and discipline; the freedom to choose positively to allow one many choices and avenues, to keep one's mind open but also the discipline to select data such that there are parameters or limits to one's choices. Freedom is critical to keeping the mind open but discipline must also play a role. In his philosophy, freedom without discipline is futile but freedom should not imply ignorance over what to select and what is relevant to value. The criteria, according to Whitehead, in evaluating all "drops" of educational experience or independent events should be the same criteria that is applied to evaluating the whole of the event. Again each event is a composite of smaller events and each event is the data for a larger event. Thus the outcome of each event, that of intellectual satisfaction and a sense of closure contributes something of value to subsequent events of prehension. Such intellectual satisfaction becomes the foundation for further intellectual progress and when guided by wisdom might be a good way of expressing the value that education is supposed to attain (Whitehead, 1967a, 1967b).

Theory of Lev Vygotsky

The Russian psychologist Lev Vygotsky, who might be considered to be more of a social constructivist than a cognitive constructivist, believed that the development of cognition occurs first through interaction with others which then gets integrated into the learner's mental structure. His theoretical framework is built on the major theme that,

Every function in the child's cultural development appears twice: first, on the social level and later, on the individual level; first between people (interpsychological) and then inside the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals. (Vygotsky, 1978, p. 57)

A rich learning environment, therefore, is one in which the students have opportunities to work with more experienced peers thus facilitating them to develop a higher level of cognitive learning (Vygotsky, 1962; Vygotsky, 1978). The *Zone of Proximal Development* (ZPD) (Vygotsky, 1978), key to his theories, suggests the area of exploration for which the student is cognitively prepared is only fully developed through the help and social interaction of others. In terms of development and learning, three theoretical positions preside:

1. The processes of child development and learning are independent such that the development cycle precedes the learning cycle and therefore maturation, so instruction should lag behind mental growth.
2. Learning is development, therefore learning and development occur simultaneously and can even be superimposed.
3. Learning and development are related processes and each influences the other. Maturation depends on the development of the nervous system and learning is in itself a developmental process.

Vygotsky rejected all three propositions of learning and development, saying the problem was more complex than that. He claimed there were two separate issues at hand, the first being the general relationship between learning and development, and the second being the features of learning and development when children reach school age. Children

do much learning before they reach school age. Any learning they do in school has a previous history but school learning introduces something fundamentally different; that of social interaction and that of learning from others.

Empirically, the established philosophy was that learning should be matched in some manner with the child's development level such that increased complexity in learning [reading, writing, and arithmetic] is age-dependent. However, in looking at developmental process in relation to learning capability as Vygotsky did, there exist two developmental levels. The first, the actual physical and mental development, is simply based on a child's development by a certain age. A child's mental age is determined by specific developmental tests administered to the child and done unassisted by the child herself. The results of such tests are indicative of the child's mental abilities. However if the child is administered these tests and assisted by someone of higher learning [an older child or a teacher] they rarely miss the independent solution to the problem and often surpass their ability [actual development] when doing the problem unassisted. This is much like a chemical reaction where the reaction may take considerable time to initiate and proceed very slowly on its own with a low yield of product in the end. If a catalyst is added to the reaction mixture, or a co-enzyme is used, then the reaction will be initiated much quicker and will proceed at a much greater rate with a generally higher yield of product. For example, a child's ability to do the problem unassisted might be that of an eight-year old but her ability to do the problem when assisted by a peer or an adult might be that of a twelve-year-old.

The difference between what the child can do unassisted [actual development] and what she can do when assisted [potential development] is termed the zone of proximal development [ZPD] and this is a critical zone in all pedagogy.

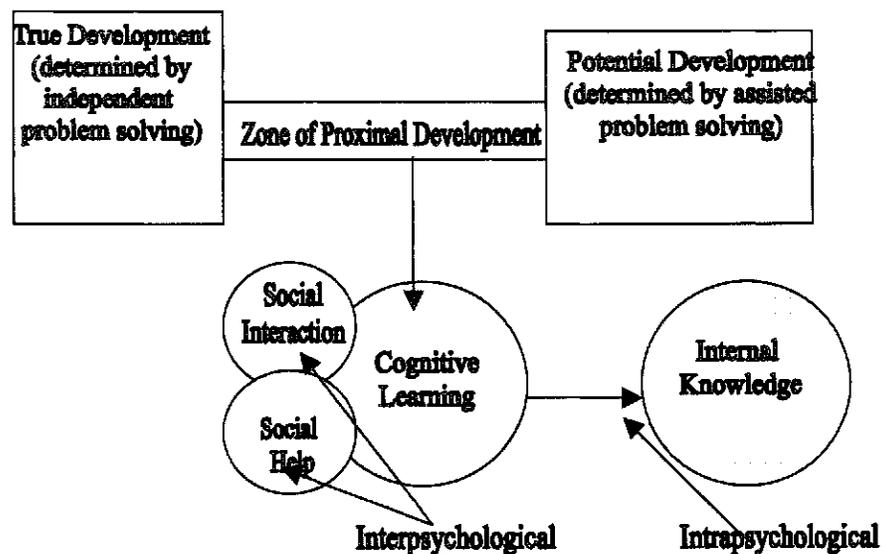


Figure 7. Vygotsky's theories summarized. The *Zone of Proximal Development* (ZPD) exists between what the individual can actually do unassisted and the potential of what the individual can do when assisted. This is the individual's true capability. Such learning is enhanced by social interaction and once these cognitive skills have been achieved they become internalized as part of the child's permanent internal knowledge.

This suggests therefore that the developmental process lags behind the learning process and that the two processes are united rather than independent. If one considers a chemical reaction, there is often a considerable yield of product difference between reactions that proceed in the presence of a catalyst or with the assistance of a coenzyme in comparison to those reactions that proceed without. Not only does the reaction proceed faster, the yield of product is generally significantly higher. In his ZPD theory, illustrated in Figure 7 above, Vygotsky believed that learning stimulated a variety of internal developmental processes that are only able to operate when the child is interacting with people in her

environment and her peers and thus learning in the ZPD is a critical window and should be maximized by early social interactions. Many elements or compounds in chemistry are quite innocuous and unreactive until they come into contact with other compounds or a specific compound. Then all of a sudden they are highly reactive often with an unexpected intensity and even yielding unexpected side reactions or products can result.

Once learned, these developmental processes become internalized and part of the permanent fabric of one's knowledge base. Vygotsky believed that learning, although related to the course of child development, was never accomplished equally or simultaneously with development. He believed there exists complex dynamic relationships that lead to learning and development.

Vygotsky's theories, although based in early childhood education do also apply to the science discipline in that laboratory skills are often learned by demonstration and then imitation. The laboratory is a highly social and interactive environment and such cognitive learning is often done by imitation of someone more highly skilled such as the instructor or peers who have some experience. Thus even in adult learning there is a ZPD whereby there is a gap between the actual and the potential learning capabilities and once learned the knowledge becomes internalized as permanent knowledge that can be further applied to more advanced skills.

The cognitive constructivist theories of Piaget, Dewey, Bruner, Whitehead and Vygotsky could, perhaps, be practically combined and applied in a cognitive apprenticeship (Collins, 1991). Such an apprenticeship is a synthesis of formal schooling (theory) and traditional apprenticeship (hands-on learning) facilitated by the "master" teacher/instructor. In this environment, the invisibility of the thinking processes of a

learning activity, such as laboratory techniques, can be made visible and applicable to the both the teacher and the learner. The teacher initially coaches and scaffolds student learning processes but gradually fades as the students become more proficient, allowing them to develop their own expertise.

The theories of cognitive constructivism take into consideration the fundamental processes and rules that describe the learning process, the levels of the cognitive domain as described by Bloom (1956) (knowledge, comprehension, application, analysis, synthesis, and evaluation) as well as hint at the effect of the experience, the affective domain (receiving, responding, valuing, organizing, characterizing by a value or value complex) (Krathwohl, 1964) of both the student and the teacher. The psychomotor principles (perception, set, guided response, mechanism and complex response) (Simpson, 1966) are less often used in describing cognitive constructivist teaching and learning and are probably more correctly housed within behaviorism and other psychological theories and are outside the interests of this research.

Meaning-Making

Both the chemistry periodic table, as well as a similar metaphoric construct for education, provide a fundamental, pedagogical framework, the fundamental rules, that prescribe and inscribe the reactions of everyday living. Not only is the periodic table an artifact that shows the epistemology and ontology (see below for definitions) of knowledge in a field (for example chemistry or education), it also illustrates the *relationships*, the periodicity and patternicity, that ultimately describe the actual experience or the chemistry of the constituents, within the fundamental framework. Polkinghorne (1988, p.1) says “experience is meaningful and human behavior is

generated from and informed by this meaningfulness.” An analysis of such experience falls under the realm of “*meaning-making*” (Polkinghorne, 1988, p. 1) and takes into consideration philosophies embedded in ontology, critical theory, hermeneutics, phenomenology, hermeneutic phenomenology, and symbolic inter-actionism and can be augmented and substantiated by narrative data in narrative research and the phenomenology of science.

Ontology, Ontic, and Ontological Inquiry

Both chemistry and education are grounded in an ontological framework. Ontology refers to the subject of existence and is the specification of a conceptualization (Gruber, 1993). It should not be confused with epistemology, which is about the roots and origins of knowledge and knowing. According to Gruber (1993a, 1993b), an ontology is considered to be a studied description [much like the formal specification of a program] of the concepts and relationships that potentially exist for an agent or a community of agents. Robert Poli (1996) defines ontology as the “theory of objects” - every type of object from concrete and abstract, existent and non-existent, real and ideal, independent and dependent has an associated ontology. An object is synonymous with the term “being” and in his theories he says that ontology is not a catalogue or a taxonomy of the world because it is significantly different than taxonomy. Rather, ontology is a general framework or a structure into which its contents may be organized [as is the periodic table]. There, however, is a definite difference between ontology and taxonomy. He also theorizes that ontology is not reducible to pure cognitive analysis nor is it an epistemology or theory of knowledge. The two in fact are quite different in that ontology is the objective side, the grounded or factual side, whereas epistemology is the

subjective side or the *knowing* side. In addition, he theorizes that it is possible for several ontologies to exist at once. Central to the field of phenomenology, *ontic inquiry* refers to *actual* things or entities of the world, having the status of real experience while *ontological inquiry* is concerned with what it means to be with the *being of things* or entities (Heidegger, 1962). An understanding of and attention to ontology is important for researchers in both education and chemistry concerned with enabling knowledge-sharing and reuse.

If one looks at the periodic table of chemistry as an ontological frame, in the extension of such theories, it becomes the phenomenological study of chemistry, a study of the interactions and reactions of the elements [the community of agents] within the table. Much like the periodic table is the ontological frame of chemistry, I envision the ontological framework of education is the curriculum into which is embedded all the concepts and relationships, the teaching of the curriculum, of the community of agents - the teachers and students. How all elements [components] react and interact is the phenomenology, the chemistry. To examine the significance of these, I also studied critical theory.

Critical Theory

In educational research, critical theory is based upon the use of critique as a method of investigation (McCarthy, 1991) and is based on the underlying philosophy that social theory of all sorts should play a significant role in changing the world through contributing to it rather than just recording the information. Its roots are in the Frankfurt School originating with the work of Jurgen Habermas (van Manen, 1994).

In education, research which has a critical theory thrust aims at promoting critical consciousness, and struggles to break down the institutional structures and

arrangements which reproduce oppressive ideologies and the social inequalities that are sustained and produced by these social structures and ideologies. (p. 176)

Critical pedagogy therefore addresses the issue of how to construct ideological and institutional conditions where the lived experience of empowerment for the student becomes the main theme of the schooling. It attempts to build a bridge connecting the philosophical and scientific understanding of society. Features of critical pedagogy (Giroux, 1981; van Manen, 1994) are;

1. an attempt to create new forms of knowledge through its emphasis on breaking down the boundaries that exist between disciplines and creating interdisciplinary knowledge thus appealing to a widened notion of rationality.
2. a resistance to all forms of domination such that questions are raised about the relationships between the margins and centers of power in schools.
3. a rejection at the distinction between high and popular culture such that curriculum knowledge is responsive to the everyday knowledge that constitutes peoples' lived histories; an orientation to praxis.
4. a focus on emancipatory practices such that they illuminate the primacy of the ethical in defining the language that teachers and others use to produce particular cultural practices.

Critical pedagogy is important when analyzing curriculum and relationships within curriculum. It argues for multiple literacies and when looking at various chemical [educational] reactions there is always more than one approach, more than one way of carrying out a reaction, more than one way of looking at something. It is important however to recognize the differences both culturally and individually of the students' and teachers' participation in the curriculum. In the periodic table of elements each of the

elements is an individual but the conversation between and among the elements [the reactions] can be varied and in many cases there can be multiple reactions. When looking at education, the myriad reactions and interactions are dependent on many variables, such as the classroom environment, the learning readiness of the student, the histories of the students, et cetera, so that there are multiple literacies that come to the equation and hence multiple outcomes [products] evolve.

According to Habermas' (1971) *fundamental theories* for critical pedagogy, three forms of knowledge and associated cognitive interests are: the technical, the practical, and the emancipatory, each of which is also rooted in the human activities of work, symbolic interactionism, and power. The technical interests are seen in the empirical-analytical sciences, which are given a more influential position, while the social sciences incorporate more practical interests and the critically-orientated sciences incorporate emancipatory interests. With critical theory in mind then, bridging the disciplines of chemistry and education using the periodic table as a metaphor to understand learning and teaching more fully, it might be possible to transgress those boundaries that reproduce oppressive ideologies and establish a better understanding of the "chemistry of education." If critical theory is an important ideological tool for educators working with critical social consciousness, hermeneutics is an important interpretive tool for educators working with related curricular texts.

Hermeneutics

Hermeneutics is concerned with the general science of interpretation, a branch of philosophy that involves interpretation and understanding of texts. Texts are primary resource material in the enterprise of all education, so an understanding of hermeneutics

can contribute added meaning to curriculum work. It is with this hermeneutics that I interpret the chemical periodic table in order to construct the educational periodic table. “Whenever rules and systems of explaining, understanding, or deciphering texts arise—there is hermeneutics” (Palmer, 1981, p. 458). Taken further, hermeneutics involves the study of the methodological principles of interpretation and describes how one interprets the texts of one’s life (Pinar et al; 1995; van Manen, 1994). It is the theory and practice of interpretation, and one of its strengths-its interdisciplinary nature-makes its application to both the sciences and social sciences an excellent means for analysis (Reynolds, 1989). Its origins can be traced to the ancient Greek study of literature and in ancient biblical interpretations of passages. In the seventeenth century, hermeneutics was used to mean biblical exegesis (Palmer, 1969). The word originates from the Greek messenger-god *Hermes* and the Greek word *hermeneuein* meaning “to interpret” (Doll, 1986, p. 134). Ancient Greeks made extrapolations to works of uncertain origin using the fundamental rules of grammar, style and ideas. Many church teachers and leaders made interpretive extrapolations, generally allegorical in nature, that were far removed from the texts’ literal meanings. Further non-literal interpretations of the Bible flourished in the Middle Ages and many bridges or links between the Old and New Testaments were made by the Christian commentators. It was felt by many churches, the Catholic in particular, that the Bible was too obscure in nature and reading of it by lay persons required guidance. Multiple interpretations abounded.

Hermeneutics, although rooted in ancient enterprises of translation and jurisprudence, began in early modern Europe with Wilhelm Dilthey's more historically conscious nineteenth century methodological hermeneutics (Connerton, 1976).

Empathetic understanding, understanding not only of the text but also the author and what the author meant, is the basis for general hermeneutics based on methodological principles as developed by Friedrich Schleiermacher [1819] and Wilhelm Dilthey [1883]. Schleiermacher in his 1819 lectures (Palmer, 1969), established hermeneutics as a theory having a technological means almost analogous to a stepwise reaction to interpretation. As the name suggests, methodologically hermeneutics was systematic and scientific in its interpretations and situated a text in the context of its productions concentrating largely on ways of knowing with specific methods of understanding structure and content of text.

Heidegger [1926] and Gadamer (1960, 1976) were primary philosophers in bringing about philosophical hermeneutics in the nineteenth and twentieth century shifting the focus from interpretation to existential understanding. Such a philosophy looked at the authentic way of being or *Dasein*, meaning there-being (Heidegger, 1926/1962) in the world rather than just as a way of knowing. In other words, the reader is placed in the middle of the hermeneutic enterprise and in order to have a dialogue with the text, it is imperative to understand our time, place, and culture (Pannenburg 1967/1986 in Doll, 1986) as well as that of the authors'. Because meaning is a dialogue with the text rather than extracted from the text and our time, place, circumstances, et cetera are different from those of the author, understanding of the difference is imperative to meaning-making of the text. Such hermeneutics deals with the ontological nature of being and the epistemological nature of knowing (Doll, 1986). As beings we can never escape our cultural situations. Therefore we are embedded within the hermeneutic circle and are defined by both our culture and language just as we define our culture and its language. In the hermeneutic circle (Stegmuller, 1977), the idea or notion that

understanding or intent definition of something employs attributes which already presuppose an understanding or definition of that thing. Circles or spirals arise as a result of interpreting and building on previous understanding and thus lead to further understanding which then becomes the base for more understanding and aids in distinguishing from background knowledge and facts and the circular nature of this raises hermeneutic questions regarding grounding and validity of understanding. This is similar to many of the cognitive constructivist theories of Piaget, Bruner, and Whitehead, where learning involves a stepwise process whereby a lower component is used to build a higher component having more breadth and depth toward understanding the meaning. Thus as Heidegger suggests, "any interpretation which is to contribute understanding, must already have understood what is to be interpreted...."(Heidegger, 1926/1962, p. 194). The contents of the circle are continuous in nature and although the circle itself can be expanded, it is not possible to break through the boundaries.

Heidegger's theories moved hermeneutics from a theory of interpretation, as in the beginning hermeneutic theories, to a theory of existential understanding. In other words, interpretation no longer followed the logical method of classical hermeneutics but rather required a conscious recognition of one's own world. Thus foreknowledge, knowledge leading to future decision making, is accumulated over time and such foreknowledge constrains [draws together] successive exercises of existential understanding. This movement to existential understanding gives hermeneutics an ontological dimension by describing understanding and interpretation as essential to one's being.

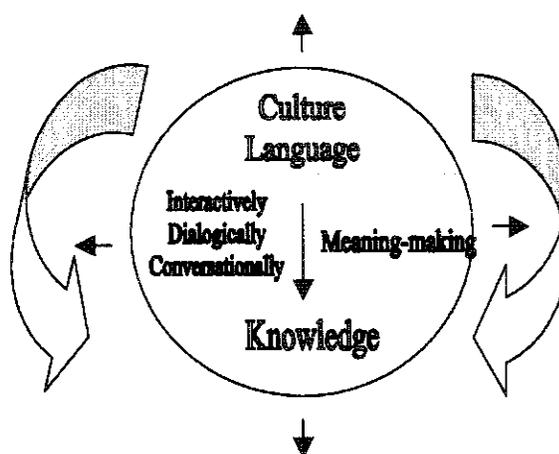


Figure 8. The hermeneutic circle. Culture and language define us just as we define our culture and its language. Thus the relationship is a continuous circular motion, forwards or backwards but we are not able to escape such boundaries only expand them [arrows] in terms of meaning-making for the ultimate goal of knowledge.

Such a framework pedagogically in education focuses on the curriculum, most specifically on the interactions or the transactions that take place between the text and the reader (Doll, 1986). The transactions that take place are transformative in nature in that we change as our transactions change and in doing so we question the assumptions and prejudices that are enveloped within our own culture and language. This leads to meaning-making. The ultimate goals we reach then are attained by personal decisions we make as beings at a specific time and place in history.

One can apply the philosophy of the hermeneutic circle to that of chemistry as well. The culture [periodic table of elements] and the language [their interactions and reactions] are contained within the periodic table. Without knowing the culture and language we cannot learn more about the science itself. More knowledge of the culture and language [learned through scientific experimentation/research] leads us to know more about the culture and language. Mendeleev in fact, knew the culture so well and the

language that existed within the culture that he was able to predict where yet undiscovered elements would be placed and what their properties would be.

Habermas (1966) and Apel (1966) reacted to the relativism of philosophical hermeneutics and introduced *critical hermeneutics* which is a methodological, self-reflective, and comprehensive reconstruction of the social foundations of discourse [language of a subject or discipline] and inter-subjective understanding. This led to the phenomenological hermeneutics, introduced by Ricoeur (1974/75) in which he attempted to synthesize the various hermeneutic philosophies with structuralism and phenomenology. Such hermeneutic theories differ in several characteristic ways in their approaches to meaning and understanding. Because hermeneutics is grounded in meaning-making rather than theory and scientific proof, the meaningful conclusions of hermeneutics are often based on practical judgement and common sense reasoning. His approach was both critical, the avoidance of misunderstanding or misinterpretation, and romantic, the desire to know the author in entirety.

Rather than concentrating solely on the individual, Dilthey, according to Palmer (1969), concentrated his theories on the “lived experience” and considered both expression, the text or artifact, as a means of objectifying or expressing the lived experience and understanding, the point of lived experience that leads to “getting it” rather than a cognitive analysis of the experience. Heidegger, according to Palmer (1969), concentrated on the power to grasp one’s own possibilities that might be first elucidated in text. This would be akin to a corresponding sentience of thought and experience between a reader and a text. In reading and interpreting subject and text, one sees the possibilities revealed by the text, finds him or herself becoming one with the text, finding

sentience and commonality. *Hermeneutic phenomenology*, is a study of the person as a kind of text of being within experience. The hermeneutic tradition thus provides a basis for prescribing and criticizing the conduct of inquiry and the development of knowledge in the natural, social and cognitive sciences. Its representatives have figured prominently in debates concerning how valid knowledge can be acquired and whether there is a need for a separate methodology in the social sciences.

Phenomenology

Phenomenology, the science of phenomena, is the study of events. It is the branch of science that classifies and describes its phenomena without any attempt at metaphysical explanation. It differs from other human science approaches of qualitative experience such as ethnography, symbolic interactionism, and ethnomethodology in that it distinguishes between appearance and essences (Merleau-Ponty, 1962; 1964).

Phenomena are any facts, circumstances or experiences that are apparent to the senses, perceived, and that can be scientifically described or appraised.

Phenomenology asks the question; *what is the nature and meaning of something?* In the study of phenomenology, we come to know the mind as it is by studying the ways in which it appears to us (Hegel, 1977). Husserl (1913/82), a major founding philosopher of phenomenology, introduced pure phenomenology as both a descriptive method and a human science movement based on praxis of the heart and of philosophic and human science thought. He further advanced pure phenomenology to become *transcendental phenomenology* (Husserl, 1970a) which looks at the effects of immediate experience unencumbered by pre-conceptions or theoretical notions. *Lifeworld*, an extension of his transcendental phenomenology, includes the experiences of the natural, taken for granted

everyday-life and the world in which we live (Husserl, 1970b). *Existential phenomenology* is an extension of Husserl's lifeworld philosophy and describes how phenomena present themselves in lived experience, in human existence. According to Merleau-Ponty (1962), phenomenology offers accounts and descriptions of the lived experiences of the space, time, body and human relations rather than producing theoretical or empirical observations or accounts. The world of chemistry and its concern with the nature and meaning of matter in the ways it appears to us is a natural cognate relative to phenomenology.

In 1960, Dwayne Heubner introduced phenomenology to education, particularly to curriculum studies. His philosophical foundation was elaborated upon by such influential educational philosophers as Maxine Greene, Janet Miller, Madeleine Grumet, William Pinar, Max van Manen and Ted Aoki (Pinar & Reynolds, 1992). Although well-rooted in the European education philosophy, phenomenology is a recent and controversial introduction to North American education with its least acceptance being within the American education system.

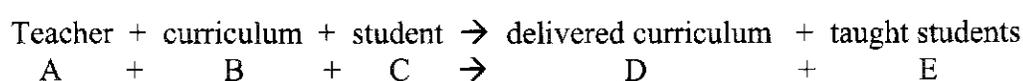
The reactional matrix of both chemistry and education can be studied from a phenomenological approach. In looking at chemical reactions, the actual reaction is the "object" or the "doing" while the effect of the reaction on the surrounding milieu and how that effect is subsequently perceived or affected by the environment, is the experience of the reaction. In a purely physical or phenomenological sense, sodium plus water combine to produce sodium hydroxide plus hydrogen gas.



⁶ s = solid; aq = aqueous; g = gas

One cannot ignore the ontological prescription of the reaction but what goes unsaid in such an indifferent description is the phenomenological essence, that can more effectively be related through narrative description: the reaction is highly exothermic and the hydrogen gas ignites with a loud popping noise, and often a spark, and the water temperature increases significantly. The phenomenological experience can be written as a narrative description of the visual experience of the spark, the auditory experience of the popping when the hydrogen gas is ignited, and the tactile experience feeling the temperature of the water increase. Superlative laboratory writing is, at its finest, exemplary phenomenology.

The same holds true for education. The reaction of teaching is the teacher plus the curriculum plus the student thus producing delivered curriculum and taught students, a pretty basic reaction:



The actual experience of that reaction and the phenomenological narrative description of that experience is a (carefully) constructed study of how that reaction is perceived by both the students and the teacher. Although the phenomenological approach to studying “lived experience” is a somewhat controversial one, “lived experience” cannot be ignored as data and, I would argue is central to all scientific writing. It has a strong footing in curriculum studies as a means of understanding the experience of the curriculum. While the chemical periodic table may serve as a metaphor to the phenomenology of chemistry, and educational periodic table might also serve as a metaphor for the phenomenology of education. The parallels are explored in the following chapters.

Heuristic Research

I had submitted the first draft of my thesis before I happened upon the book *Heuristic Research* by Clark, Moustakas (1990). It turned out to be quite similar to the analytic process I had been using in my own research. I have incorporated some of the principles in the analysis portion of my own research process of developing a periodic table for education.

The root meaning of *heuristic* comes from the Greek word *heuriskein*, meaning to discover or to find. It refers to a process of internal search through which one discovers the nature and meaning of experience and develops methods and procedures for further investigation and analysis. The self of the researcher is present throughout the process and, while understanding the phenomenon with increasing depth, the researcher also experiences growing self-awareness and self-knowledge. Heuristic processes incorporate creative self-processes and self-discoveries. (Moustakas, 1990, p. 9)

The concepts and processes of heuristic research include:

- a) Identifying the focus of inquiry where the researcher is expected to have an intense connection with the phenomenon being investigated.
- b) Self-dialogue where the researcher discloses herself thus facilitating the disclosure of others to the researcher.
- c) Tacit knowing which is the process of making the implicit explicit.
- d) Intuition, the bridge between the tacit and observable data.
- e) Indwelling, the deep inner-seeking allowing the researcher to fully experience the phenomenon.
- f) Focusing which is the clearing of the inner space so one is able to receive the answers.
- g) Internal frame of reference thus allowing one to become attuned to others.

These concepts are embodied in the specific phases of heuristic research which included: a) initial engagement to discover an intense or passionate concern b)immersion

in the question c) incubation of the question while one does other things d) illumination where there is a breakthrough into conscious awareness e) explication or the full examination of what has been illuminated f) internal focusing such that one becomes fully familiar with the explication of the meanings and details of the phenomenon and finally g) creative synthesis where the results are related in the form of narrative or some other creative expression.

In carrying out heuristic research a) one first gathers data from all participants and b) then immerses herself in the data until it is comprehensively understood after which c) one sets down the data for awhile while it incubates. This is followed by d) the writing down of what is known about the data identifying the qualities and themes after which e) individual stories are constructed of the participants maintaining the integrity or the original data. This is done for each individual and for the group as a whole. Once this is complete the researcher f) returns to the original individual data to select one or two exemplars of the group as a whole and then finally g) the researcher creatively synthesizes an aesthetic rendition of the experience of the research and her relationship to it. Such a rendition is most often related through narrative expression.

Narrative Expression

The discourse used in this thesis to augment developed periodicity and patternicity theories of the educational periodic table will concentrate on both the discourse of formal science (Polkinghorne, 1988) and on the narrational discourse (Polkinghorne, 1988) of stories in the form of tropes, which, although different in their organizational patterns, are meant to produce meaning. The ubiquity of narrative tropes, vignettes or stories reflect our fundamentally relational understanding of reality and they

offer a kind of validity (Reddy, 1979; Mishler, 1986). Reality is framed within systems of analogy (Reddy, 1979; Silverman & Barode, 1980).

"Narrative is a function of the relational processes of the realm of meaning." (Polkinghorne, 1988, p. 22). It can be considered as belonging to the cognitive realm or process in that it is a means of making meaning of experience through cognitive and affective processing and relating that meaning through languaged storying of phenomena [experiences]. Narrative is an interactive and engaging connection between meaning and the verbal expression of that meaning, through autobiographies, stories, tales, histories, historiographies, et cetera. The search for true conditional events is governed by paradigmatic mode which can be correlated to "truths" of the periodicity of the elements of the periodic table. The patternicity of the periodic table, both in chemistry and education, can be equated to the narrative mode which seeks to explore relational connections between events in some periodic and patterned way. Such a literal connection of events and relationships requires the use of literary, narrative discourse presented as a unit of words written or spoken larger than a sentence - a trope, a story, a novel, but certainly narratively with an author of perceptive vision.

The Use of Narrative in Research

Having come from a physical or "hard" science background, where quantitative data is the only acceptable route to establishing validity and reliability in research, the use of narratives as a form of research is shunned, looked upon as the "touchy-feely verbose stuff", as some scientists will often be heard to say, of the "soft, artsy, not true science" areas. Narrative in science is not viewed as worthy research yet I would argue that narrative and narrative truth in fact, are used in the "hard" sciences without realization.

The laboratory notebook for example, is in fact a narrative journal for scientists, one in which a good scientist will document verbally and in great detail the qualitative observations he or she has observed throughout the experiment. The results of the true narration might not be included as a "story" per se in the final document but narration is used throughout hard-science research and is the basis of many of the final conclusions.

Jane O'Dea (1994), in her paper "*Pursuing truth in narrative research*," summarizes many of the philosophies of educational philosophers such as Bruner (1986), Connelly and Clanandin (1990), van Manen (1990), and Barone (1992) who all talk essentially about narrative as a "story-telling" rather than an "epistemically respectable" (Phillips in O'Dea, 1994, p. 161) means of research. However, throughout her paper, she makes the point that good narrative is truthful narrative, and in fact such narrative does have a respectable place in research. Paulo Freire (1970) in his critical theory states that reflection and praxis are critical to good teaching. I would argue such reflection and praxis transgress the boundaries to science as well, that reflection and praxis are critical to good science too. Truthful narration is simply the means whereby that boundary can be extended and explained.

This being said, the beginnings of chemistry, or the "coming-of-age" (Sacks, 2001, p. 117) of chemistry as an adult science is documented more through narration than actual scientific or quantitative research [data]. Pioneer chemists such as Antoine Lavoisier, Thomas Beddoes, William James, and Alessandro Voltas kept amazing qualitative notebooks and their theories were substantiated by narrative descriptions in addition to quantitative data and data analysis. Perhaps this was because in the nineteenth century, the definite boundaries later established between the literary and scientific

cultures, were blurred and much less defined. Humphrey Davy, also known as a "poet-chemist" (Sacks, 2001, p. 117), who appeared at the end of the Lavoisier revolution, was perhaps one of the most verbosely narrative scientists in his practical as well as philosophical descriptions of his research. Sacks (2001), in his description of Davy's contributions to chemistry, describes Davy's laboratory notebooks as "...his notebooks [which] mix details of chemical experiments, poems and philosophical reflections all together; and these did not seem to exist in separate compartments in his mind" (p.126). And in his description of Davy's ability to teach, to relate his scientific knowledge to others in a lecture format, Sacks (2001) states,

. . . . his famous lectures, or lecture-demonstrations, were exciting, eloquent and often literally explosive. His lectures moved from the most intimate details of his experiments to speculation about the universe and about life, delivered in a style and with a richness of language that nobody else could match. (p. 125)

Mendeleev is perhaps the most narrative of all chemists, building his experimental observations and experiences into a true story with plot, setting, characters and theme. His book, *The Principles*, was not only a textbook of chemistry but a story, an accurate, truthful narrative of chemistry. Sacks says of Mendeleev's book,

In his very first footnote, in the preface, Mendeleev spoke of 'how contented, free, and joyous is life in the realm of science'--and one could see, in every sentence, how true this was for him. *The Principles* grew like a living thing in Medeleev's lifetime, each edition larger, fuller, more mature than its predecessors, each filled with exuberating and spreading footnotes (footnotes which became so enormous that in the last editions they filled more pages than the text; indeed, some occupied nine-tenths of the page. (p. 195)

I do not believe that quantitative and qualitative research are mutually exclusive or that one precludes the other. In fact, the complement of the two is critical to quality research and can lead to very effective change or discovery. Narrative research carries

with it the connotation of a "careful systematic study of some area of knowledge" (O'Dea, 1994, p. 165) and narrative researchers, as O'Dea says,

are engaged in interpreting situations that actually occurred, not imaginary ones. And that being the case, the researcher is bound to honour the details and incidents that in fact happened. To do otherwise, to ignore or repress certain happenings in the interests of creating a better, more coherent story or to portray the teacher [or researcher] is to be dishonest, to 'fake the data'. (p. 166)

One can 'cook the data' in both quantitative and qualitative studies--the fact that a research study uses numbers of itself does not tell us whether the study is true or false. In both styles of research, one ultimately has to trust the integrity of the scholar. (p.166)

Merging boundaries, whether they be those of quantitative or qualitative research, hard or soft science or chemistry and education, the base of effective change or discovery, does in fact require truthful narrative [experiential] documentation [data].

Narrative Inquiry

The telling of stories can be a profound form of scholarship moving serious study close to the frontiers of art... (Joseph Featherstone, *To Make the Wounded Whole*, Harvard Educational Review, 1989).

Narrative inquiry is not considered research in the physical scientific field yet narrative is a very large component of scientific research. Narrative is masked by the fact that scientists distill the results of research (the narrative experience; the lab notebook) generally down to a simple reaction mechanism. Scientists are known to get a feeling, a "gut" feeling that something should work in a particular way and often this feeling arises not from the quantitative data but from qualitative observation of the outcomes, expected or not expected, of the research. This "gut feeling" of the researcher is often what drives research, furthers the intuitive quest for the right answer. I believe the boundaries between quantitative [pure or hard] science and the qualitative [soft] science are not so strict. Oliver Sacks (2001) states,

[Chemistry] developed in me the faculty, which is peculiar to chemists more than to other natural philosophers, of thinking in terms of phenomena; it is not very easy to give a clear idea of phenomena to anyone who cannot recall in his imagination a mental picture of what he sees and hears, like the poet and artist, for example... There is in the chemist a form of thought by which all ideas become visible in the mind as the strains of an imagined piece of music...

The faculty of thinking in phenomena can only be cultivated if the mind is constantly trained, (p. 128).

Narrative inquiry includes a variety of research practices ranging from the telling of a story to understanding one's actions through oral and written accounts of a particular episode or incident (Reissmann, 1993) to the methodological exploration of aspects of storytelling (Richardson, 1997). Narrative in both education and chemistry is an interpretation of what took place but in the "hard" scientific field, narrative inquiry is not considered to be true research; such knowledge presented in terms of narratives [stories] is suspect as "true" data. I argue against this notion of suspect research, as narrative is often a large component of scientific research with observations of reactions being verbally [narratively] recorded in the laboratory notebook. Narrative, therefore, is the qualitative observation of what happens when reactants A and B are mixed together while the quantitative data generated answers questions such as: How much of the reactants is required to generate the product? What are the specific reaction conditions? How much product is generated? Science, chemistry in particular, seems to rely on quantification, the concrete presentation of results in a countable and statistical fashion. Some might say it is more justifiable and safe, because narrative representation of results is subjective rather than objective, issues of legitimacy, validity, and representation are often brought to question when narrative is used as data. But narrative and narrative inquiry, I suggest, makes one accountable because it does not allow one immunity behind the simplification

of the complex and sometimes difficult. Thus in chemistry and in education the bridge is the whole experience of a given reaction and the true representation of that occurs through narration either in the narrative form [tropes, vignettes, stories] or through the laboratory notebook.

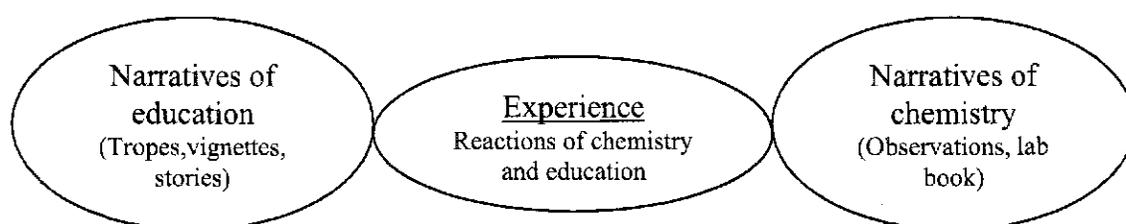


Figure 9. The narratives of experience. Narratives are a more accurate representation of the experience that takes place in reactions of chemistry and education.

CHAPTER III

SOME BASIC ⁷ CHEMISTRY

Historically Speaking

Chemistry was used long before it became known as a formal science. When cave dwellers first learned how to harness fire and cook their food, they were already using chemistry; pottery and metallurgy are two ancient chemical industries, and people have also known for thousands of years how to make beer and wine, and how to use plants to dye cloth. The alchemists [early chemists] believed that it was possible to transform one substance into another, for example to transform lead into gold. Their study of matter was based as much on magic and religion as on science. Although the name "alchemy" conjures up images of bearded men in long gowns mixing up strange brews, alchemists during the Middle Ages made real discoveries in some areas of science such as metallurgy.

Approximately 400 BC, a philosopher named Democritus (Holliday, 1970) developed the first atomic theory. He believed that nature is made of atoms; tiny particles

⁷The chemistry concepts presented in this chapter are an amalgamation of standard concepts for chemistry from the following six sources:

Brown, T. L., Lemay, H. E. Jr., & Bursten, B.E. (2000). *Chemistry: The central science*. Upper Saddle River, New Jersey. Prentice Hall.

Chang, R. (1994). *Chemistry*. 5th Ed. Montreal. McGraw-Hill Inc.

Kotz, J. C. & Treichel, P. Jr. (1996). *Chemistry & chemical reactivity*. 3rd. Ed. Toronto. Saunders College Publishing.

Masterton, W. L, Slowinski, E. J. & Stanitski, C. L. (1986). *Chemical principles with qualitative analysis*. 6th Ed. Toronto. Saunders College Publishing.

Petrucci, R. H., Harwood, W. S. & Henning, F. G. (2002). *General chemistry*. 8th Ed. Upper Saddle River, New Jersey. Prentice Hall.

Robinson, W. R., Odom, J. D. & Holtzelaw, H. F. (1992). *Chemistry: Concepts and models*. Toronto. D.C. Heath and Company.

that are attached to one another. He also realized that the number of atoms, their arrangement, and the strength of the bonds between them varied from one substance to another and he theorized that the strongest bonds between atoms were formed by a hook-and-eye connection. A little later, around 300 B.C., Epicurus theorized that atoms had mass and around 100 B.C., Asklepiades introduced the idea of atoms occurring in clusters. We now call such clusters molecules.

Democritus was way ahead of his time. It took scientists 2000 years to realize that his theory was basically correct, except for the hooks. He used the concept of atoms, and their ability to scatter [move further apart] or pack tightly together to explain the properties, such as density and evaporation of substances. All atomic theory is built on the theory of Leucippus and Democritus; "the properties of matter that we can see are explained by the properties and behavior of atoms we cannot see" (Kotz and Treichel, (1996, p. 59).

John Dalton was responsible for our modern concept of the atom. In 1803, he proposed a theory that was quickly accepted and increasingly confirmed as an explanation for the composition of matter. He linked the existence of elements which cannot be decomposed chemically to atoms which are the smallest indivisible, unique [own characteristics and mass] particles. Compounds are comprised of two or more different kinds of atoms and are able to be broken down into two or more new substances. His mass theory of atoms paved the way for quantitative analysis in chemistry. Dalton's atomic theory enabled chemists to analyze [decompose] and synthesize [or build] known molecules, as well as many other molecules that are not

found in nature. Dalton's ideas led to his postulates of atomic theory (Kotz and Treichel, 1996).

Ancient Greek philosophers such as Plato and Aristotle argued against the existence of atoms. Aristotle theorized that everything that exists is made up of four elements: earth, air, water and fire. This theory was generally accepted until the eighteenth century, and it influenced everyone who tried to explain the nature of matter. In the seventeenth century, scientists began performing experiments that led to the birth of modern chemistry. Through the systematic use of a balance and other measuring instruments such as a barometer and a thermometer, Antoine Lavoisier (1743-1794) (Kotz and Treichel, 1996, p. 60), considered to be the Father of Modern Chemistry, replaced the theory with a new concept of elements comprising matter rather than the general elements of earth, water, wind and fire. With such a concept of individual elements and the introduction of his rigorous experimental method, Lavoisier changed the course of chemistry and paved the way for future research.

States of Matter and Atomic Structure

Matter is anything that has mass and takes up space. You could say that everything in the universe is matter and all matter in the universe is comprised of atoms that combine with each other to form molecules. Chemistry and all participants of chemical reactions can be distilled down to the simplest, indivisible, most significant component, the *atom*, which from its Greek etymology means *uncuttable*. Atoms are extremely small, having a radius of about 0.0000000003 meters. According to Kotz and Treichel (1996), if one were to put this into context, one teaspoon of water would contain about three times as many atoms as the number of teaspoons of water in the Atlantic

Ocean. An atom is the smallest particle of an element having the properties of that element and atoms are the basic units of molecules; ordered arrangements of like atoms. A *compound* occurs when two or more elements bond together and such compounds are capable of being broken down into their individual atoms. A *substance* may be comprised of many compounds and have specific properties associated with it

If one looks at chemistry as a metaphor for education, then *matter* in education would be considered the whole of education. It is comprised of everything that makes up education, the teachers, the students, the curriculum, the schools, the administration, the rules and policies, et cetera. The atoms of education, the smallest indivisible parts, are the teachers and the students and as in chemistry, the molecules in education would be an ordered arrangement of like atoms for example, the students of a class or the teachers of a school or a university department. A *compound* occurs when two or more elements come together and would be equitable to the various relationships the elements form. Such compounds or faculties are capable of being broken down into their individual atoms [professors, students, teachers, et cetera]. A *substance* may be comprised of many compounds and has specific properties associated with it. One might consider a substance in education to be a subject of the curriculum, math for example, that has specific properties and characteristics that are different from another substance such as, say, art. A substance is a collective group.

The three basic constituents of a chemical atom are the *electrons*, *protons*, and *neutrons*. The atom has a dense central core, a *nucleus*, which contains the protons and neutrons surrounded by the electrons housed in orbitals in the space around the nucleus. *Protons* have a positive electric charge and the number of protons in the nucleus

determines the type of atom [or person] it is as well as its position within the periodic table. Rutherford noticed a discrepancy in the mass of the nucleus relative to the number of protons and suggested another particle having no net charge but a similar mass to the proton, a *neutron*, must be responsible for this. His assistant, James Chadwick, proved the existence of the neutron in 1932 (Peake, 1989). *Neutrons* are "neutral," as they carry no electric charge. The number of neutrons in an atom can be the same as the number of protons, but is usually higher. An *element* is a particular "type" of atom having a specific number of protons and electrons and is a pure substance that cannot be broken down into simpler components by ordinary chemical means. A *molecule* is an ordered arrangement of atoms of one or more elements and is the smallest particle of a substance that can exist independently and have all the properties of that substance. *Electrons* have a negative charge, rotate in orbits or "energy levels" around the nucleus of an atom and are the principle components of all chemical reactions. They are missing something so are in continual search of an attachment, a connection. Considered to be the chemist's glue, they are the currency that is exchanged between atoms and the movement or jumping of the electrons from one orbital to another is the basis of the chemistry of all reactions and formation of compounds. The number of electrons is equivalent to the number of protons in an electrically neutral atom.

Rutherford, in 1911, theorized that the electrons circled around the nucleus much like the planets orbit the sun, with a large space between the nucleus and the orbiting electrons thus forming a concentric ring-like structure which he initially called orbitals. The orbitals can more correctly be described as energy levels and the bigger the orbital the higher the energy level. Therefore those orbitals closest to the core or nucleus of the

atom, being the smallest in diameter, are the lowest energy level. Because the size of the orbitals increases as electrons move away from the central core, energy levels also increase. A positively-charged atom has fewer electrons than protons and a negatively-charged atom has more electrons than protons. A neutral atom, therefore has the same number of protons and electrons.

What is the nucleus of the education atoms [the teachers and the students]? I would argue the nucleus is each individual's *way-of-being*, their knowledge base of existence. It is the core of the individual. According to Dalton, atoms are indivisible but as Marie and Pierre Curie discovered, atoms are also comprised of subatomic particles and in particular cases they are capable of being further broken down to become something different and removed from the original. The nucleus or core of each individual is comprised of further subatomic particles; the protons and the neutrons. The *protons* [positively charged, subatomic parts of the nucleus], in the educational atom, represent the individual's values, beliefs, knowledge base, et cetera, entities that are long established and central to one's being. What happens though when the protons break down into their subatomic particles, when those values, systems of belief and knowledge that comprise one's nucleus, one's way of being, one's central core, are challenged? Do they become different atoms/individuals, changed forever? Is this new form beneficial? How do they go on in this new form?

Housed within the nucleus are also the neutrons, those subatomic particles possessing no net charge [no judgement] which give weight or mass to the nucleus and augment or support the protons but are not the fundamental base or system of beliefs. They have no net charge [do not react] and thus form a concrete base. For example, the

belief in a God might be considered a fundamental subatomic particle of one's nuclear makeup, but which church one attends is really irrelevant, and therefore neutral, a neutron, to the overall belief in a God. The *electrons* of each individual/atom are the individual's learning capabilities which have been developed throughout her life. The level of education of the individual determines how they react and interact with the learning capabilities [electrons] of other atoms. The atoms' capabilities, which also incorporate their personalities, are subject to change, movement, volatility, and variability and this allows for a myriad of interactions and reactions [positive or negative] to be possible with other elements [individuals] of varying composition and personality. Figure 10 is a composite, pictorial representation of the analogous atoms of chemistry and education.

Within the interior of the atom and external to the nucleus are located the electrons [chemical or educational glue]. Each electron has a specific "address" [location] within the atom, the combination of which serves as a blueprint, a unique personality of the atom [individual]. The blueprint dictates how that atom will interact or react in a given encounter with another atom. The same holds true for the unique personalities of the atoms [individuals] of education. How they react or interact is dependent on many factors one of the greatest being personality.

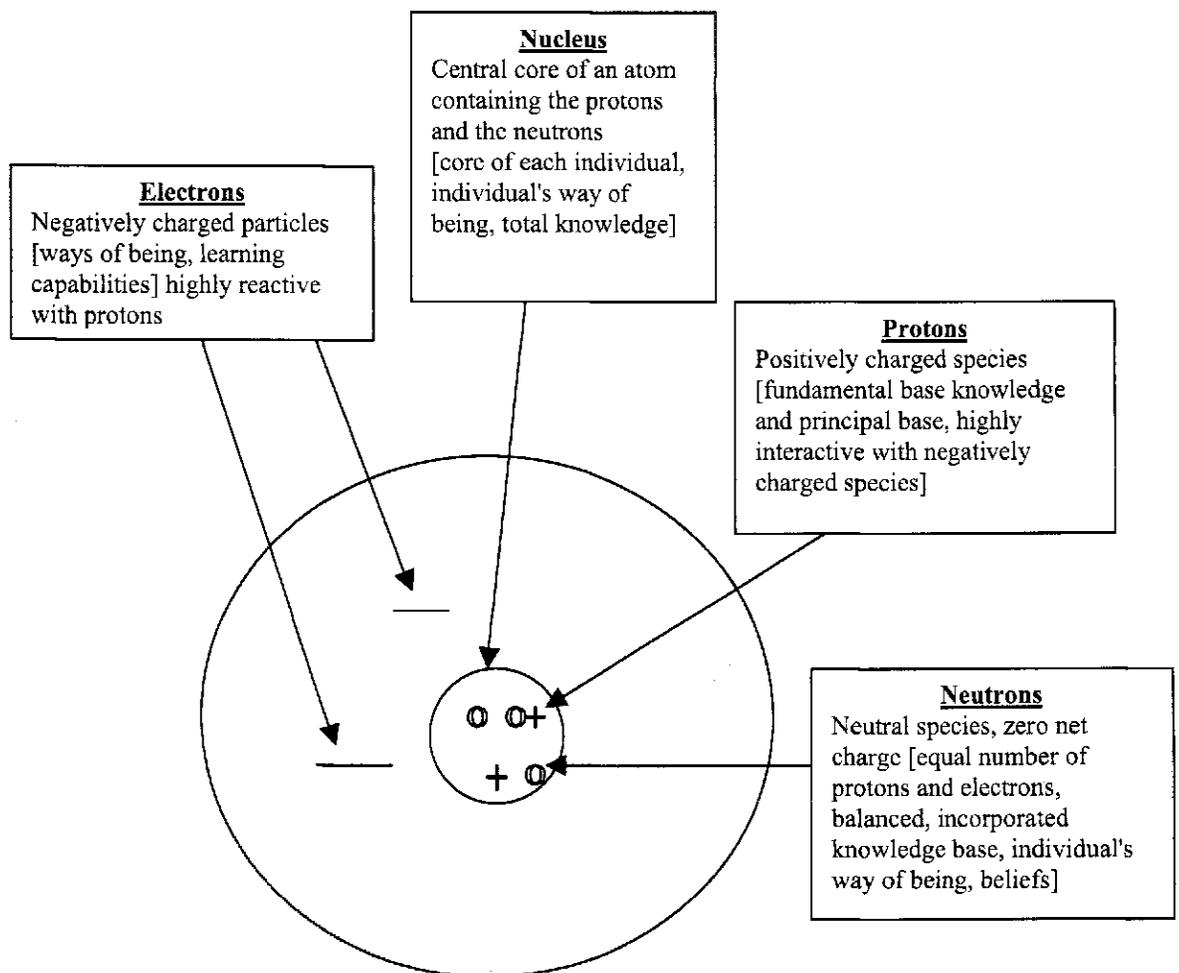


Figure 10. Diagram of a chemical/educational atom [individual students]. The square brackets give the analogous and comparative definition for education. The nucleus, the core of the atom, contains one or more tightly packed protons carrying a positive charge and the neutrons which carry no charge. The electrons, having a negative charge, are arranged in space as a "cloud" around the nucleus with the number of electrons being equivalent to the number of protons in an electrically neutral atom. If there are more electrons than protons the overall charge on the molecule is negative and if there are more protons than electrons, the overall charge on the molecule is positive.

The specific location or address of the electrons within an atom is designated by the quantum numbers. The principal or first quantum number (n) designates the *shell*, equivalent to a row in the periodic table (see the chemical periodic table, Chapter V). Since there are seven rows to the periodic table there are seven principle quantum numbers. The lower the quantum number, the closer to the nucleus the electron is and the smaller the shell size due to the strength of the electric draw by the nucleus. The shell size increases with increasing quantum numbers as the charge draw on the electron decreases with increasing distance, allowing for freer movement of the electrons. Filled shells, (core shells) are generally not of interest in terms of chemical reactions as they contain the core, paired, unreactive and unavailable electrons. It is only those shells that are partially full, the valence [outermost] shells containing the valence [unpaired] electrons, which impart an atom's chemical properties.

One might consider the shell of the educational atom [the individual] to be the levels of knowledge, both learning and learned, for any given subject or situation within education. As in the chemical atom, the lower the quantum number the closer to the nucleus the shell is and as one moves away from the nucleus the shell size increases. If we look at the seven rows of the periodic table as being levels of knowledge, then the layers closest to the nucleus are the most central; "the core/learned knowledge" [consolidated, therefore the orbital size is smaller, more condensed] while those shells further away from the nucleus are larger [more room] allowing for more reactivity and incorporation of [learning] knowledge. As the shells become filled [electrons paired] they become "core knowledge".

Embedded within each shell are the very important subshells (shell within the principal shell) designated by l and there are $n-1$ subshells within each shell of an atom. The orbitals within the subshell, designated by the third quantum number m_l , are the regions surrounding the nucleus where the electrons are most likely to be. Subshells within education could be equated to the various subjects or areas of learning and the electrons contained within the subshells the interactions [abilities] for learning. The spin state, $+1/2$ or $-1/2$ of the electron within each orbital is designated by the fourth quantum number m_s . In education, such positive, negative and neutral [containing both spin states so that they cancel each other out] spin states might reflect the different [positive, negative and neutral] personalities of atoms. Thus each electron within an atom has its own unique fingerprint set of quantum numbers, its own personality or character or profile.

This layered knowledge of depth and ability is the fundamental core established in the earlier years of learning [fundamental principles of all learning] that are built upon by experience and that are continually being added to. As the shells are being filled, they become the foundation of one's being, one's philosophy. Ability refers to one's ability to interact and react with other atoms [individuals] much of which is based on the central core and one's depth. If one thinks of the outer shells as being experience and as not being totally filled, then there is the ability for interaction; for engagement; for learning. As one moves across and down the periodic table the number and size of the shells increases as does the filling of the shells, the number of electrons in the shell [the capacity].

The various layers of the electron can be equated to instructional scaffolding in education (Herber and Herber, 1993 p. 138) and much like the scaffold provides a structure to support workers in their job, so too do the shells of the electron provide support for the electron/student. As a teaching strategy, instructional scaffolding provides students with modelling, guided practice with new knowledge, new skills, and new attributes that would normally be too difficult for them by providing extensive instructional support [scaffolding] to assist them. Much like filling the levels of the electron, once the students bridge what they already know to deep understanding of new material and once having mastered the task it becomes permanently internalized as core knowledge (Turnbull et al, 1999). The instructor in the beginning models the task in its entirety and the students, once having observed the model and had guided practice, perform the task independently and go on to produce creative extensions. The different instructional scaffolding techniques: modeling of desired behaviors, offering explanations, inviting student participation, verifying and clarifying student understandings, and inviting student to contribute clues (Hogan and Pressley, 1997) are equitable to performing reactions in chemistry such that learning the reaction [task or knowledge to be learned] moves to a deeper understanding that becomes incorporated into the core knowledge thus allowing one to apply that knowledge to further learning.

If learning and learning capabilities are considered to be the electrons and the protons the knowledge base then, a neutral atom, is considered to be a balanced atom/individual having the same number of protons as electrons; learning becomes processed to knowledge immediately [core of nucleus]. This is possibly when learning new material is essentially easy. When there is a deficit of electrons relative to the

number of protons, then the atom is a positively charged atom and is capable of taking in more information, capable of higher learning and will react favorably with negatively-charged atoms to form *learning compounds* [chemical compounds]; learning gets processed very rapidly; “sucked up”. I often think of how quickly small children learn and think of them as learning magnets or knowledge *sinks*. A negative atom is one that has more electrons than protons and thus has an overall negative charge, has learned “enough” [for awhile] such that there is spillover and now the learning has to be processed to become part of the knowledge base [proton]. This is when learning is more difficult and this type of atom attracts or is attracted to positively charged atoms, possibly to learn from their knowledge base. One could think of the student-teacher relationship in this way; the student is “absorbing” or learning the information provided by the knowledge base of the teacher. Within each category of neutral, negative and positive atoms are of course the different personalities, the neutral, negative and positive individuals. Such personalities will impact greatly on the learning capabilities of the various atoms.

All like atoms have the same number of protons in the nucleus. The number of protons is referred to as the atomic number and this atomic number, denoted by the symbol Z , designates an atom's position within the chemical or educational periodic table of elements. The mass number, designated by the symbol A , is a combination of the mass of the protons and the mass of the neutrons. In the educational atom, the mass number represents one's learning potential and learned/incorporated knowledge.

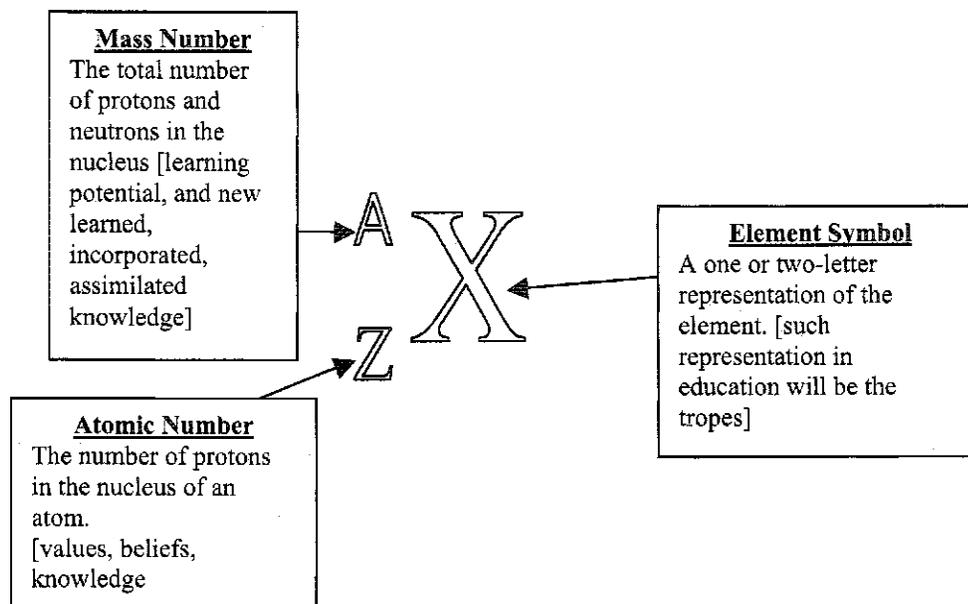


Figure 11. Symbolic designation of an element.

Isotopes, different forms of the same element much like different colored socks in your wardrobe or the different hats an individual has to wear within the educational system, have the same atomic number Z but a different mass number A . Most elements have one or two stable non radioactive isotopes. Hydrogen (protium) the simplest atom containing one proton and one neutron for example, has two isotopes deuterium (heavy hydrogen) which is non radioactive and a radioactive isotope tritium.

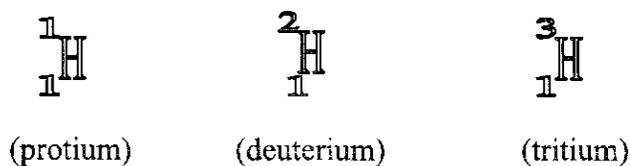


Figure 12. The non-radioactive and radioactive isotopes of hydrogen.

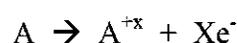
A radioactive element, first discovered by Marie and Pierre Currie (McGrayne, 1993) is one which emits alpha, beta, and gamma particles. In the loss of particles, the nucleus of the atoms of radioactive substances themselves disintegrate over time to become new sub elements. As a result of their discovery, Dalton's theory of the non-reducibility of atoms had to be extended to include subatomic particles, particles [alpha, beta and gamma] smaller than an atom. Even though isotopes have the same atomic number, the substitution of one isotope for another in a compound can change the compound's properties drastically and can have very different results [think of the effects and implications of substituting a radioactive isotope for a non-radioactive isotope in a compound or a chemical reaction].

If one considers the teachers and the students to be the basic indivisible atoms of education, then one needs to consider the reactions and interactions of these elements. Isotopes in education would be the different "ways of being" [personifications] of an individual atom; the different hats worn by an individual. Like the chemical elements, most elements of education have one or two [or more] stable isotopes but each element/person has a radioactive "way of being," the highly reactive "way of being" that we, for the most part, "keep a leash on." This radioactive way of being, like in the chemical element, leads to decomposition and possibly difficulty [either teaching or learning] and generally results in a "new" [not always better] way of being in teaching and learning.

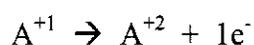
Chemical Reactions

Chemical reactions occur as a result of the interactions (loss or gain) of the valence electrons, in the outermost orbitals of the elements. Electrons may be lost (given

up to another element), shared equally between elements, or gained (gained from another element). The most stable form of an atom is when that atom is neutral, contains the same number of protons as electrons such that there is a net or overall charge. The loss of electrons from an atom results in the atom, a cation, carrying a more positive charge.

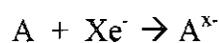


The number of electrons lost determines the degree of charge on the atom thus making a neutral atom more positive, a positive atom even more positive and a negative atom more positive. For example,



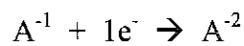
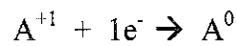
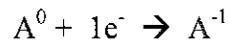
This can be equated to education where the loss of an electron or electrons therefore can serve to make any situation of any sort [learning environment, learning ability, teaching environment, teaching or learning difficulty, et cetera] more positive [more favorable].

The gain of electrons by an atom results in an atom, an anion, carrying a more negative charge.



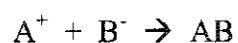
Again, the number of electrons gained will determine the degree of charge on the atom.

A neutral atom can become more negative, a positive atom more negative or neutral and a negative atom even more negative. The degree of charge change will be dependent on the number of electrons gained. For example,

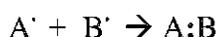


Although knowledge of electronic structure of atoms is imperative, generally isolated atoms are not involved in chemical reactions, rather groups of two or more atoms and the attractive forces between them referred to as chemical bonds hold the atoms together. Electrons are the chemists' glue and as such free electrons of one element will react with free electrons of another element to form bonds, the type and strength of which is dependent on the element, the reaction environment and available electrons. Such reaction of the elements leads to the formation of chemical compounds. If the atoms separate, the bonds are destroyed and the compounds as well are destroyed. Other compounds may be formed as a result of the breakdown of the compound, liberation of the atoms and the formation of new bonds and compounds. Equitably, the reaction of educational compounds (see following section) rearrangement of the atoms or the breakdown of the educational compound [whatever that may be] leading to the liberation of the atoms [students, teachers, philosophies, pedagogies, curriculum, et cetera comprising the above compound] can result in the formation of new associations and may lead to the formation of new bonds [interactions/relationships] and new compounds.

Two basic types of bonding important for chemical reactions are *ionic bonding* and *covalent bonding*. Ionic bonding occurs when there is electrostatic attraction between ions of opposite charge resulting in an electrically neutral compound. For example,



Such a compound in education could result at many levels of teaching and learning where two opposite personalities, philosophies, et cetera are attracted or come together, forming possibly a greater more functional compound. Covalent bonds are formed through the sharing of electrons in the overlapping of orbitals of the constituent atoms. For example,



In most cases when compounds share electrons they do so to form the status of a noble gas (see periodic table). Educationally such a bond would exist in the sharing of information, knowledge, et cetera, leading to the formation of strong, cohesive groups [compounds].

The electrons involved in reactions reside in the outermost energy level and the energy required to send this electron off or for this electron to react is termed *ionization energy*. The amount of energy required is dependent on how tightly bound the electron is to the nucleus and if there is more than one electron involved in the reaction.

The more electrons there are the greater the amount of energy required to send them off or have them interact/react. Therefore as we move across the periodic tables, the number of outermost electrons increases and thus does the complexity of reactivity. Young children are very enthusiastic and thus very willingly engage interactively in reactions and are very receptive to learning. Thus in Groups 1 and 2, the very early learning years, the energy required for engagement in learning is low relative to the higher educational levels. Sometimes, energy-wise, it is more economical to accept electrons than to send them off when the orbitals are nearly full as is the case with the elements of Group 7, the halogens [or graduates in the educational periodic table] (see the chemical and educational periodic tables, Chapter V). Such an affinity for gaining electrons allows

them to act like an *electron sink* and makes them highly reactive and interactive with elements such as the alkali metals that willingly donate their electrons. I often think of the willingness of small children to engage and learn, to interact with older children and how they learn so quickly from them; mentoring in the school system is a good example of such learning. In the university setting, graduate students are often used to teach in the introductory level courses and graduate students often serve as mentors for incoming freshmen. Thus they become a sink of experience for new students coming in.

The filling of the outermost orbitals ($s = 2$ and $p = 6$ for a total of eight outermost valence electrons) provides stability to an element and thus making it unreactive. The elements of Group 18, the noble gases [stable professional status] have a filled outermost orbital (eight electrons) and thus are the most stable and unreactive of the elements. Essentially they are complete [full] and unreactive [in terms of chemical reactions such as bonding]. The goal in chemical reactions is to provide stability to the reacting elements by gaining or losing electrons such that there are no unpaired electrons. The highest stability is achieved when there are eight (an octet) paired electrons in the outermost shell. This is called the *octet rule* and in education this would be considered the completed curriculum [either orbital or at a specific level].

The goal/aim of education is to complete the curriculum, fill the orbitals, for each subject and level of learning. The ultimate stability is achieved when all levels of education [learning] have been completed and there is an octet [completion of education] achieved and a transition from learner [student] to knower [teacher/ professional] in the completion of the whole of the curriculum.

If one considers the teachers and students to be the basic, indivisible atoms of education, then it is enlightening to consider what happens when these atoms interact. It is my theory that transferring those concepts to a periodic table of education can assist with new undertaking of the chemistry of education.

CHAPTER IV

⁸A HERMENEUTIC STUDY OF THE DISCOURSE OF THE CHEMICAL LANGUAGE

Analogous Definitions to Education

A metaphor is considered to be an assertion or identity, a comparison between to unlike objects that does not use "like" or "as" but rather is an implied comparison in which the word or phrase that is used ordinarily for one is applied to another. In this thesis, I have used the Periodic Table of Chemistry to develop an elaborated metaphor for teaching that can be applied to the discipline of education. As a result, this thesis employs extensive vocabulary from both disciplines. I will clarify that double helix of terminology in this section, so that a discourse can emerge as one that "grows in the middle" (Aoki, 1993, p.9).

Every discipline has its own vocabulary, its own specific lexicon or dictionary of terminology. The semantics of the lexicon, the context-independent truth or meaning of a particular word or phrase is understood and used by those in the discipline without much

⁸ The chemistry definitions are an amalgamation of standard definitions for chemistry terminology from the following six sources:

Brown, T.L., Lemay, H.E.Jr., & Bursten, B.E. (2000). *Chemistry: The central science*. Upper Saddle River, New Jersey. Prentice Hall.

Chang, R. (1994). *Chemistry*. 5th Ed. Montreal. McGraw-Hill Inc.

Kotz, J.C. & Treichel, P. Jr. (1996). *Chemistry & chemical reactivity*. 3rd. Ed. Toronto. Saunders College Publishing.

Masterton, W.L, Slowinski, E.J. & Stanitski, C.L. (1986). *Chemical principles with qualitative analysis*. 6th Ed. Toronto. Saunders College Publishing.

Petrucci, R.H., Harwood, W.S. & Henning, F.G. (2002). *General chemistry*. 8th Ed. Upper Saddle River, New Jersey. Prentice Hall.

Robinson, W.R., Odom, J.D. & Holtzclaw, H. F. (1992). *Chemistry: Concepts and models*. Toronto. D.C. Heath and Company.

forethought. However, in bridging the disciplines of chemistry and education and to have a discourse or conversational interaction between the two disciplines, to discuss the chemistry of education, one must have an understanding of the lexical semantics, the semantic structure associated with a word, phrase or sentence as represented in the lexicon. Because I am trying to understand the chemistry of education, the pragmatics of this section will involve a study of the relations between language and context that are basic to the language of chemistry. Such pragmatics will look at the interaction between specific linguistic knowledge [chemical vocabulary] and its relation to more general world knowledge, that of education, much like a metaphor. A pragmatic linguistic analysis will allow for the building of analogous definitions to bridge the two disciplines. The analogous, bridging definitions developed are based on my own knowledge and experience of the language of chemistry and my current, less-experienced knowledge of the discipline of education. Implicit in these definitions is the assumption that the language of one discipline can be used to bridge another discipline through the development of an extended or more encompassing relational vocabulary. Also implicit is that pragmatic reasoning works to logically build a relationship between the syntactic and semantic analysis of a word. Thus the idiosyncratic uses and interpretations of words in chemistry will be expanded to encompass a comparative relational lexicon in education.

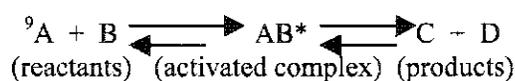
The following relational definitions have involved much research and thought and are thus one interpretation for the purpose of this thesis with the realization [on my part] that many of the analogous definitions are open-ended and subject to much conversation and even debate.

Glossary of Terms

Accuracy: Accuracy refers to how close to the true value a given measurement is. In chemistry accuracy refers to the results of work done and how close those results are to the known value. Many factors, some controllable others uncontrollable, influence accuracy. *Educational accuracy* may refer to how close to the true curriculum teaching comes. As in chemistry, accuracy in education is influenced by both controllable and uncontrollable factors.

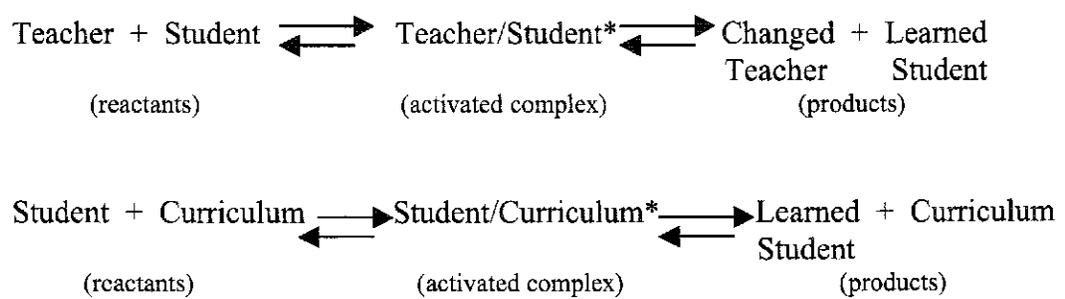
Acid: An acid is a substance that will donate hydrogen (H^+) atoms when dissolved in water. It lowers the pH of the solution and if sufficiently lowered (removed from neutral pH of 7) the solution can be corrosive and damaging to the skin and other materials. Acids serve as proton donors according to the Bronsted-Lowry theory or, according to Lewis theory as electron pair acceptors thus enabling the formation of a covalent bond. An *educational acid* may be any individual [teacher, student, administrator, et cetera] who can make a situation less than favorable; removes it from the optimum. If sufficiently removed then the environment can become uncomfortable and even hostile to others. Comparatively, acidic individuals can serve to bring a more basic situation closer to neutrality, thus making a situation or an environment more neutral.

Activated complex: An activated complex is the intermediate compound formed in a chemical reaction that is generally not sustained in this form but that is capable of either dissociating back to re-form the reactants or forward to form the products.



⁹ A and B represent generic symbols for elements and are used to illustrate a *general* concept or reaction mechanism rather than a *specific* reaction throughout this paper.

In a similar fashion, an *educational activated complex* may be an intermediate that is not sustained but that is formed in any reaction of teaching and learning in the delivery and acquisition of the curriculum.



Activation energy: The activation energy is the minimum amount of energy required to produce sufficient collisions of the reacting molecules thus driving the reaction to produce the products. *Educational activation energy* is/may be the amount of energy input (from various input sources) required to make a teaching/learning reaction successful. It may also be the amount of personal energy required by the teacher/instructor to navigate in times of teaching difficulty. Comparatively, it may also be the amount of energy (perseverance) required by the student to “stick with it” in times of learning difficulty.

Active site: An active site is the small three-dimensional region of an enzyme, having a specific shape necessary to bind the substrate and catalyze the appropriate reaction. The active site is stabilized by the three-dimensional structure of the enzyme the loss of which generally renders an enzyme non functional. The loss of that three dimensional structure is most often due to a change in the environment in which the enzyme exists. The *educational active site*, the heart of teaching, is the curriculum. Curriculum is the site of reaction/interaction between the student and the teacher. Like

the active site of an enzyme, it has a specific, conformational structure. In parallel though, the active site of education might also be considered to be the teacher. Without the teacher, the delivery of the curriculum is non-existent. The functionality of the active site, the three-dimensional structure, is stabilized by the strength of the teacher but may be influenced by many extraneous factors that maintain the environment. Disruption or damage of the active site can lead to teaching difficulty.

Actual yield: The actual yield is the amount, or measured quantity of product actually obtained from a reaction. The *educational actual yield* is considered to be the performance, outcome or assessed value of the student in an activity, an assignment, a class, et cetera; the actual achievement of the student. Actual yield may also refer to the performance of the teacher or instructor as assessed by the students, her colleagues or her superiors. It may also refer to the actual outcome or effectiveness of the delivery of the curriculum.

Allotropy: Allotropy is the existence of a molecule in two or more different molecular forms such as oxygen (O₂) and ozone (O₃) or red and white phosphorus. *Educational allotropy* refers to those individuals capable of wearing more than one hat, who have many roles within the system. It may also refer to multiple ways of presenting or delivering the same curriculum such as different rubrics or different teaching styles. In addition, it could also refer to different learning abilities and styles. In other words, it is a component of education that may appear in one or more different forms.

Alkali metal: Alkali metals refer to any element in Group 1 of the Chemical Periodic Table. *Educational alkali metals* refer to any element in Group 1 of the

Educational Periodic Table, those elements/individuals of the early childhood (pre-K and K) group.

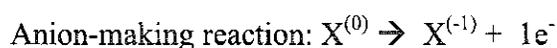
Alkaline earth metal: Alkaline earth metals refer to any element belonging to Group 2 of the Chemical Periodic Table. *Educational alkaline earth metals* refer to any element in Group 2 of the Educational Periodic Table, early elementary education (grades 1-3).

Amphoteric: Amphoteric refers to a compound that exhibits both acidic and basic properties; has the capabilities of behaving as both an acid or a base. *Amphoteric in education* refers to those individuals who can display opposing personalities and behaviors, those individuals who might "say one thing" but do another. In contrast, amphoteric individuals are those individuals who are able to interact and adapt to completely opposing situations; resilient individuals.

Anabolism: Anabolism is a metabolic reaction sequence that assembles larger molecules by putting building blocks or smaller molecules/fragments together; building reactions. *Educational anabolism* refers to building on the basics, for example; starting with the alphabet, moving to phonetic sounds, words, sentences, with the eventual end product of reading; building more complicated curriculum from the fundamental basics; stepwise learning processes, building on fundamentals.

Anion: An anion is a negatively charged atom or group of atoms attracted preferentially to cations, oppositely charged [positive] ions, but repel like anions. *An educational anion* is a negatively charged individual, group of individuals, or a situation that interacts with individuals or situations of opposite charge or personality resulting in a neutralization [opposites attract/interact] while like-charged individuals could upset the

dynamics and serve as a source of conflict [like atoms repel] or be antagonistic. Anions could possibly represent the recognition of the lesser positive side of oneself.



Aqueous solution: An aqueous solution is any solution comprised of water as the solvent; the reaction medium for non organic reactions in which the solute [compound or substance] is dissolved. All reactions must take place in some type of medium. The *educational aqueous solution* or the medium for reactions in education would be the environment in which reactions [teaching and learning] take place. In the case of teaching/learning, it can be individual classes or classrooms, or a more larger environment such as the school or institution. Such an environment is generally favorable as the reactants and the products are dissolved in the medium rather than precipitating out.

Atom: An atom is the smallest particle, the basic building block of material, that retains the chemical properties of an element. It is comprised of a central core called a nucleus containing protons and neutrons surrounded by outer orbitals housing electrons. *In education, the atom* refers to the smallest particle that retains the properties of the elements (the teachers and the students). The smallest particle therefore would be the individual teachers and students, each comprised of a central core or nucleus, his or her mind, while the individual and varied personalities (positive, negative or neutral) would be the orbitals, how they present themselves and interact with the rest of the world. The individual parts of the whole of the curriculum might also be considered to be atoms with the nucleus being the basics or fundamental principles of curriculum and the orbitals are the various rubrics and levels of the curriculum.

Atomic mass: Atomic mass refers to the weighted average mass of an element's naturally occurring isotopes. An *educational atomic mass* refers to the weighted average mass (philosophies, pedagogies or ways of thinking) of an element's naturally occurring isotopes, the various types of teachers. If the atomic mass represents students as the atoms, then it refers to the weighted average mass of the naturally occurring types of students and their differing stages, personalities, abilities to learn et cetera. It may also refer to the weighted average mass (variations or rubrics) of a particular curriculum.

Atomic number (Z): Atomic number refers to the number of protons in an atom's nucleus. All atoms of the same element have the same number of protons in their nucleus. Differing elements have different atomic numbers and are thus distinguishable from one another based on this. It is also how elements are positioned within the periodic table. In *education the atomic number* refers to the different students within each of the groups and periods [stage of learning]. All students [elements] at a given point have the same number of protons [ability] but differ in their experience, personality, and reactivity, thus allowing them to be distinguished by their position within the educational periodic table.

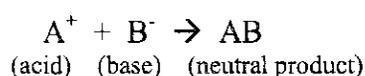
Atomic orbital: Atomic orbital, or orbital, refers to the region of space where an electron is likely to be found. Orbitals encircle and extend from the nucleus and contain the electrons. Atomic orbitals are designated by the *Schrodinger Wave Equation* and are comprised of *s*, *p*, *d*, and *f* orbitals. The degree to which the orbitals are filled by electrons determines the reactivity of the elements. The *educational atomic orbital* refers to the region of the curriculum where a student may be found. The orbitals might be considered to be the layers or content within the curriculum. The degree to which the orbitals are filled is indicative of the levels of learned curriculum.

Balanced equation: A chemical equation is said to be balanced when the number and kinds of atoms on both sides of the reaction arrow (reactant and products) are said to be equal. In *education*, a *balanced equation* may refer to equal numbers of individuals putting in an effort as those reaping the rewards of such efforts (effort = rewards), reciprocity (give = take situations) and the dynamics of these. It may also refer to a balanced curriculum, one which incorporates all areas of the curriculum equally.

Base: A base is a compound capable of producing negative hydroxide (OH⁻) ions in an aqueous environment. For example, sodium hydroxide dissociates to yield a positive sodium cation and a negatively charge hydroxide anion,



Both the cation and anion generated are capable of entering into further reactions. *A base in education* may be considered to be a counterpart to an acidic individual such that the combination or reaction of the two leads to a neutralization, or at the very least, an elevation of pH to a more neutral environment or relationship. A base is capable of neutralization through the elevation of pH by adding negatively charged anionic compounds to the positively charged acidic environment.



Biochemistry: Biochemistry is the integration of chemistry and biology in dealing with the chemistry of living organisms. *Educational biochemistry* refers to the chemistry of the inter- and intra-relationships of education. The chemistry of education is governed by the dynamic and unpredictable complications of human nature much like the chemistry of living organisms is governed by the unpredictability of a living system. Education is a living system and is thus subject to the unpredictability and unreliability of

living systems. Reactions in either chemistry or education are rarely black and white having no side reactions or interferences.

Boiling point: The boiling point is the point at which the temperature of a liquid and vapor coexist in equilibrium, the vapor being the transition or escape of the molecules constrained by the liquid phase to the gaseous phase of more freedom and movement. In boiling, as the temperature is increased and the boiling point reached the interactions between the molecules, the number of collisions increases such that eventually some of the collisions result in some of the molecules being bumped from the liquid phase to the vapor or gaseous phase. The *educational boiling point* is the point at which there is a change in state (dynamics, operation, functioning, et cetera) of an environment, a reaction, a situation, et cetera. It might be the point at which students leave the constraints of the educational curriculum to apply their knowledge (learned curriculum) to their lives; the point at which the student moves from the affective domain [liquid state] to the psychomotor [gaseous state] (Bloom, 1956). It might also be considered to be the point at which "all hell breaks loose" [where chaos occurs] in a difficult environment. In this case the classroom might contain the difficulty to an extent and when the difficulty becomes too great then there is a breakdown in the dynamics of the classroom. Boiling point might also be the point at which teachers with teaching difficulty lose it; the difficulty is contained within the individual for a period of time and then erupts into a visible difficulty or breakdown when it is no longer confinable. The educational boiling point may also refer to the point at which a curriculum breaks down, where it is no longer effective. In other words, the boiling point is the point at which there is a change in physical state; the "breakpoint".

Bond: A bond is one of the various types of linkages, connections, between two atoms. A *bond in education* is one of the various types of connections between two educational atoms, teachers, students, teachers and students, parts of a curriculum, courses within a program, et cetera.

Bond dissociation energy: The bond dissociation energy is the amount of energy required to break a chemical bond in an isolated molecule when it is in the gaseous state. The *bond dissociation energy in education* is the amount of energy required to break any bond, be it bonds of curriculum, bonds between the teacher and the student, between students, or between teachers. What is the energy input required to accomplish this? What does it take to break a specific bond?

Bonding electron pair: The bonding electron pair refers to the pair of valence electrons involved in covalent bonding. The *bonding electron pair in education* is the attraction or connection between entities [individuals, teachers, students, et cetera]. It may be the personalities of the individuals, a common interest, a common experience, that attracts or bonds two individuals, the strength of which can be variable.

Buffer capacity: Buffering capacity refers to a measure of the amount of acid or base that can be absorbed without significant changes in pH; the ability of the system to compensate for changes in pH. *Buffering capacity in education* is a measure of the ability of the teacher, student, or institution to absorb change or difficulty such that there is a steady environment; the ability to go with the flow.

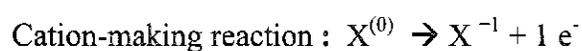
Buffer solution: A buffer solution is a solution comprised of a weak acid and its conjugate base such that it is capable of absorbing excess H^+ or OH^- by neutralizing them, thus acting like an acid-base sponge. This enables the environment to resist small

changes in pH with relatively large changes in volume. *In education, a buffer* is the philosophy of the teacher and her way of being such that she/he is able to interfere and delay the effects of acidic or basic situations or individuals; the teacher's ability to handle tough situations. A buffer might also refer to the system, to the administration within the system, such as the principal, to provide support for the teachers in both bad and good situations. In terms of the curriculum, a buffer might be represented by the ability of the curriculum to withstand small changes or to allow for more changes without losing sight of the basic fundamental principles or the ultimate goal.

By-products: In a chemical process, they are the compounds produced along with the principal product either as a result of the main reaction or as a result of side reactions. *Educational by-products* are those side effects, either good or bad, that occur as a result of teaching/learning inter and intra-reactions of education that are extraneous to the main reaction. For example, in learning to read, the side reaction might be that one develops a love for poetry.

Catalyst: A catalyst is a substance that takes part in a chemical reaction such that it changes the rate of the reaction by lowering the activation energy, thus enabling a more rapid mechanism, but does not affect the products produced. The catalyst itself does not undergo permanent chemical transformation and is regenerated in the process. An *educational catalyst* is any thing or individual [for example a paraprofessional, a person hired to assist a teacher in a classroom, a technological device, et cetera] capable of lowering the activation energy of any type of reaction, either by helping, making the reaction easier or possibly by shouldering responsibility; someone or something that makes the situation easier by their own abilities.

Cation: A cation is a positively charged ion having less electrons than its neutral counterpart thus resulting in an overall positive charge. For example, solid sodium metal has a net charge of zero, meaning there are the same number of positive ions as there are electrons. If one electron is lost then there are more positive ions or less negative ions resulting in an overall net charge of positive one.



In education, a cation may refer to a change in an individual, teacher or student, whereby the loss of an electron tends to make them more positive or acidic thus making them more reactive; a neutral to highly charged transformation. This charged transformation may result in a motivational change whereby the individual in the charged state is more re/active and inter/active.

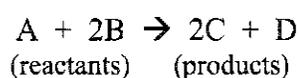
Chain reaction: In a chain reaction, a series of reactions is repeated over and over such that the product of a late step serves to provide the starting material or reactants for the next step. It allows for the reaction, once it has started, to proceed continuously [much like a domino-effect] to produce a product. *Chain reactions in education* occur at many levels. The relationship between the teacher and student is a perpetual chain reaction. Curriculum itself is a chain reaction as one piece provides the foundation for the next such that the process is ongoing and continuous. A halt in the sequence of the chain reaction serves to stop the whole of the reaction.

Chemical change: A chemical change occurs when there is a change such that a different kind of matter is produced from the original matter – the reactants are transformed into the products. There is often an irreversible physical change as well. An *educational change* occurs as a result of the teaching/learning process such that the

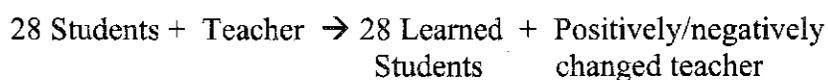
student and/or teacher are transformed with the student moving onward to something else. Both the teacher and the student may be changed internally or externally as a result of the educational experience. Chemical change is considered to be a compositional or a physical state change, therefore *educational [chemical] change* results in an internal or external change in the individual; the individual's way of thinking and being is affected, either positively or negatively.

Chemical energy: Chemical energy refers to the stored or useable energy associated with chemical bonds and intermolecular forces. *Educational energy* is that stored or useable energy associated with bonds or inter or intra relationships between teachers, students and teachers and students. Such stored energy might be referred to as dynamics and can often be used as a fuel for further inter and intra-reactions; fuel for further learning.

Chemical equation: A chemical equation is a symbolically written equation that qualitatively and quantitatively describes a chemical reaction. The reactants and products are represented by symbols and formulas and stoichiometric coefficients [whole numbers in front of the symbol or formula] are used to represent amounts when the equation is balanced. For example,



An *educational equation* is one developed to qualitatively and quantitatively describe the inter and intra- teaching/learning reactions that take place within education. For example,



Chemical equilibrium: Chemical equilibrium is the state in which the forward reaction [conversion of the reactants to products] and the reverse reaction [the conversion

of the products to the reactants] occurs simultaneously at the same rate. In equilibrium reactions, the removal of one or more of the reactants will disrupt the equilibrium.

Educational equilibrium is also when the rate of the forward teaching/learning reaction is equal to the rate of the reverse reaction [reciprocity]. Many equilibrium dynamics exist in education from classroom dynamics between the teacher and students, between students, in teaching and learning and in teaching and learning difficulty. Removal of one of the reactants or products will upset that equilibrium in either a positive or a negative fashion. Such a removal results in the equilibrium being re-established at a different level.

Chemical/molecular formula: A chemical formula is the symbolic representation of the number, through numerical subscripts, and kinds of atoms in a substance. Water, for example, has the molecular formula H_2O indicating there are two hydrogen atoms and one oxygen atom in the molecule. One could develop an *educational molecular formula* as a means of representing the number and types of teachers and students that comprise a given environment (classroom, lab, committee, et cetera) or a reaction. For example, a class having one teacher [T] and thirty-two students [S] could be represented by the formula TS_{32} . The components of the whole of the curriculum may also be depicted by a similar-type molecular formula that represents the number and types of courses that must be taken for a grade, a degree or a program.

Chemical property: The chemical property of a substance or a compound is its ability or inability to undergo a particular chemical reaction. The *educational property* is a characteristic property of an educational entity; a teacher, student, classroom, curriculum, et cetera which defines its ability or inability to undergo a particular reaction;

a teaching pedagogy, philosophy, personality trait, dynamics of a classroom, structure of a curriculum. It is a description of the composition or characteristics of an individual.

Chemical reaction: A chemical reaction is the process where one set of substances [the reactants] are transformed to another set of substances [the products]. There are many *reactions within education*, but as in a chemical reaction, the reactants are transformed into the products. In both cases, how this is done is dependent on many variables.

Chemical symbols: Chemical symbols are abbreviations, comprised of one or two letters that are used to denote or represent the elements of the chemical periodic table [for example, H = hydrogen]. *Educational symbols* are those symbols derived to denote or represent the names of the elements [narrative elements] of the educational periodic table. The symbols begin with the lowercase alphabet and move across the table to the uppercase alphabet and finally to a combined upper/lowercase symbol. For example, the first element in the educational periodic table is analogous to the simplest chemical element, hydrogen, and is represented by the beginning of the lowercase alphabet "a" indicative of the beginning of word development leading to word usage and reading. The narrative, *The Joy of a Simple Atom* (Chapter V) represents both the chemical and educational first element.

Chemistry: Chemistry is an area of science dealing with the composition and properties of substances and with the reactions by which substances are produced from or converted into other substances; how substances react with one another. The *chemistry of education* looks at the composition and properties of the components of education and

how they react and interact with one another. It is the *how* of the teaching and learning of the curriculum.

Collision frequency: In chemistry, or chemical reactions, the collision frequency refers to the number of collisions that occur between molecules per unit of time and successful collisions result in reactants being converted to products. Comparatively, the *educational collision frequency* refers also to the number of collisions between the components of education in the teaching/learning process [connections or engagements at all levels]. Positive collisions may lead to successful teaching/learning reactions, while less than positive collisions may lead to difficulty in teaching/learning reactions, curriculum functioning reactions, institutional operation reactions, et cetera.

Complex: In chemistry, a complex refers to a compound, a polyatomic cation, anion or neutral molecule in which the molecules or ions (ligands) are bonded to a central atom or ion. When such a complex has a net electrical charge, it is referred to as a complex ion. An *educational complex* may be anything within education comprised of a central core [individual, principle, idea, pedagogy, curriculum] to which are bonded other components. In general, such complexes can be multi-layered. An important, engaging and varied complex is that of the teacher/students in a classroom or course environment where the teacher is the central core and the students are bonded to her for the duration of the class/year or course. The curriculum itself is comprised of many complexes which themselves are composed of individual units.

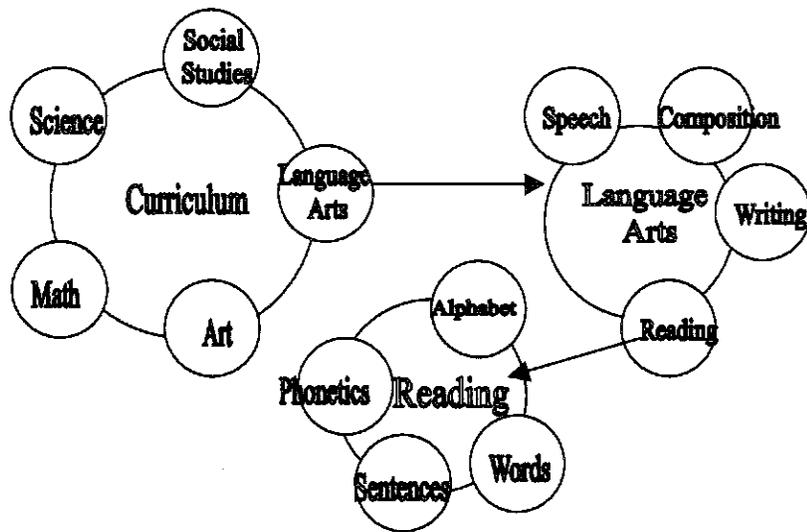
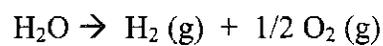


Figure 13. Various complexes of education. Each complex is comprised of multiple entities of which each entity is a complex and can be further broken down.

Compound: A compound is a substance comprised of two or more elements.

Physical change does not change its composition but it can be broken down into its constituent elements by chemical change. For example the compound water can physically exist as ice, liquid or vapour but it is still the compound water [H₂O]. It can however, be chemically broken down into its constituents as in the following reaction:



In the same context, an *educational compound* may refer to any education substance comprised of two or more constituents that are not affected in composition by physical change but may be broken down by a “chemical” change. For example, each teacher will have a different approach to teaching the curriculum [which may affect both the teaching and learning of it] but in general the curriculum remains the same. However the curriculum as a whole may be broken down into its individual components [reading, writing, arithmetic, et cetera].

Condensation reaction: A condensation reaction occurs when two molecules are combined together through the elimination of a smaller molecule, such as water, between them. An *educational condensation reaction* similarly combines smaller elements together thus forming a larger compound and in the process eliminates a smaller, possibly less effectual component. In the development of curriculum for example, smaller pieces of curriculum are combined to form the whole of the curriculum but in the synthesis some of the smaller parts may be eliminated possibly because they are redundant or do not work in the larger picture. At all levels of education there are many condensation reactions. Perhaps one of the most critical is that enforced by the government where schools, programs, classes, courses are condensed or consolidated resulting in larger classrooms, fewer resources [lost or eliminated components] but often leading to a less effective product [education] and in the long run teaching and learning difficulty.

Condensed formula: A condensed formula refers to a simplified representation of the structure of a molecule, for example the large molecule of starch which is comprised solely of many glucose molecules can be represented by the formula $[C_6H_{12}O_6]_n$ where “n” equals the number of glucose molecules. *A condensed formula in education* is a simplified representation of a structural component of education. For example, the content of a course can be represented or condensed into the course outline or the syllabus or the summary at the end of a chapter in a textbook can condense the themes of the chapter into a few sentences.

Conformation: Conformation refers to the different possible arrangements of a particular compound; the molecular formula stays the same but the orientation of the atoms in space is different. *Educational conformations* are different arrangements of a

particular compound having the same composition. For example teachers within a school may teach different grades or courses but the collective group of “total” teachers remains the same. Variations on teaching curriculum occur as the result of different approaches and teaching styles of teachers but the collective *teaching of the curriculum* and the curriculum content remains the same. Within the classroom the students may be in rows, tables, or a circle but the students within the classroom remain the same for the year.

Conversion factor: A conversion factor, written as a ratio of two quantities that are equivalent to one another, is used to express the relationship between the two quantities generally having different units. For example, in the conversion of inches to centimeters one inch is equivalent to 2.5 centimeters therefore ten inches would be equal to twenty-five centimeters. A conversion factor is a standard that holds true.

$$\begin{array}{l} 1 \text{ inch} / 2.5 \text{ cm} = 10 / X \quad X = 25 \text{ cm} \\ \text{(conversion factor)} \end{array}$$

Conversion factors in education may be used to relate two components, having different units/composition, to each other. For example, relating an old and new curriculum to each other, one institution’s curriculum to another’s, the performance of students on an exam or in a course for one year to that of other years may require the incorporation of a factor if the parameters are not exactly the same.

Coordinate covalent bond: A coordinate covalent bond is a bond formed between two atoms such that the shared electrons are donated by only one of the atoms thus resulting in a formal charge on the atoms ¹⁰[A: + B → A-B]. This is in contrast to a covalent bond where each atom of the bonding pair contributes an electron. In a *double covalent bond*, designated by a double dashed line (=), two pairs of electrons are shared

¹⁰ The dots between the elements represent the electrons and the dashes the bonds.

between the bonded atoms. An *educational coordinate covalent bond* may be formed such that the electrons/components are donated by only one of the members of the bond, which results in powers of relation or control issues. A covalent bond is a relationship/bond formed where both parties equally contribute one component. The result is reciprocity, equal sharing and no relational power. In a double covalent bond, both participants contribute and share equally two components/electrons of the bond thus creating strength and equality.

Coordination compound: Coordination compounds are neutral compounds comprised of complex ions [FeCl₃]. In *education, a coordination compound* is any large compound comprised of smaller more complex units such that the overall effect is a neutral compound. For example, an educational institution has the appearance of being a neutral, balanced structure but it is comprised of many complex entities, the sum of which give the overall neutral/balanced appearance. The same may apply to the classroom. The overall appearance may be harmonious but within the classroom [as any teacher knows] there are many smaller dynamics happening.

Curriculum: Curriculum is a very complex, multifaceted, and dynamic enterprise and central to all education. A fundamental question to understanding and improving a curriculum is; *what is a curriculum?* According to Bloom (1981),

Curriculum refers to both the process and substance of an educational program. It comprises the purpose, design, conduct and evaluation of educational experiences. Curricula exist at different levels, range from the single course to the educational program to the department or discipline to the college or university. The organization of curricula is defined by educational philosophy, the structure and content of the knowledge imparted, and the institutional context and climate. Effective curricula have coherence and explicit definitions of aims and standards of attainment. They accomplish their aims through sequence and structure of learning experiences to facilitate student learning and development. They provide sufficient content and coverage to exhibit but not exhaust the limits of the subject

of study. They include mastery of basic terms, concepts, models and theories as well as some application of them to context. Good curricula have hallmarks of effective instruction and the evidence of enhancement of student learning. (p. 25)

Theories of curriculum are descriptive or prescriptive for the most part, rather than transformational. Theoretical models serve to explain and describe the functioning of particular curricula but do little to analyze or influence its effects on the learners/students. Descriptive models portray how the various hierarchies of curriculum exist within curriculum but again do little in terms of effecting change.

Curriculum is equated to chemical reactions in chemistry. Each reaction is in itself a curriculum requiring specific reagents, reaction conditions, et cetera. Each element of the periodic table has its own curriculum.

Currere: Currere is one method of curriculum research that incorporates a phenomenologically related form of autobiographical curriculum theory. This form of research focuses on the educational experience of the individual as narrated by the individual (Pinar et al, 1995). Currere seeks to describe the experience rather than to quantitate it. In terms of *chemistry*, the laboratory notebook and observations of the researcher lend its way to the method of currere; the description of what takes place in the experiment or reaction and the researcher's interpretation or analysis.

Degree of ionization: The degree of ionization is a measure of the extent to which the molecules of a weak acid or base will ionize (gain or lose electrons) in solution. It is an indicator of the degree of reactivity, how much they participate or become involved. The *degree of ionization in education* is the degree to which the teachers, students, administration, et cetera participate or become involved. It could also be the degree to which the weaker components are more easily swayed [or controlled] or

a measure of their instability or volatility, both of which could lead to difficulty in teaching and learning.

Decomposition reaction: In a decomposition reaction, a compound is broken down into two or more components. An *educational decomposition* reaction is also a breakdown reaction and can occur at a multitude of levels and in a multitude of contexts. Perhaps the most critical are those reactions causing teacher or student breakdown leading to teaching or learning difficulty as well as burnout.

Density: The density (D) of a compound is a physical property which may be obtained by dividing the mass (m) of the compound by its volume (V) [$D = m / V$]. *Educational density* may refer to either population density in terms of an institution, a class or course or it may refer to the content density in terms of the curriculum, how much and how difficult.

Diagonal relationships: Diagonal relationships are similarities between pairs of elements in different groups and periods of both the *chemical* as well as the *educational* periodic tables. What are the similarities? What are the differences? Why?

Diffusion: Diffusion refers to the spreading of a substance into an uncharacteristic region or area as a result of random molecular motion. In *education*, diffusion may refer to the development and spreading of an idea, of an unfamiliar concept, in some ways the learning process but even more deeply, the acceptance of an unfamiliar idea, concept, practice et cetera, largely by general acceptance and open/broad-mindedness. The polar contrast might also be the spreading of a bad idea or situation.

Dilution: Dilution is the process whereby the concentration of a solution is reduced through the addition of more solvent. *Dilution in education* refers to any

situation where the more concentrated becomes less concentrated, the result of which may be either beneficial or detrimental to the overall functioning or product. For example, the dilution of the curriculum by the addition of less difficult components may result in the content becoming easier. The quality of teaching may be diluted by the addition of more students per class, more requirements of teachers, more stress on teachers all of which may have detrimental effects on the quality of teaching and learning. At the post-secondary level [particularly in recent years] there is a dilution of “standards” or “the setting of the bar” in order to have good teaching evaluations or to keep “bums on seats”. The addition of more teachers to the pool serves to reduce the teaching load of individual teachers thus having an overall positive effect. This unfortunately in times of cutbacks does not often happen rather the addition of more students to the class dilutes the contact of the teacher and possibly the delivery of the curriculum.

Discourse: Discourse refers to a communication of ideas or information by talking or by narration. It refers to a long and formal treatment of a subject in speech, writing, lecture, treatise, et cetera. The periodic table of chemistry and one developed for education could be considered a discourse in their respective disciplines.

Education: The common premise of education is that it is the formal schooling at an institution of learning and is the process of developing the knowledge, mind, character of the students by such formal schooling. From the educator point it is the process of teaching and learning, the result of which is the knowledge and ability. Education encompasses the whole of the systematic study of the methods and theories of teaching and learning. The *chemistry of education*, therefore refers to the processes of synthesis or

analysis, similar to the process used in chemistry, to understand the inter- and intra-relationships of education. How does it work? What is happening? Why is it happening? These are all questions that lead to the understanding, the chemistry, of education.

Electrolyte: An electrolyte is a substance which when dissolved in an aqueous solution is capable of conducting electricity. *In education an electrolyte* is someone or something which when put into an environment enhances the flow or functioning of the components of the environment. In a difficult environment, such an individual may serve as a mediator. It may also be something that enhances the teaching/learning process. Technology, for example, could be considered to be an electrolyte. In education, counselors, teacher assistants, et cetera would also be considered electrolytes as they serve to enhance the flow of the classroom.

Electron: An electron is a subatomic particle, having a very low mass and carrying a single negative electric charge. Electrons are the principle components of the bonds joining atoms together and can be referred to as the chemical glue. *The electrons of education* or the *educational glue* are the principle components of bonds that join educational components together [the ability to learn]. Learning capabilities are governed or affected by many factors such as a student's readiness to learn [background, desire, et cetera], teacher-student, teacher-teacher and student-student relationships, the personalities and abilities of the individuals involved et cetera, all of which dictate the affinity and strength of the bond formed.

Electron affinity: Electron affinity refers to the energy change associated with the gain of an electron by a neutral atom in the gaseous state. *In education, electron affinity* refers to any number of situations in which there is a change from a neutral position to

one of attraction and how readily this occurs. A high electron affinity means a high attraction whereas a low electron affinity means a low attraction. In teaching/learning, electron affinity might be how readily a concept is caught by the student(s). Some will *catch on* more quickly than others but the energy change from pre to post knowledge might be significantly less than that of an individual who caught on more slowly and had a much larger learning curve. The end-product, the acquisition of knowledge, might be the same but the energy change significantly different.

Electronegativity: Electronegativity is a measure of the electron attracting ability of an atom in a bond. The resultant difference in electronegativity between two atoms bonded together is used to assess the polarity (charge distribution) in the bond. *In education, electronegativity* is also a measure of the electron attracting ability of the participants in a bond, the greater the electron attracting ability, the drawing ability, the greater the polarity. In education this sets up relations of power with those possessing the greatest electronegativity generally having the most control or power.

Element: An element is a substance comprised of like atoms that cannot be broken down into simpler substances by chemical reactions. *Elements of education* are any of the fundamentals or the basics of curriculum, the fundamental philosophies, pedagogies, curriculum, et cetera. The *individual* teachers and students are essential to the basics of education and are also elements of education. Each *individual component* cannot be broken down further into simpler components.

Elementary process: An elementary process is a single step in a reaction mechanism that has a significant result such as altering a molecule's energy, geometry or producing a new molecule. The elementary steps are a series of simple reactions the sum

of which represents the overall reaction. An *elementary process in education* is any single step of a given educational reaction that has a significant effect or contribution to the overall reaction sequence. For example, it might be a single step in any teaching or learning process such that the culmination of the elementary steps is the learned curriculum. Learning the alphabet, for example, leads to word recognition, which leads to sentence formation and recognition and finally to reading.

Empirical formula: The empirical formula of a molecule is the simplest chemical formula that can be written for that compound having the smallest integer subscripts as possible. It shows the types of elements present and the ratios of the different kinds of atoms in the molecule and is often a reduced form of the molecular formula. The *empirical formula in education* refers to the basic constituents of any part of education, such as the different curricula, the classroom, the institution, a program, et cetera. When everything is reduced down, what is the foundation or the simplest formula that is the backbone of a particular component of education? Whatever that simplest foundation is then, is considered to be the empirical formula. All curricula for example, have a basic foundation or set of principles upon which the rest of the curriculum is built. The entire curriculum is a “multiple” of the foundation. Even more simply put, a story can be broken down into its simpler components of plot, character, setting, et cetera.

Endothermic processes (reactions): Endothermic processes lower the temperature of the system by absorbing heat from the surrounding environment. *Endothermic processes in education* are those processes requiring an input of energy. Such processes may involve individuals who put in a great amount of energy to make an educational process, a particular group, a curriculum et cetera work. It also may include those

individuals or any process that absorbs "heat" from the environment; that intervenes and alleviates a potentially difficult situation or reaction. Endothermic processes may also be those processes or individuals that act as a drain on the overall system rather than contributing to it by requiring the input of great amounts of energy.

Energy: Energy is the capacity to do work or to produce change. The capacity to do work or produce change *in education* is generally through the teacher in teaching or the student in his/her effort to learn; how much energy is required to teach or learn? The amount of energy expended may or may not be proportional to the amount of work done or the change effected. Energy though, can neither be created or destroyed, it can only be moved around. As a result there may be a great difference in the energy expended and the energy gained in a given reaction.

Enzyme: An enzyme is high molecular weight protein that serves as a biological catalyst to enhance the rate of a biological reaction by lowering the activation energy. *An enzyme in education* is anything or anyone who can affect the rate of a reaction by lowering its activation energy thus reducing the amount of energy required to make the reaction proceed. Enzymes are not consumed in the reaction but are recycled to be used over and over again. This continued re-use in education may lead to difficulty in terms of burnout, particularly if the environment is not favorable for the enzyme.

Epistemology: Epistemology refers to the study or theory of the origin or nature of something. In education, epistemology refers to the study and understanding of the workings of education. Analogously, epistemology in chemistry refers to the understanding of the workings of chemistry. The periodic table is an epistemological

metaphor in that it is the foundation on which chemistry is based and thus can be translated to become an epistemological metaphor for the foundations of education.

Equilibrium: Equilibrium is the condition where the rate of the forward reaction is equivalent to the rate of the reverse reaction such that the amount of reactants and products remains constant, with no net change, over time. *Equilibrium in education* refers to a balanced situation such that the forward and reverse reactions are equal; reciprocity in teaching and learning, for example, might exist in equilibrium.

Exothermic processes: Exothermic processes produce an increase in heat that is transferred to the surrounding system; they evolve heat. *Exothermic processes in education* may be viewed as those processes capable of creating heat or effecting change. The energy or heat they provide to the system may be garnered to drive other reactions. In contrast exothermic reactions of education are also those potentially volatile reactions that, rather than effect a positive change, serve to have a negative impact on a situation, a reaction, an individual, et cetera.

Family: In both the chemical and educational periodic table, *family* refers to the elements in the vertical column of the periodic table, most often referred to as groups. Families have identifying characteristics and those elements that exist within a family [group] share those identifying characteristics [to varying degrees]. For example, members of the Group 1 elements all react with water to produce hydrogen gas but do so with varying intensities and the violence of the reaction and amount of gas produced decreases as one goes down the family. Such familial characteristics apply to education as well. Members of a grade five class, for example, all have the characteristic of having passed grade four but they will have done so with varying abilities and grades. Thus in

grade five the students will have varying abilities as well which may be related to their learned knowledge from grade four.

Ground state: The lowest energy, most stable state for electrons of an atom or a molecule, is the ground state. The *ground state in education* is also the most stable state for the “electrons” of the teachers, the students, administrators, et cetera; the state of least volatility. If one considers the electrons to be the abilities and inter/actibility of the elements, the ground state is the desired state of both teachers and students, the state of least volatility, least conflict and least difficulty.

Group: The members of a vertical column of both the chemical and educational periodic tables are referred to as a group or, sometimes a family [see family above]. Members of the group or family will have similar properties.

Heat: Heat refers to the transfer of energy between two bodies not at the same temperature. In the *heat of a reaction*, the energy is converted from chemical energy to thermal energy resulting in a temperature change to the system. Heat can either be evolved [exothermic] providing a source of energy for other reactions or it can be absorbed from the system [endothermic] and used as energy to drive a reaction. *In education heat* is not a temperature change per se but rather an effect of a reaction or, series of reactions, where its evolved effect can provide energy to further channel positive or negative reactions or it can be channeled internally to provide inner strength [endothermic] for internal reactions. Heat in education might be the negative result of a reaction.

Heterogeneous mixture: A heterogenous mixture is one in which the components are physically separated such that they exist in distinct regions often having differing

properties and composition. For example, one might be a liquid, the other a solid [sand and water] or two immiscible liquids [oil and water]. *A heterogeneous mixture in education* occurs when the reacting individuals have different properties or characteristics such as a way of practice, a way of thought, or personalities. They exist in different, unmixable regions having dichotomous philosophies, practices and ways of being and always separate out of the solution (group) and even with continued mixing/interaction, they never become part of the group.

Homogeneous mixture: A homogeneous mixture or solution is one in which the components have uniform composition and properties and thus upon sufficient stirring result in a mixture with the same composition throughout. Once homogeneous, the components cannot generally be separated by physical means. *A homogenous mixture in education* is one in which reacting individuals, although they may at first differ in their properties, philosophies, pedagogies, approaches, et cetera, become blended and part of the total mixture after time. They are no longer distinguishable as separate entities but are blended as part of the group. The result of such blending or mixing may be the loss of free-will or conformity to a group, situation, practice, et cetera. It may also result in a unified front, philosophy, or a practice.

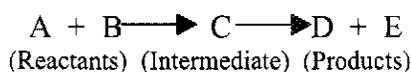
Hypothesis: In both chemistry and education, *a hypothesis* is a tentative explanation of a series of observations or of a natural law that is generally proven or defeated through the results [facts] of experimentation or research.

Induced dipole: An induced dipole is the separation of positive and negative charges in a neutral molecule subjected to the charge effects of another polar molecule in close proximity. *In education, induced dipoles* refer to the effects of a highly charged

(polar) but opposing individual or group in trying to sway or influence a more neutral, not yet committed, individual or group.

Inert complex: An inert complex is one in which there is a very slow exchange of ligands such that it is considered to be largely unreactive. *An inert complex in education* is one that does not readily change, is essentially unreactive but is also a mainstay of tradition. Such inert complexes might be those individuals who are senior in their positions or within the system and so are less volatile in their responses to situations; a tried and true curriculum that has stood the test of time; the basic fundamental philosophies and pedagogies of education, et cetera.

Intermediate: An intermediate is a product of the reactants that is one of the steps between the reactants and the products in a multi-stepped reaction which is short-lived and consumed to yield the products.



It does not appear in the overall balanced equation of the reaction but does appear as a mechanism in the reaction. *An intermediate in education* might be considered to be someone who significantly contributes to a process in a *behind the scenes* fashion, assistants of various sorts for example, whose efforts are consumed but often go unrecognized in the overall picture. The work and effort of graduate students, support staff and technicians, for example, often goes unrecognized but is key to the operation of the whole at the post secondary level. The work of student teachers, classroom assistants, even parents is often consumed and unnoticed. In the whole process of education,

teachers are intermediates in many reactions, contributing and doing work behind the scenes for which they get no recognition and is not part of the job description [listening to student's problems is only one example]. We all know of a teacher who has made a significant impact in our life simply by some little thing she said or did or simply by her way of being.

Intermolecular forces: Intermolecular forces are the attractions between molecules. The attraction between students and teachers, teachers and teachers, students and students, et cetera are considered *intermolecular forces in education*. Such intermolecular forces lead to reactions and inter/actions [positive or negative] the results of which lead to effective or ineffective teaching and learning.

Intramolecular forces: Intramolecular forces are those forces [the glue] that hold atoms together in a molecule. *Intramolecular forces in education*, are those forces that govern, in either a positive or a negative fashion, the classroom, the institution, the system, the curriculum, et cetera and which serve to hold the whole of these together. What are the intramolecular forces that hold teachers together and keep them out of teaching difficulty?

Ion: An ion is comprised of either an atom or a group of atoms that upon losing or gaining an electron(s) become charged. An *ion in education* is someone, either a student or a teacher, who is charged and highly reactive. Such a charge may be directly related to the fundamental personality of the individual [student or teacher] or their response to a situation and may be either negative or positive in nature but being highly charged they engage.

Ionic bond: An ionic bond is formed when electrons are transferred between a metal and nonmetal element resulting in positive and negative ions that are held together by the electrostatic forces of attraction between the oppositely charged ions [ionic bond]. The resultant compound is an ionic compound. *In education, ionic bonds* may be formed between the attraction of two individuals having differing opinions, philosophies, approaches to teaching, personalities, et cetera but who by their very differences, work effectively together. Such an effective unit can be considered to be an *ionic compound in education*.

Ionization energy: The ionization energy is the minimum amount of energy required to remove an electron from an isolated atom (or ion) in its ground [most stable] state thus resulting in a charged ion. *Ionization energy in education* refers to the minimum amount of energy required to have an effect in either teaching or learning, the minimum amount of energy required to make something or someone reactive, interactive or responsive; to engage.

Isolated system: An isolated system is one in which there is neither transfer nor exchange of mass or energy to or from its surroundings. *Isolated systems in education* are stand-alone systems or incidents. They may be critical in their moment and may even have profound effects but are limited to a single place and time.

Labile complex: A labile complex is considered to be one in which there is a rapid exchange of ligands, a relatively unstable or highly reactive complex that is readily destroyed. *In education, a labile complex* is a highly unstable and reactive complex and it may refer to the fragility or volatility of either students or teachers or any combination there of at any level. One might think of student teachers here, beginning teachers who

are unsure, unstable, reactive, but who are easily crushed or destroyed. Students who are less confident, frustrated, in difficulty at school or at home might be more labile [volatile] and as a result more unstable.

Law: A law is a concise verbal or mathematical statement explaining a relationship that is constant and unvaried under consistent, unvaried conditions. Such fundamental laws in chemistry include: The Law of Conservation of Energy, The Law of Conservation of Mass, The Law of Definite Proportions and the Law of Multiple Proportions. *Laws in education* refer to fundamental principles of teaching, standards of practice that remain constant with time under consistent and unvaried conditions; tried, true and proven philosophies, pedagogies, or practices.

Limiting reagent: The limiting reagent is the reactant that is consumed completely in the reaction thus limiting the quantity of products formed by its initial amount present; the reactant that is used up first. *In education, the limiting reagent* is the component consumed first; it could be the energy of the teacher, the ability or desire of the student, the materials at hand for teaching the curriculum, et cetera. Each component of education has a limiting reagent.

Mass: Mass is the measure of the quantity of matter contained in an object. *In education, mass* refers to the quantity of students and teachers within the classroom or within the institution as a whole. It might also refer to the components of the curriculum or the system. In fact there is often a *critical mass*, which in some cases is necessary for an effective response but which beyond that can lead to breakdown.

Matter: Matter refers to anything that occupies space, has the property of mass and displays inertia. *Matter in education* refers to the body of students and teachers that

occupy the classroom or institution as well as all physical components of the institution used both for the teaching and operation; the resources.

Metabolism: Metabolism refers to the sum of all reactions of a living system.

Metabolism in education refers to the sum of the reactions involved in teaching, learning and the operation of the living system. The living system is education. Metabolism, therefore, is the sum of all reactions that lead to a particular education, whether it is a part of the education or the education as a whole.

Metal: A metal is a compound generally having a lustrous appearance, is malleable and able to conduct electricity. Such elements have a small number of easily removed electrons in the outermost shell, the removal of which results in a cation and enables it for ready combination with other elements. *Metals in education* are those individuals [students or teachers] who stand out, who shine, who are highly reactive and interactive, who by their personality draw others to them.

Mixture: A mixture is comprised of more than one component. It may be either homogeneous [evenly distributed] or heterogeneous [not evenly distributed] in composition. *In education, a mixture* is anything comprised of two or more different components or constituents. For example, a class of students, comprised of males and females all with different personalities and abilities would be considered a mixture. The dynamics of a classroom is a mixture of the personalities of the constituent individuals. The whole of the curriculum of education, for example, is a mixture of its parts [language arts, social studies, science, math, et cetera].

Mole: A mole is the amount of substance that contains as many elementary entities [constituents] as there are in exactly twelve grams of the carbon twelve (C-12)

isotope [the standard of reference]. *In education the mole* is more difficult to standardize, but it might be considered the various curriculums each of which is comprised of its elementary constituents. For example, the curriculum of a particular grade would be comprised of the individual subjects and levels achieved for that curriculum. So for each aspect of education, there might be a mole or standard of reference.

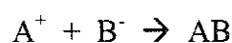
Molecular formula: The molecular formula of a compound denotes the number and type of atoms of each element in the molecule. For example, A_2B_3 represents two atoms of A and three atoms of B. Such a formula *in education* refers to the composition of a group, a class, a course, the curriculum, et cetera. It denotes the number and type of components. For example a class of twenty-eight having fifteen girls (G) and thirteen boys (B) and one teacher (T) may have a molecular formula $B_{13}G_{15}T$. One could develop a molecular formula for the curriculum and each of its parts. In essence, a course outline might be considered to be the molecular formula of the course.

Molecule: A molecule is an aggregate of bonded atoms held together by special forces called covalent bonds such that they exist as a separate entity, the smallest of which has the characteristic proportions of the constituent atoms present in a substance. *A molecule in education* is any group that is comprised of aggregated atoms (teachers, students, committees, et cetera) bonded together by some commonality. The properties of the molecule are an amalgamation of the philosophies, ideas, personalities, et cetera of the atoms or members of the molecule and are thus a representative blend of the whole.

Narrative: Narrative is "the primary form by which human experience is made meaningful" (Polkinghorne, 1988, p.1); a story or an account of such human experience; also to tell or write a story or give account of, to relate such a story by narration, the

process of telling. *In chemistry the narrative* is the laboratory notebook, the observations, the story of the observed reactions. It is also the written discussion of any paper or report.

Neutralization reaction: A neutralization reaction occurs between an acid and a base in the correct stoichiometric proportions such that there is not an excess of either the acid or base in the final solution. The product of such a reaction is a neutral solution.



A neutralization reaction in education might refer to the correct stoichiometric proportions of two opposing personalities or philosophies such that the situation or difficulty is resolved leading to a more neutral environment.

Neutron: A neutron is a fundamental subatomic uncharged particle found in all atomic nuclei, except the hydrogen atom, having a mass slightly greater than that of a proton. It is neutral in charge and is not involved in reactions or bonding. *A neutron in education* refers to an uncharged person, with slightly greater mass (authority, experience, et cetera) who is to remain neutral in a given situation or responsibility; does not participate in reactions, perhaps a mediator, a counselor, or a principal.

Non metals: Non metals are those elements of the periodic table that are poor conductors of electricity and heat. They are capable of gaining small numbers of electron such that they have the electron configuration of a stable noble gas or they may alter their electron configuration by sharing electrons. *Non metals in education* are those individuals who generally tend to take on responsibility or shoulder difficulty, who have trouble saying "no". They tend to be individuals who share or give of themselves in difficulty but in doing so are often taken advantage of and they may become the scapegoat or the "door mat".

Nucleus: A nucleus is the central core of an atom containing the protons or positive charge. The *nucleus in education* refers to the fundamental principles of education or the curriculum; to some the nucleus is the teacher, to others the nucleus is the curriculum, still others believe the nucleus is the founding principles of education. Possibly more accurately, each of those are elements having their own nucleus or central core. If one considers the elements to be the individual students at a particular place and time in education, then the nucleus is comprised of the knowledge base, experience, personality, et cetera of the elements [students].

Observation: The qualitative and quantitative description of what takes place in a chemical reaction are referred to as observations and they are recorded in laboratory notebooks; they are the qualitative description, the story, of the reaction. *In education, observation* is equated to descriptions, affective results, viewed outcomes of what takes place in education and like chemistry may be of the qualitative or quantitative nature. Narratives are equitable to the laboratory notebook and are the way of relating the qualitative results of an educational reaction.

Octet: An octet refers to eight electrons, the most stable and least reactive configuration in the outermost valence or electronic shell of an atom. The octet rule states that the number of bonding and lone pairs of electrons in a structure is eight which thus provides the most stability. *In education, an octet* refers to the stages or levels of education starting with pre-K and finishing with the doctoral level. At the doctoral level, the outermost shell will contain the full octet and be the most stable, most knowledge; the highest learned state [filled shell]. Throughout one's academic journey an atom associates

with other more knowledgeable individuals/atoms making connections [reactions, bonding, et cetera] that fulfill the octet rule and any specific voids or needs.

Open system: In an open system, matter and energy (generally in the form of heat) can be exchanged with their surroundings as opposed to a closed system in which they cannot. *An open system in education* is any system, environment, pedagogy that readily allows interaction with its surroundings; the exchange of knowledge, teaching/learning practices, et cetera.

Orbital: An orbital is a region of an atom in which the electron charge density or the probability of finding electrons is high. It exists outside the nucleus. The classroom *in education* might be considered to be the *orbital*, the place where the greatest charge density or where the electrons (students) are found; the site closest to the teacher. Orbitals also exist within the curriculum with the nucleus being the fundamental principles or central core and the orbitals being the various branches or levels. Orbitals can be equated to knowledge and filled orbitals are equivalent to completed knowledge.

Overall reaction: The overall reaction is the net change that occurs as a result of a multi-stepped process. In *education the overall reaction or net change* refers to any situation or process that involves a multi-stepped pathway from the initial to the final stage; teaching and learning are both multi-stepped processes with the overall reaction being the process for a specific duration of time. The overall reaction might be viewed in terms of curriculum mapping; the outlining of the content, skills and concepts of a curriculum [experiment] into a "framework" or a design for instruction.

Oxidation: Oxidation is the process whereby electrons are "lost" generally to another atom thus increasing its oxidation number. Oxidation is always coupled with

reduction such that one species is oxidized, the other species is reduced, thus gaining electrons. This is referred to as a redox reaction. *In education oxidation* refers to the philosophy of "*when something is lost, something else is gained*". Teaching and learning are both redox reactions in that the transfer of knowledge [electrons] from the teacher is gained by the student.

Oxidation state: The oxidation state of an atom refers to the number of electrons that can be lost, gained or shared by combining with other atoms to form molecules or polyatomic ions. *In education, the oxidation state* may refer to limits - what is the number of electrons that can be lost, gained or can take place in a given reaction?

Oxidizing agent: An oxidizing agent is capable of accepting electrons from another substance thus allowing it to be reduced. *In education, the oxidizing agent* is the student who is capable of accepting electrons [the curriculum, the experience, the teachings of the teacher, et cetera]. It might also be considered to be the individual, teacher perhaps, who shoulders the responsibility and in doing so may become reduced and if continued for long enough without replenishment it may lead to "burn out".

Patternicity: A word synthesized by Fowler (1997) to refer to a predictable, prescribed or repeated characteristic; a regular patterned (but not identical) way of acting, doing or behaving, a pattern - patternicity is repeatability of the pattern in educational phenomena. *In chemistry and education, patternicity* is the repeated observed trends. A prime example of patternicity is the consistency of the repeated relationships and reactions of the periodic table.

Pedagogy: In both education and chemistry, pedagogy refers to the profession or function of a teacher, the process, art or science of teaching.

Percent/Percent composition: In both chemistry and education, percent refers to the number of parts of a single component out of the total parts of the total composition multiplied by 100.

$$\text{A parts/AB parts} \times 100\% = \% \text{ AB that is comprised of A}$$

Percent yield: In both *chemistry* and *education*, percent yield is the amount of product actually obtained out of what was theoretically expected multiplied by one hundred.

$$\% \text{ Yield} = \text{Actual yield of A/theoretical yield of A} \times 100\%$$

Period: A period in both the Periodic Table of Chemistry and the Periodic Table of Education is a horizontal row where all members of the period have atoms of the same highest principal quantum number.

Periodicity: Periodicity refers to the tendency, quality or fact of reoccurring at regular intervals. Within the periodic table for either chemistry or education, it refers to the re/occurrence of similar properties of the constituents occupying similar positions within their respective column of the periodic table. Thus every eighth element of Groups 1, 2 and 13 to 18 [excluding the transition metals] will have a repeated characteristic as one moves down the periods of the table [periodic relationship to the patternicity of the table]

Periodic table: The Periodic Table of Chemistry is the tabular arrangement of the elements in order of increasing atomic number such that elements with similar physical and chemical properties are grouped together in vertical columns. The *Periodic Table developed for education* is also an arrangement of the elements of education. The elements are given alphabet symbols that are ordered in increasing progression through

the alphabet beginning with lowercase and moving to uppercase. Each of the vertical columns contains those elements [students] with similar educational properties. The periodic law applies to both chemistry and education and refers to the recurrence of certain physical and chemical properties as the elements are considered in increasing atomic number/letter. The periodic table for both chemistry and education is a *temenos*, a crucible, that holds the whole of each discipline. The elements, how they interact and react, can be predicted by their position within the periodic tables.

Philosophy: A philosophy is a belief. It is also a theory or logical analysis of the principles underlying conduct, the general principles or laws of a field of knowledge. Chemistry and education therefore have their own embedded philosophies and principles. Teachers have their own philosophies about teaching and such philosophies are as individual as the teachers themselves.

Physical property: A physical property is a characteristic property of a substance that can be observed [what something looks like, tastes like, smells like, feels like] without transforming the composition of the substance. *A physical property in education* refers to any observable property of teachers, students, the environment of teaching and learning, or the institution.

Physical change: A physical change is a change in one or more properties of a component but the composition remains the same. For example, in melting a solid such as ice becomes a liquid but both the solid and the liquid are comprised of the same atoms [hydrogen and oxygen] in the same proportions [H₂O]. *In education, a physical change* refers to any change in teaching, learning or the dynamics of the teaching/learning

environment such that the composition [integrity] remains the same but the resultant physical representations, good or bad, may be observed.

Polar molecule: A polar molecule is one in which the positive and negative charges are separated as a result of the presence of one or more covalent bonds such that there is a dipole moment created much like that of a magnetic field. *In education a polar molecule* refers to a separation in opposing individuals such that a polarity or a difference exists where one group or individual has more drawing capacity and therefore gets more attention or recognition.

Polyatomic molecule: A polyatomic is a molecule than contains more that one covalently bonded atom. *In education, a polyatomic molecule* refers to any tight-knit cohesive or organized group; teachers, students, committees, cliques, gangs, et cetera which might be heterogenous in nature [unlike elements grouped] or homogenous [like elements grouped].

Polymer: A polymer is a high molecular weight complex comprised of many, hundreds or thousands, of smaller monomer subunits. Starch, for example is a polymer of glucose subunits. *A polymer in education* may refer to the institution such as the school or university, a *body or group* of students or teachers comprised of monomer subunits, the individual teachers or students. The curriculum as a whole is a polymer of its many parts.

Precipitate: A precipitate is an insoluble solid that falls out of or separates from solution as a result of a decrease in solubility. This decrease in solubility may be the result of a physical parameter such as a temperature decrease or it may result once the saturation point of dissolved particles has been achieved such that the holding capacity of the solution has been exceeded and particles drop out of solution. *In education, a*

precipitate may refer to an individual who is excluded from or who leaves a particular group. It may also refer to the “fall out” or repercussions from a particular situation or reaction; reaching a "saturation" point at which compounds drop out of solution; such a precipitate may lead to teaching difficulty. Teaching difficulty may eventually precipitate as "teacher burnout".

Primary: Primary refers to the first level in chemistry, or to the principle level. In a reaction it is the basics of the reaction, the first reaction. In a protein or an enzyme it refers to the basic structure, the amino acid sequence that comprises that protein.

Primary in education also refers to the basic or initial level of anything. Primary grades refer to the initial grades of education; there are primary pedagogies, primary parts of any curriculum, et cetera; the elementary or beginning, basic level.

Product: The products are the substances formed in a chemical reaction. *In education, products* are outcomes; the precise outcome of the learner once there is mastery of a prescribed learning task. For example, passing a course would be the outcome or mastering of the learning in the course.

Qualitative: Qualitative refers to general descriptive observations about a system. *Qualitative analysis in chemistry* refers to the descriptive observations and subsequent analysis (reasoning and conclusion-drawing) of any aspect of a chemical reaction. *In education, qualitative observations*, are those descriptive observations about any aspect of education; the inter and intra reactions, actions, et cetera of teaching and learning. Qualitative research is "*researching lived experience*" (van Manen, 1994) and the "what" of the experience. *Qualitative analysis in education*, refers to the descriptive (narrative)

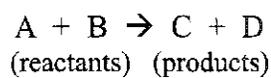
analysis (reasoning and conclusion-drawing) of any aspect of education [heuristics, hermeneutics, phenomenological hermeneutics, autobiography, et cetera]

Quantitative: Quantitative refers to various numerical measurements that are used to obtain a quantity or amount of substance [how much] rather than the mere presence or absence of the component. *Quantitative analysis* is the reasoning or conclusion-drawing as a result of such numerical measurements. *Quantitative in education* also refers to the numerical measurements used to obtain quantities or amounts of any aspect of education. *Quantitative analysis in education*, is the analysis (reasoning or conclusion-drawing) of the results of such numerical measurements: quantitative results do not necessarily reflect on the qualitative results and in fact may be quite ambiguous. In both disciplines, it also refers to the statistical measurements used in the evaluation of those quantitative numbers [the data].

Rate-determining step: The rate-determining step, sometimes referred to as rate-limiting step, is the one which proceeds the slowest in a reaction and consequently the overall rate of the reaction will be dependent on this step as the reaction can only proceed as fast as the slowest step. *In education, the rate-determining step* is also the step that determines how fast or slow a reaction will proceed. For example, it may be how fast the topic or concept is comprehended by the student or students. Many factors can be considered to be the rate determining step from the slowest individual in the class, how the concept is presented, the difficulty of the concept, the preparedness of the group [students] et cetera.

Reactants: The reactants are the starting materials in both a chemical or educational reaction; the interaction or reaction of which leads to the formation of products.

Reaction mechanism: A reaction mechanism, in both *chemistry* and *education*, is the sequence of elementary steps that leads to the formation of products. In chemistry this is represented by the reaction equation. For example,



In education, the reaction mechanism might be more defined as the curriculum, the structured areas of intended learning experiences; the integration or reaction of two or more subjects around a common theme, much like two or more reactants in a chemical reaction. It might also be the strategies used to teach a particular concept, a course, a curriculum, et cetera.

Reaction rate (rate of reaction): In both *chemistry* and *education* the reaction rate refers to the change in concentration of reactants and products over time. *In education, the reaction rate* refers to the time it takes for a change in the educational reactants to be converted to the educational products whatever they may be deemed to be.

Reversible reaction: A reversible reaction, in both *chemistry* and *education*, is one that can proceed in both the forward and reverse directions.

Rhetorical tropes: Rhetoric refers to the art or science of using words effectively in speaking or writing. The term trope, first recognized by such Greek philosophers as Aristotle, Quintillion and Cicero, in Greek means "a turn". These figures of speech were and are regarded as methods to compare dissimilar items to achieve effects that transcend the literal meaning. Rhetorical tropes therefore, are the art of using such "figures of

speech" effectively in speaking and writing (Corbett, 1990). Throughout this thesis, rhetorical tropes will be short narratives used to describe, augment or support a particular concept.

Saturated solution: A saturated solution is one in which there is the maximum amount of dissolved substance [solute] at a given temperature, such that the holding capacity of the solvent is exceeded and the dissolved substance will precipitate [fall out] out of solution if more is added. *In education, a saturated solution* is any condition (from teaching, to learning, to governing or operation of the system) in which the holding capacity of the situation is exceeded and the addition of more "components" to the system results in a "fall out". This can lead to difficulty and even burnout in learning or teaching.

Scientific method: Scientific method refers to any systematic approach (method of doing) to research; the general sequence of activities – from observation, experimentation, the formulation of hypothesis, laws, theories, et cetera that lead to the advancement of knowledge. Scientific method does not only govern science, rather the systematic approach can be applied to any situation in which data, quantitative or qualitative is being collected. Thus *scientific method in education* or chemistry is the procedural method of prescribed rules which have little flexibility. Deviation from the method often invalidates the results.

Secondary: In chemistry secondary may refer to side reactions that take place at the same time as the primary reaction. It may also refer to secondary reagents required to be added at some point in the reaction or secondary products formed. *In education,* secondary refers to the next level of education [learning] once the primary or first level

has been attained. The most obvious secondary level of education, is that of high school, grades ten to twelve. It also refers to the secondary level of any curriculum once the basics or the primary level have been mastered; secondary levels of knowledge, more advanced and integrated teaching, secondary philosophies, pedagogies, et cetera. It can also refer to the level of hierarchy in the administration within the education system.

Shielding effect: The shielding effect is the ability of the inner shell electrons to protect the outer shell electrons from the nuclear charge effects of the nucleus. Such a *shielding effect in education* would be the shielding effect or safe environment the teacher provides in which the student can learn. It can also be the various layers of knowledge or philosophy one develops with time that protect, substantiate, or augment, one's central core.

Simultaneous reactions: Simultaneous reactions in both *chemistry* and *education* occur when two or more reactions proceed at the same time. These reactions may be side or tangential reactions that occur at the same time as the major or paramount reaction. What is going on at the same time? What is the hidden curriculum; those unplanned or unanticipated experiences that occur simultaneously?

Solid: A solid in chemistry, is when atoms and molecules are ordered and packed in a highly organized fashion such that there is a definite volume and shape to the group of atoms or molecules. *A solid in education* refers to any tight, cohesive, group such as a grade/class of students, a committee, a clique, a gang et cetera or it may refer to the hierarchy (organized system) of the educational institution.

Solute, solvent and solution: A solute is the individual component dissolved in the *solvent* (the aqueous or organic liquid used to dissolve the solute) the result of which is a

solution (solute + solvent). *In education, the solute* refers to the teachers, students, or the curriculum within the classroom, institution, system (the solvent) or course. The resultant solution is the interaction of the teachers and/or the students within the classroom, institution or system, or how a particular component of the curriculum serves to augment or work within the curriculum.

Spectator ions: Ionic species present in a reaction that do not participate in the overall reaction are referred to as spectator ions. *In education*, such *spectator ions* would be those individuals (students, teachers, administrators, et cetera) who are on-lookers, who stand on the sideline of a situation (reaction) observing rather than participating. In both cases, their purpose is undefined but they may serve as a support system for those ions actually involved in the reaction.

Spin state: The spin state of an electron can be either $+1/2$ or $-1/2$ which *in education* could be equated to positive and negative [opposing] personalities, philosophies, interactions, situations, et cetera.

Spontaneous reactions (spontaneous/natural process): A spontaneous reaction is one that takes place on its own when the system is left to itself, without any external action or energy to make the reaction go. Such reactions [like radioactive decay] may take a very long time. *Spontaneous reactions in education* occur at all levels and are those reactions that take place on their own without any external influences. The initiation of such reactions may be largely dependent on the dynamics of the environment and may also take a long time or may seemingly appear to happen right out of nowhere such that one is taken by surprise.

Stoichiometric proportions: When referring to stoichiometric proportions, the relative mole amounts of each of the substances present is in the same mole ratio as implied by the balanced chemical equation. Therefore if two reactants are present in a 1:2 mole ratio in the balanced equation, they will be present in that ratio or a multiple of that ratio (i.e. 2:4, 3:6, et cetera). *Stoichiometric proportions in education* refer to the number or proportion of participants present in a given situation such that the most effective results are a multiple of the original reaction.

Structural formula: The structural formula of a compound is the symbolic representation of which atoms are bonded together and how they are bonded together whether be by single, double or triple bonds. *Structural formulas in education* may refer to the composition of a classroom, a committee, et cetera and may include such categories as the number of individuals further broken down into various categories of gender, appearance, experience, et cetera and who is friends with who (bonds) and how many friends (single, double or triple bonds) per group.

Substance: A substance is a form of matter having a definite or constant composition and distinct properties throughout a given sample and which are consistent from one sample to another. In chemistry, all substances are either elements or compounds. *In education a substance* may refer to any component of education such as the curriculum, the teachers and students or groups within the system having a definite composition and distinct properties; a volleyball team, a basketball team, a band, a specific committee, a program, a particular class, et cetera.

Substrate: A substrate is the substance acted upon by an enzyme in an enzyme-catalyzed reaction. The substrate is converted to products and the enzyme is regenerated.

Many *substrates* exist *within education* in which an enzyme converts the substrate to products. For example, the students within a learning situation can be considered the substrate while the teacher is the enzyme. The unlearned students (substrate) are converted to “learned” students through the reaction of teaching/learning and the teacher, the enzyme [the teachers], is regenerated to continue the process with the next substrate [new students].

Surroundings: The surroundings refer to the rest of the universe, outside the system with which the system interacts. The surroundings often have a great impact on the reaction. *In education, the surroundings* refers to anything extraneous to the system, the environment in which the system interacts that may have an impact on the reactions within. For example, how the classroom exists and functions is impacted by the surroundings, other classrooms, teachers, students, et cetera. Within the surroundings, one might consider the scope, the boundaries of the curriculum that define what is included and what is excluded and the sequence, the order in which content or objectives are arranged in the curriculum. In a chemical reaction, it is the way in which the reagents are added to a reaction.

System: A system refers to the specific part of the universe of interest or part being studied. Systems may be open, closed or isolated. *Systems in education* refer to the specific part of the educational system being studied such as a particular class, a program, a group, et cetera. As in chemistry, systems in education may be open, closed or isolated.

Tertiary: Tertiary refers to the third more complex level in chemistry. In terms of a protein or an enzyme it is the stabilizing forces, such as the disulfide bridges, various hydrogen bonds, et cetera that stabilize the three dimensional structure of the molecule.

Tertiary *in education* is also the more complex level, post secondary (university) where learning is more advanced. It is the stage of advanced higher learning of the curriculum. It is the most advanced stabilizing level or factor when looking at all aspects of education.

Theoretical yield: The theoretical yield refers to the amount of product that can be expected from a chemical reaction, calculated from the balanced equation, when all of the limiting reagent is used up. The *theoretical yield in education* refers to the expected product or result of a particular reaction, the expected outcome when all the factors affecting the “educational reaction” being studied are considered. A simple theoretical yield is the number of individuals expected to pass the course at the end of the term relative to the number that started.

Theory: A theory in both *chemistry* and *education* is a unifying principle, model or conceptual framework used to explain or make predictions about a natural phenomena or a body of facts and the principles upon which they are based.

Transition metals/elements: Transition metals are those metals/elements of the periodic table which have partially filled *d* or *f* subshells. Transition metals bridge the non metals with the metals and reside within the middle of the periodic table. *In education*, the transition metals are anything that is able to bridge one entity with another through a progression; a bridging philosophy, teaching style, a course within a curriculum, et cetera. The transition element may also possess characteristics of both entities.

Transition state: The transition state of a chemical reaction is the intermediate state between the reactants and the products. *In education*, the *transition state* may refer

to any state in which there is a transition from the original to the final state, a state partway or intermediate in the journey; possibly the part of processing information in the process of learning.

Valence electrons: Valence electrons are those electrons in the outermost shell of an atom involved in chemical bonding. *Valence electrons in education* are those individuals that are immediately involved in linking or joining groups together in some fashion, they are the most reactive and could be considered the doers; they are involved in reactions and form compounds and complexes by either donating or sharing electrons.

Valence shell: The valence shell of an atom is the outermost shell holding the electrons involved in bonding. A *valence shell in education* is the individual or group that has the [where-with-all], the ability/desire to become involved in a reaction. Many individuals or groups have the ability and capability of becoming involved in reactions but this has to be coupled with a desire to do so.

Work: In both *chemistry* and *education*, work is the directed energy change as a result of a process.

Yield of the reaction: In both *chemistry* and *education*, the yield of the reaction is the quantity, and some might consider the quality as well, of the product obtained from the reaction. In education, the issue of accountability should be considered with yield. What is the outcome, orientation or return on investment? This question can be asked of the reactions for both chemistry and education. Accountability in the classroom holds teachers responsible for student learning. What is the yield?

The rudiments of a bridging language provide structure for opening theoretical and functional conversations across the disciplines of chemistry and education. It is essential to have a shared lexicon so that generative research, knowledge and practice can bridge the current boundaries of discourse.

CHAPTER V

CONSTRUCTING THE BRIDGE

The Chemical → Educational Periodic Table

The periodic table was incredibly beautiful, the most beautiful thing I had ever seen. I could never adequately analyze what I meant by beauty--simplicity? coherence? rhythm? inevitability? Or perhaps it was the symmetry, the comprehensiveness of every element firmly locked into its place, with no gaps, no exceptions, everything implying everything else. (Sacks, 2001, p. 203)

...the periodic table is the universe at its essence...every element has its place in order secure, no matter what. (Robin Williams in the film *Awakenings*, 1998)

*The Origin of the Periodic Table of Chemistry*¹⁰

The Russian chemist, Dmitri Mendeleev, after twenty years of studying the properties of the at-the-time known chemical elements, developed a system of organizing them based on increasing atomic weight. He developed the notion of a periodicity, the repetition of properties that occurs when the elements are organized in increasing atomic

¹⁰ The chemistry principles described throughout this section are amalgamations of basic chemistry theory from the following six sources:

Brown, T. L., Lemay, H. E. Jr. & Bursten, B. E. (2000). *Chemistry: The central science*. Upper Saddle River, New Jersey: Prentice Hall.

Chang, R. (1994). *Chemistry*. (5th ed.) Montreal: McGraw-Hill Inc.

Kotz, J. C. & Treichel, P. Jr. (1996). *Chemistry and chemical reactivity*. (3rd ed.) Toronto: Saunders College Publishing.

Masterton, W. L., Slowinski, E. J. & Stanitski, C. L. (1986). *Chemical principles with qualitative analysis*. (6th ed.) Toronto: Saunders College Publishing.

Petrucci, R. H., Harwood, W. S. & Henning, F. G. (2002). *General chemistry*. (8th ed.) Upper Saddle River, New Jersey: Prentice Hall.

Puddephatt, R. J. & Monaghan. (1986). *The periodic table of the elements*. (2nd ed.) Oxford Chemistry Series 32, Oxford, Clarendon Press.

Robinson, W. R., Odom, J. D. & Holtzclaw, H. F. (1992). *Chemistry: Concepts and models*. Toronto: D.C. Heath and Company.

weight and into their respective groups or categories, a property that governs all elements and a notion that eventually led to the Periodic Law (Sacks, 2001). The Periodic Table of chemical elements (see Figures 14a and 14b), produced in 1869, was the culmination of Mendeleev's insatiable passion to taxonomize the chemical elements. In this chapter I explore the basis of the observed periodicity of properties of the elements of the Chemical Periodic Table and use the principles to bridge education and build an Educational Periodic Table.

The basic principle of the table is that the elements are organized in increasing atomic weight across the table resulting in rows (periods) and columns (groups) of elements. The elements within a group are considered a family and the properties of any element within a group are similar to those of their group or column-mates. Based on this, elements with close atomic weights can be very different in their properties, while elements whose atomic weights are far apart may have similar chemical and physical properties. For example sodium (Na), a soft metal, highly reactive with water, has an atomic weight of approximately 23 grams per ¹¹mole and is much different in chemical and physical properties than neon (Ne), a gas not highly reactive with water and whose atomic weight is similar at 20 grams per mole. However it has similar properties to cesium (Cs), a harder metal like sodium with an atomic weight very far removed at 133 grams per mole but that can be found in the same group or column (Group 1) as sodium. Thus as you move from lighter to heavier elements across the table you *periodically* run across the same properties.

¹¹A mole is the amount of substance that contains as many elementary entities (atoms, molecules or other particles as there are in exactly twelve grams of the carbon-12 isotope (see Chapter IV).

Groups		Nonmetals																		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
1		Periods															2			
H		Metals																		He
3	4	Transition Metals										5	6	7	8	9	10			
<i>Li</i>	<i>Be</i>											B	C	N	O	F	Ne			
11	12											13	14	15	16	17	18			
<i>Na</i>	<i>Mg</i>											<i>Al</i>	<i>Si</i>	<i>P</i>	<i>S</i>	<i>Cl</i>	<i>Ar</i>			
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
<i>K</i>	<i>Ca</i>	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	<i>Zn</i>	<i>Ga</i>	<i>Ge</i>	As	Se	Br	Kr			
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
<i>Rb</i>	<i>Sr</i>	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	<i>Cd</i>	<i>In</i>	<i>Sn</i>	<i>Sb</i>	Te	I	Xe			
55	56	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
<i>Cs</i>	<i>Ba</i>	Lanthanides	Hf	Ta	W	Re	Os	Ir	Pt	Au	<i>Hg</i>	<i>Tl</i>	<i>Pb</i>	<i>Bi</i>	<i>Po</i>	At	Rn			
87	88	103	104	105	106	107	108	109												
<i>Fr</i>	<i>Ra</i>	Actinides	Unq	Unp	Unh	Uns	Uuo	Uue												

← electron configuration, electronegativity, ionization energy → ← atomic radius, metallic character →

Figure 14a. The chemical periodic table of elements. Those elements to the left of the stair-step line are metals. The representative metals are those to the left of the stair-step line that are bold-faced and in italics. Within the metals are the transition and inner transition metals. The nonmetals lie to the right of the stair-step line and are not bold-faced or in italics. The lanthanides of the inner transition metals begin at element 71 while the actinides of the transition metals begins at element 89. Elements of groups 1 and 2 are collectively called the s-block elements, those of groups 13-18 are the p-block, the transition metals are the d-block elements, groups 3-12 and the lanthanides and actinides in figure 14b are the f-block elements.

The discovery of this periodic behavior of the elements across the table was paramount in stimulating further research. There were many holes in Mendeleev's table simply because the elements had not yet been discovered but he was able to predict the chemical properties of each of these elements based on the position within the table. When these elements were later discovered, Mendeleev's predictions were amazingly accurate. It was not until the electronic structure of atoms was understood that the full significance of the periodic table could be appreciated.

An element is only as reactive as the number of unpaired electrons present in its outermost reactive shell--the valence shell. With the exception of the transition metals [those elements in groups three to twelve in the middle of the Periodic Table, see Figure 14a], Mendeleev also noted a patternicity to the valence electrons (the reactive, unpaired, electrons in the valence shell) that held true for all the elements in the representative groups of the periodic table. Ignoring the valences of the transition metals, the valences of the seven columns; 1, 2, 13-17 of the periodic table exactly follow this sequence of available reactive electrons; 1, 2, [transition metals] 3, 4, 3, 2, 1. In Mendeleev's original table column 18, the noble gases, was missing. When the noble gases were discovered, it was found they were unreactive with other elements and were neutral in their nature, the result of no unpaired electrons. Thus Mendeleev gave them a valence of zero and created an eighth column to the right of the table where they were placed based on their large atomic weight. The patternicity of the reactive electrons in the outermost valence shell for this modification to the table can be represented as such; 1, 2, (transition metals), 3, 4, 3, 2, 1, 0.

Further, knowing virtually nothing about atomic structure, Mendeleev boldly defied the theories of his contemporaries and established a table with missing spaces for *yet unknown* elements, and based on the properties and extrapolation from the elements above, below and from the sides, he predicted the atomic weight and properties of the missing elements. As the elements were discovered, the exactness of his predictions of the missing, and then newly discovered elements, was proven and the Periodic Table which was initially considered to be an aesthetically pleasing but unproven tabulation of the chemical elements was transformed from theory to practice and has become the *bible of chemistry*. In essence it is the *temenos* or theoretical crucible (Fowler, 1997) that holds all the principles of chemistry within it.

The vast expansion of knowledge about the elements and their compounds can best be understood in terms of the periodic table. Individual properties of elements are of lesser importance than the broad trends that can be rationalized using the periodic table. The contemporary Periodic Table is a praxical map of the arrangement of the chemical elements consisting to date of one hundred and nine elements, each represented by a one- or two-letter chemical symbol, horizontally organized by increasing atomic weight. The result is a tabular system of horizontal rows and vertical columns or groups. Every eighth element repeats to form the groups with every member of a group or family having the same number of valence electrons. Every member/element of the group is slightly heavier and echoes the properties of the one above (Sacks, 2001) resulting in all elements within a group having similar chemical properties to other members of its family. This periodicity, the repeating of patterns across the rows, lends itself to the name, *Periodic Table*.

As previously described (see Chapter IV), every electron in an atom has its designated position within that atom and the quantum numbers provide that address which lends itself to the governing feature of the chemical periodic table, the electron configuration. In order to understand the electron configuration of an atom it is important to understand the *aufbau principle* or the “building principle”, how electrons fill orbitals, which is always from the lowest to the highest energy level.

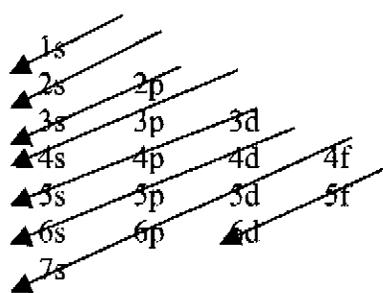


Figure 15. The Aufbau principle of the filling of orbitals by electrons. The orbitals are listed horizontally for each row and filling occurs from the orbital of lowest energy to highest, thus from the end of the arrow to the tip or from the right to left down the arrow.

Each *s*-orbital can hold two electrons, while the *p*- orbitals hold a total of six electrons, the *d*-orbitals ten and the *f*-orbitals fourteen. When the orbitals are correctly filled the electron configuration is considered to be in the *ground state* [most stable state]. For the purpose of this research, suffice it to say that valence bond theory describes covalent bonding in terms of overlapping orbitals [hybridization] and the pairing of electrons. For bonding purposes a paired electron can be promoted to a higher empty orbital resulting in more unpaired electrons and thus available space for pairing. In bonding, unpaired electrons of one atom will pair with unpaired electrons of another atom thus connecting the two atoms together and forming a bond. The number of bonds

capable of being formed by a particular atom is dependent on the number of available valence electrons.

In addition to rows and columns the periodic table can also be categorized into four blocks; the *s*-block contains the two columns furthest to the left on the periodic table as well as the element He [the first element of group 18, the noble gases). The six columns furthest to the right (columns 13-18) are designated the *p*-block. The ten columns of the *d*-block, the transition metals, are sandwiched between the *s*- and *p*-blocks and comprise the middle of the periodic table. The *f*-block consists of the actinides and lanthanides, the two horizontal rows depicted at the bottom of the table.

The transition metals are those elements in the middle of the periodic table. Rather than being easily divided into neat groups, the transition metals all have similar properties, but unlike the other “grouped” non-transition-metal elements, the number of valence electrons they use in their chemical reactions can vary. This variability is attributed to the arrangement and filling of the outermost orbitals. All the transition metals have the same arrangement of outer valence electrons, a filled outer *s*- and *p*-orbital, which contributes to their similar properties, but differing filled lower *d*-orbitals, which contributes to the variability of electrons involved in chemical reactions.

The greatest electrostatic attraction is felt by those electrons closest to the nucleus. As we move away from the nucleus, say from the 1s to the 2s orbital, there are electrons sandwiched between the orbitals which serve to shield the electrons in the 2s orbital from the charge effects of the nucleus and thus the electrons in those orbitals are more weakly held and can enter into chemical reactions more readily. The same is true of education. The elements in Group 1 (early childhood education) are more closely

associated with the nucleus [the teacher] but are less so as they mature [Group 2 onward] and are thus less tightly held and able to inter/react. The stability of a multi-electron atoms can be summarized as $1s > 2s > 3s > 4s$ and in looking at a particular level $4s > 4p > 4d > 4f$.

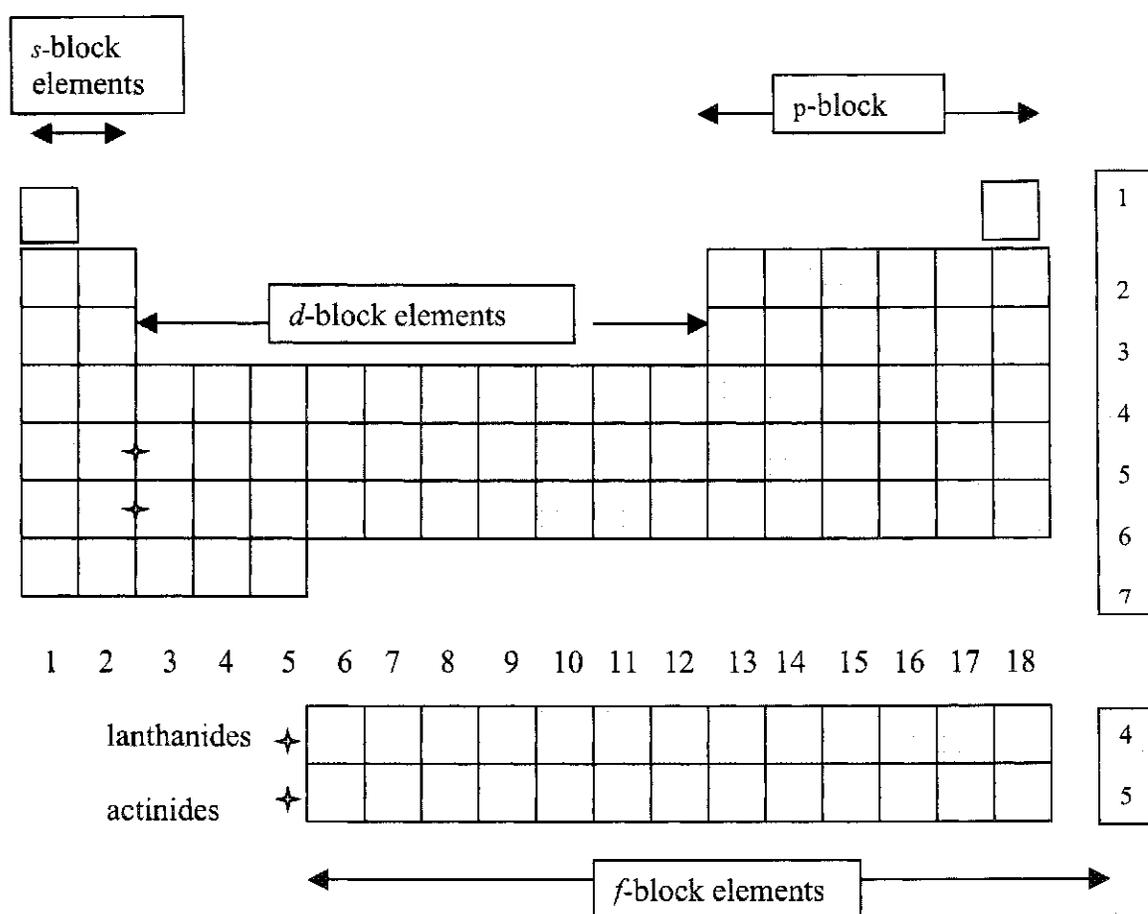


Figure 16. The basic structure of the Chemical Periodic Table of Elements showing the *s*-, *p*-, *d*-, and *f*-blocks. The numbers to the right of the table indicate the rows and thus the location of the various energy levels.

Within the representative groups (Groups 1, 2, 13-18) the *s* and *p* are the defining energy levels and can house up to a total of ten electrons [eight of which are actually the reactive electrons due to the filled *1s* orbital after hydrogen (H) thus rendering those

electrons unavailable for reaction]. The electron configuration is the written representation of the outer valence electrons for a given element and can be considered the profile of that element much like the transcript of a student is the written educational profile of that student. Thus if we wanted to represent the element hydrogen which contains one unpaired electron in its 1s orbital we could indicate the electron by an arrow up [paired electrons would be illustrated by one arrow up and one arrow down]. Hydrogen is the element used as an example here and is the only element with a single reactive electron in the 1s orbital. Helium (He) which also has electrons in the 1s orbital has two, completing the orbital and rendering it unreactive. Thus it is a noble gas and belongs to Group 18.

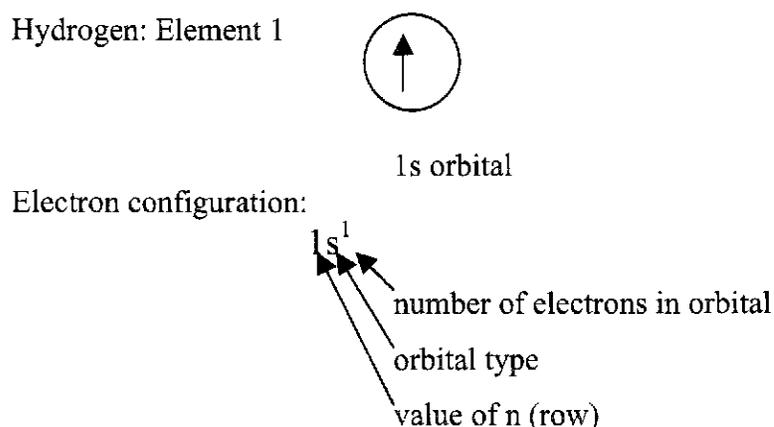


Figure 17: An example of an orbital diagram [representation of electrons in their orbit for a specific element] and the resultant electron configuration [profile] of the atom.

An Educational Periodic Table

Whether one thought in terms of the verticals or in terms of the horizontals-either way one arrived at the same grid. It was like a crossword puzzle that could be approached by either the "down" or the "across" clues, except that a crossword was arbitrary, a purely human construct, while the periodic table reflected a deep order in nature, for it showed all the elements arrayed in a fundamental relationship. I had the sense that it harbored a marvelous secret, but it was a cryptogram without a key--why was this relationship so? (Sacks, 2002, p.190).

I know of many teachers, I among them, who would like to explore the idea of a deep order of education that showed all the elements arranged in a fundamental relationship. Many have been exploring self-organizing systems of chaos theory, but I posit that the periodic table is a useful theoretical and practical relational map. I suggest the chemical periodic table can be used as a template for the development of an *educational periodic table*. Such a table may serve as a *metaphorical temenos* for education holding the whole of education; the curriculum including the philosophies, pedagogies, epistemologies, et cetera, as they pertain to teaching and learning. Each individual element represents those students [learners] at the same point and with the same capabilities/reactivity within the curriculum and the individuality of each element and its relationship to the whole of the table is based on the learning capabilities [valences] of the student and the educational teaching philosophies and practices.

As in the chemical periodic table, the elements of the educational periodic table (see Figures 18a and 18b) are organized horizontally in increasing capability or *educational* [atomic] *weight* and *valence* [reactivity] such that the result is a tabular system of horizontal rows (periods) and vertical columns (groups). Thus if the groups are considered families or individuals with the same properties and reactivity, one could look at the groups as representing the various “educational divisions”.

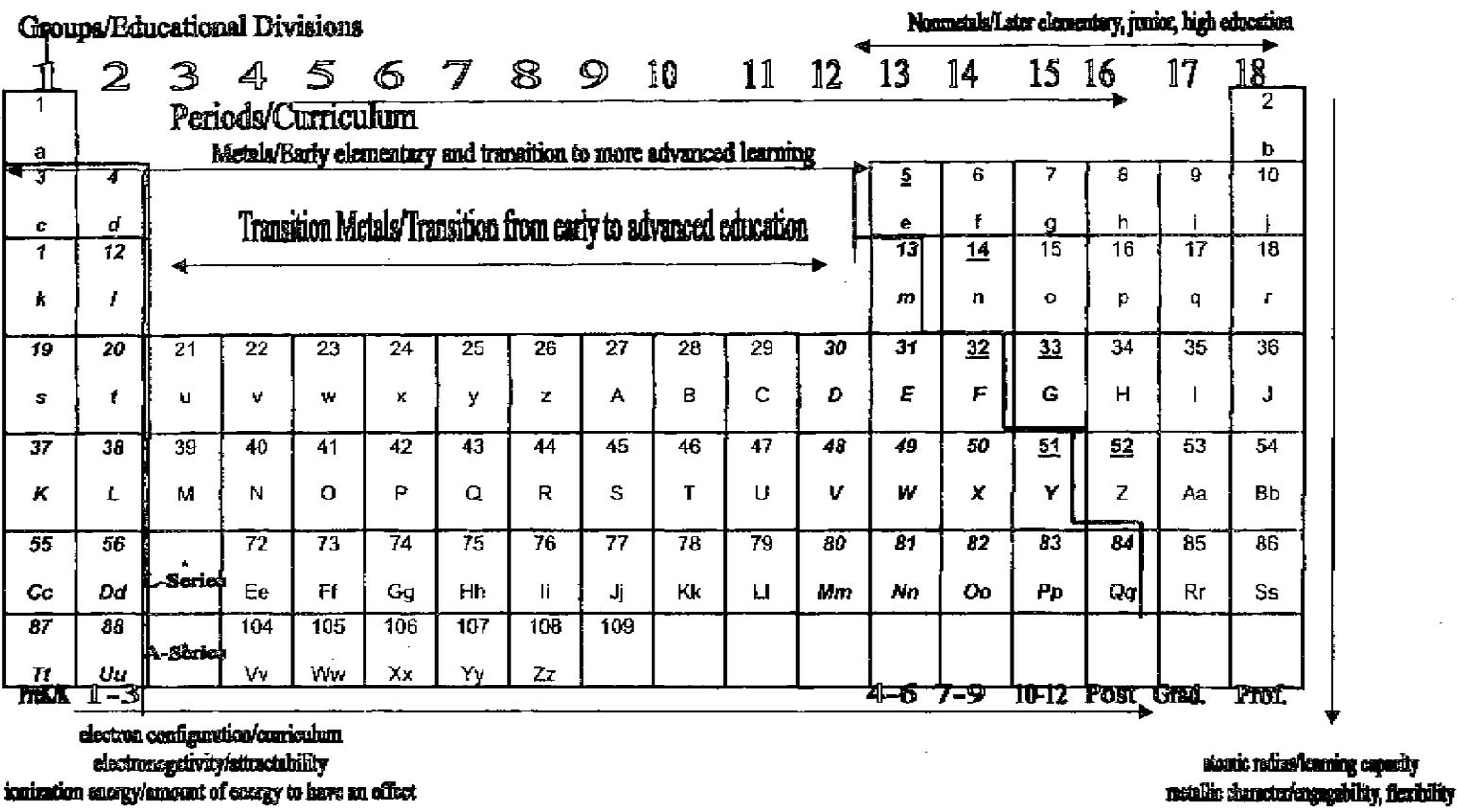


Figure 18a. The educational periodic table of elements. Each group is represented by a grade unit within the education system. To the left of the stair-step are the metals, the younger yet untarnished individuals, while to the right of the stair step are the non metals, less shiny and malleable. The transition metals are those individuals in the transition stage between primary learning and higher learning capabilities. Elements of the first two columns and 13, 31, 49, 50, 81-84 are the main group metals (early education and most malleable) Elements of groups 3 to 12 of the middle are the transition elements (those elements/individuals making the transition from early education to more cognitive upper education) along with the inner transition metals (I and A) shown in figure 13. Elements that are bold-faced and underlined elements along the stair step are the metalloids and they show characteristics of early education (not quite ready) and more advanced education (higher skill level) Elements to the right of the stair step line as well as hydrogen are the non metals; those elements less malleable, upper elementary, junior, high and post secondary levels.

Group 1, therefore, would represent early childhood education, Group 2 grades 1-3, Group 13 grades 4-6, Group 14 grades 7-9, Group 15 grades 10-12, Group 16 post secondary education, Groups 17 graduate school and Group 18 [the unreactive noble gases] would represent achievement of professional [completed] status. Like the chemical periodic table, the groups are formed through the repetition of every eighth element. Each of the horizontal rows or periods represent the various subject areas or goals of the curriculum which increase in complexity as one moves across the table [levels of education].

The elements of the educational periodic table, like the elements of the chemical periodic table, have been given representative symbols beginning with the most elementary first element having the most elementary symbol of the alphabet, the lowercase letter "a". As in the chemical periodic table, "a" like hydrogen (H) is the simplest, but most interactive element of the periodic table and is found in Group 1 [see periodic relationships among groups below]. Like hydrogen [H], "a" is highly reactive having only one electron in an orbital close to the nucleus and being young and still in need of guidance it is shielded or protected by the nucleus. If we equate the Group 1 elements to small children coming into the education system, one can see the potential of learning, the enthusiasm, the excitement, the inter/reactability and re/activity. Such enthusiasm and potential is a contagious joy to see.

The alphabet increases across the table with increasing atomic [educational] weight eventually moving into uppercase letters and finally two-letter upper and lowercase combinations. The inner transition elements [the lanthanides and actinides of the chemical periodic table] have been designated by "c-number" and "d-number" simply

because they reside in their own category and have their own general set of characteristics. The “c-number” series is equivalent to *complexity* housing all the complex and complicated elements of education while “d-number” is equivalent to *differentiated instruction*; instruction of special or different needs. They represent those elements within the education system that do not fit neatly, the "exceptional" elements, into the table and collectively they may represent difficulty at both the teaching and learning levels [the learning gifted, the learning challenged, the behaviorally challenged; perhaps the more radioactive elements/students].

Every member of a group or family has the same number of valence electrons, or essentially the same capability, based on educational level [or chemical level], for learning/reaction, the same general educational profile [electron configuration]. Thus members of a family will have similar educational properties to other members of the same family [will have completed a certain level of education, for example]. As in the chemical periodic table, as we move across the table from one group to the next, we see a patternicity and the same properties periodically reappear [every eighth group]. Exceptions to this occur in the transition stage, the middle of the educational table, [columns 3-12] where the properties of the elements, although similar, show great variability in reactivity. Like any transition (Websters Dictionary, p. 1510), the passing from one condition, position, form, place, stage, activity, et cetera, to another, there is much variability and individuality in how this takes place. Thus the elements of this stage all have the same properties [electron configuration/general educational profile], but they are at different stages or levels both in ability and capability [filled orbitals] thus the variability in reactivity of this stage.

The educational periodic table, like the chemical periodic table, can be similarly divided into the *s*-, *p*-, *d*- and *f*-blocks. The first two columns furthest to the left [see the educational periodic table] represent the *s*-block, those elements with electrons in the *s*-orbital, the orbital closest to the nucleus, the *elementary* orbital. The abilities of individuals in the early elementary stages (the early childhood and grades 1-3) are very basic and require much assistance and guidance from the teacher/instructor. This is where basic instruction is learned (Piaget, 1952) and much learning is based on previous foundations of home or social life (Vygotsky, 1986).

The *p*-block region encompassing the six columns furthest to the right [columns 13 to 18], is characterized by electrons in the three *p*-orbitals and filling occurs across the groups such that by the eighth or final group all the orbitals are filled and essentially learning in terms of an educational institution is complete. This block houses higher, more cognitive learning levels, with a movement from late elementary in column 13 to junior and senior high and levels of post secondary education. The eighteenth group, the halogens [professionals] have completely filled orbitals [eight electrons] and thus are no longer reactive in terms of learning but can now make the transformation from learner to teacher/instructor. The *d*-block or transition elements, the section between the *s*- and *p*-blocks, is characterized by differential filling of the *d*-orbital and is characteristic of the differential learning capabilities of students making the transition from cognitive, basic learning to affective or applied learning (Vygotsky, 1986), and essentially “growing up.” How this is done is largely based on the community--the classroom (Thompkins et al., 2002). The *f*-block, the bottom two rows of the table are the radioactive elements and in education may represent those elements [individuals] that represent a challenge to the

system, those elements that are outside the *norm* [however that is defined] of the educational system [possibly the exceptional or difficult students]. Elements within those divisions have similarly filled *s*, *p*, *d* or *f*-orbitals and such a division lends itself to an explanation of the reactivity [capability] of the elements.

The governing feature of education is the curriculum. Thus in filling [teaching] orbitals [knowledge] of the students [atoms/elements], to develop their educational profile [electron configuration], we start with the basics at the basic levels and fill those levels first. Much like the filled orbitals of atoms become the core electrons, the learned knowledge becomes the incorporated/core knowledge upon which further learning can build [for example, the proverbial "Three R's" of reading, writing and arithmetic are the fundamental base of all further education]. Thus as we move across the periodic table we begin with basic learning, ground-level learning, the transmission of knowledge at the beginning of learning becomes transacted to core knowledge such that eventually the core knowledge can be translated to other learning and thinking beyond or outside the box (Miller & Seller, 1990).

As in the chemical periodic table, "a" like hydrogen (H) is the simplest, but most interactive element of the periodic table, having a single electron in the *1s* orbital, the orbital closest to the nucleus. Being young and still in need of guidance, it is shielded or protected by the nucleus. The strength of the attraction between the positive energy of the nucleus and the negative energy of the electron holds the electron close to the nucleus and keeps the orbital in which the electron circulates small, thus providing boundaries. If we equate this atom to a small child coming into the education system, one can see the potential of learning, the enthusiasm, the excitement, the inter/actability and re/activity,

but also there is the need for the electron of that young, naïve atom to be sheltered, protected, and coddled along in the learning process. Such enthusiasm and potential is a contagious joy to see [see Trope 1- *The Joy of a Simple Atom* -Chapter VI] and such unadulterated reactivity often becomes lost with increased learning as biases and philosophies are formed that color one's perspectives.

The chemical periodic table is also divided into qualitative categories of metals, non metals, and metalloids with the metals being further subdivided into the main-group or representative metals, the transition metals and the inner transition metals. The majority of the chemical periodic table is comprised of metals, those elements to the left of the bold, stair-step line (see the chemical periodic table). Metals have the characteristic property of being shiny (unless otherwise covered with an oxide), malleable (easily pounded into sheets), ductile (capable of being bent or drawn into wires) and are good conductors of heat and electricity.

Such metals in education are those individuals, usually in the elementary grades but particularly in the early elementary grades, that have the characteristic property of being shiny [enthusiastic, beaming with excitement at learning, being in school]. They are malleable in that they are easily molded or shaped by teachers simply because they do not yet have the cognitive skills to form concrete pedagogies or biases of their own. Also at this stage they are governed by the environment, both the educational environment as well as their external environments [home, play, et cetera] (Vygotsky, 1962). And again, because they do not yet have the cognitive and affective skills (Bloom, 1981), they are ductile or capable of being bent or drawn, able to be swayed easily and drawn into a situation, philosophy, way of being et cetera. Like all metals, they are good conductors of

electricity, highly engaging at this level both socially and academically, willing and enthusiastic about learning and able to "share", transmit and conduct that enthusiasm.

In contrast, non metals, those elements to the right of the bold, stair-step line [groups 14 to 16] are generally poor conductors of heat and electricity, are brittle rather than malleable, cannot be drawn into wires or pounded into sheets, are generally dull rather than lustrous as they are incapable of reflecting light and at room temperature are either a gas (hydrogen, oxygen, and nitrogen) or a solid (carbon, phosphorous, sulfur and selenium) but are never liquids [not in-between]. As with the *other metals*, they have unique oxidation states of +4, -3 and -2 in comparison to the oxidation states of +1, +2, or +3 of the metals and can therefore take part in many types of reactions [see Trope 15-*Luminous Allusions to Adequacy* - Chapter VI]

The non metals of the educational periodic table are those of "upper learning", where philosophies and biases have been established. These individuals [elements] are less malleable because they now have their own opinions and philosophies based on their own core of knowledge [experiential and educational] which may be significantly different for each element. Elements at this level, although showing general characteristics, are more individual in their reactions largely because their "educational path and experience" is more individual. They are generally opinionated and not "fence-sitters"; they are either a solid or a gas, not a middle-ground liquid, and as a result are less malleable because they now have their own indoctrinated philosophies and principles.

The metalloids or semi-metals, those elements sitting on the stair-step line distinguishing the metals from the non metals, have both metallic and non metallic properties. Some are semi-conductors while others are not, some shiny and malleable and

some not, et cetera. The variability in their properties can be governed by the environment they are in and so they may exhibit a particular property in one environment but not in another. The metalloids of the educational periodic table represent those individuals/elements bridging or in transition between still needing guidance in developing philosophies and one's educational core to having a developed core. Thus, like the variability seen in teenagers, they have characteristics of the young more malleable and shiny elements/individuals as well as characteristics of the more mature/less malleable/oxidized elements/individuals.

The transition metals, housed by groups 3 to 12, have the unique property of valence electrons used to combine with other elements being contained in more than one shell thus allowing them to exhibit many common oxidation states [ways of being]. As with the other metals, the transition metals are shiny, malleable, ductile and good conductors of heat and electricity. Many of the compounds of the transition elements are unique in that they have certain properties that are not possessed by the compounds of the main-group elements as a consequent result of their partially filled shells of *d* electrons. Educationally, they represent those elements [students] who are in transition, who are generally willing and are highly engaged and reactive; those students who do not quite fit into a group yet who are in transition between early elementary and more advanced learning.

The noble gases were not initially included in the periodic table until their discovery some time later. Based on their atomic weights, Mendeleev added the noble gases to the far right of the periodic table, and because they were unreactive, he gave them an oxidation state of zero. Their unreactivity is a result of a completely-filled

outermost valence shell making them highly stable as there are no unpaired electrons available for reaction. Educationally, these are the elements/individuals who have completed education and moved on to a professional status. Having a full outermost orbital [completed knowledge], they are highly stable and have a solid knowledge base they are now able to share and as a result can now make the transition from learner to teacher/professional.

The rare earths, include all the elements found in group 3 as well as those found in periods 6 and 7, the lanthanide and actinide series. They are often designated by separate boxes at the bottom of the periodic table in order to fit into the table in a concise and aesthetic fashion. Such rare elements/individuals are those that do not fit *inside the box* and in education there are many students who do not fit the norm, who do not conform to the norm as a result of their capabilities or incapacities. These include the gifted, the challenged [academically, physically, emotionally] and those in difficulty. As in the chemical periodic table, they are removed from the "mainstream" table to maintain the aesthetics of the table/system.

Because the chemical Periodic Table is actually a relationship between the elements that exist within it, it is in itself a curriculum, a *temenos* for chemistry. As such, it can serve as a metaphoric translation for education, allowing for the illustration of relational properties that exist between the elements of education.

The Bridging Periodic Metaphoric Relationships

The frame of the *Educational Periodic Table of Narrative Elements* presented in Figure 19 is an exemplar of a relational periodic table, the bridge for the *Chemistry of Education*. A trope for each element within the table serves as educational relational

data. Because the table itself is comprised of one hundred and nine elements and as such, one hundred and nine tropes are too voluminous for this thesis, only representative tropes for each group will be presented as relational data in this section. The rest of the tropes will appear in another document. The majority of these tropes have also been used throughout this thesis to illustrate other parameters of chemistry such as chemical reactions or particular elements. Thus for the purposes of this section, the appropriate element block will be given directing the reader to the relevant trope and page number but the trope will not appear in this section to keep the reader engaged in the relevant application. Figures 19a, 19b and 19c are exemplars of tropes in their relevant positions within the synthesized relational table.

The electron configuration is also illustrated with each group showing the bonding capabilities of the elements within the group. Unpaired electrons are capable of entering into bonding with other unpaired electrons of other elements. Unpaired electrons represent the personalities of the students [the elements of education] and thus often pair up with compatible personalities of other individuals or elements.

The First Orbital Elements: Hydrogen and Helium

Hydrogen: Element 1:



1
II
Hydrogen
1.008

Helium: Element 2:



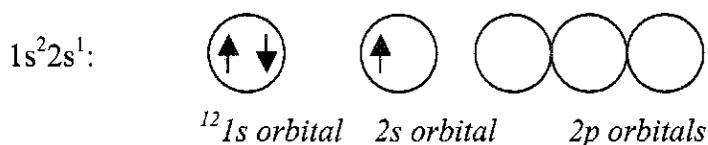
1
a
The Joy of a Simple Atom
(p. 197)

Hydrogen, the first element of Group 1 and helium the first element of Group 18 are somewhat different from the rest of their congeners or group-mates in that the electrons in their outermost valence shell occupy the $1s$ orbital and these are the only two elements that have electrons only at this level. Hydrogen, having only one electron in the $1s$ orbital wants to have it paired for stability. As a result it is highly reactive and will combine with many elements forming a variety of compounds. If not combined with other elements, it will combine with another hydrogen forming the diatomic molecule hydrogen gas, (H_2), a highly explosive gas, and the by-product of many reactions particularly of Group 1 and 2 two elements.

Helium is also a gas and like hydrogen has electrons only in the $1s$ orbital. It differs from hydrogen in that the electrons of this orbital are paired, filling the orbital and essentially rendering it inert. Because the orbital is filled, it is considered to be a noble gas and being the first and simplest element of Group 18, the noble gases, it is ubiquitous in nature.

The first element of Group 1 in the educational periodic table is "a", a ubiquitous letter, found in the whole of vocabulary comprising many thousands of words. It is highly reactive and interactive much like a small preschool child. Helium is designated by "b" and it is also ubiquitous in nature, although it is inert having filled orbitals and thus might be equated to those young individuals who obtain professional/doctoral status early in their career.

Group 1: The Alkali Metals (Li, Na, K, Rb, Cs, Fr) and Early Childhood



1	1
Sodium 1.008	<i>Skipping Lessons (p. 281)</i>

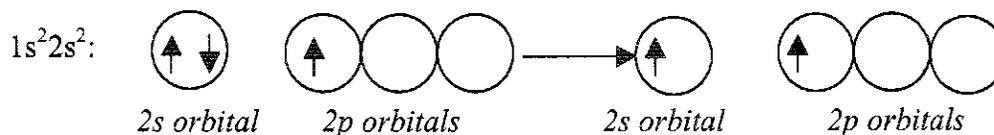
The elements of the leftmost column, the Group 1 elements, the *alkali* metals are solid at room temperature and are highly reactive owing to the one electron contained in their outermost *s*-shell. It is loosely bound and thus is readily given up resulting in the formation of stable cations having a +1 charge. As a result, the alkali metals have the largest atomic radii and the lowest first ionization energy [energy required to release an electron] in bonding to other elements, and are thus never found freely in nature. Although they are metals, the Group 1 elements tend to be softer than other metals, so soft in fact ones such as lithium, sodium and potassium are readily cut with a butter knife.

¹² Each group will illustrate the bonding electrons in such a orbital diagram. Because the 1s orbital is filled after from helium on, it will be excluded from the other orbital diagrams for ease of representation. Assume its presence.

Their reactivity increases with increasing atomic size from the top of the group to the bottom and as a result, ionization energy decreases from the top to the bottom as well because the increased size results in electrons being less tightly bound to the nucleus. The most reactive of the group are cesium and francium, with francium being highly radioactive. All react vigorously with water to form hydrogen gas, which is highly explosive and readily ignites with the heat generated and a basic solution of the metal hydroxide. They readily form bonds with other elements such as hydrogen [the simplest atom] to form compounds such as lithium hydride (LiH) or sodium hydride (NaH) or with chlorine to form salts such as common table salt, sodium chloride (NaCl). These elements are never found free in nature but are always found in compounds.

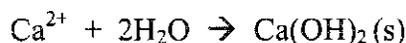
Such characteristics are analogous to the Group 1 elements of the Educational Periodic Table, the pre-K/K elements/individuals. Such young children are easily impressionable, enthusiastic, ready and willing to engage and so it takes little energy [ionization energy] to get them to engage [react]; they readily interact/react and get involved in reactions. Being young and in need of much guidance, they are rarely, if ever, found free in nature and are always found in compounds or groups. They have a large atomic radii, a large space for which their curiosity [knowledge seeking electron] can explore, many interests and often limited focus. Because they are so highly reactive they are in need of much guidance and individual attention and are generally tightly bound to the nucleus/central core [teacher].

Group 2: The Alkaline Earth Metals (Be, Mg, Ca, Sr, Ba, Ra) and Grades 1-3

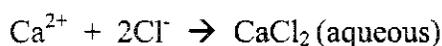


12 Mg Magnesium 24.31	12 1 Precipitating Cations (p. 275)	20 Ca Calcium 40.08	20 t Precipitating Cations (p. 275)
------------------------------------	---	----------------------------------	---

The *alkaline* earth metals belonging to Group 2 of the periodic table possess the characteristic properties of metals. Electron promotion of one *s* electron to the *p* orbital results in an oxidation state of +2 making them highly reactive and as a result, like the Group 1 metals, they are not found freely in nature. In addition there is a greater nuclear charge which results in smaller, more tightly bound elements and thus a greater ionization energy is required to release that second electron. Consequently, they are less active than the alkali metals and are all found in nature in the form of compounds such as calcium chloride (CaCl_2 [a product of soft water heaters]) or barium chloride (BaCl_2 [a compound used in medical imaging]). With the exception of beryllium (Be), they all form quite insoluble alkaline [basic] solutions in their reaction with water. Calcium in its reaction with water, for example, produces the insoluble calcium hydroxide a major component of hard water scale.

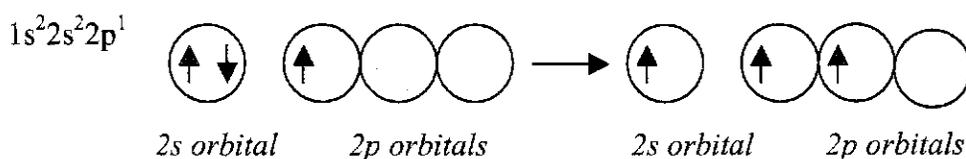


But when reacted with chlorine in a soft water heater it is converted to the more soluble chloride form that is easily removed.



The elements of Group 2 of the educational periodic table are those elements/individuals in the early primary years of school (grades 1 - 3). They are somewhat less impressionable simply because they are older and now have "some" education and experience and consequently have the buddings of their own philosophies [young and uneducated though they may be]. Because there is an increasing nuclear charge [knowledge base] they tend to be more tightly bound and the result is somewhat less impressionable elements and thus a larger ionization energy is required for engagement. Nevertheless, they are still very highly reactive and reactivity, like with the chemical elements, increases with increasing size and decreasing ionization energy. Because of their still high reactivity [willingness and enthusiasm to learn and engage] they still require much guidance and so are never found alone.

Group 13: The Boron Group (B, Al, Ga, In, Tl) and Grades 4-6



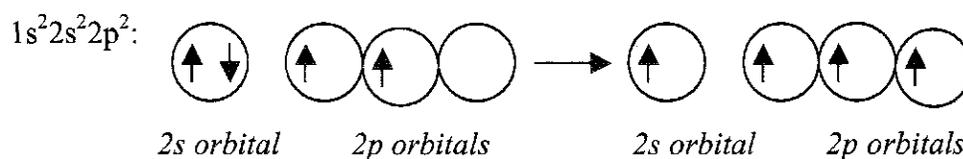
13 Al	13 m
Aluminum 26.98	<i>The Game of Dodgeball (p. 212)</i>

These elements have three valence electrons in their outermost energy level. Electron promotion of one 2s electron to a 2p orbital results in the ability of the elements to bond with three other elements. The elements of this group are all metals except for boron which is a metalloid. The metallic character of the elements increases moving down the group. The covalent compounds formed by boron are non metallic in nature

while the hydroxides and oxides of the gallium and aluminum compounds exhibit the characteristic property of amphotericity, the ability to be both acidic and basic in nature. Indium and thallium exhibit the metallic characteristic of basicity. The oxidation number of the elements in this group is +3, corresponding to their group number, thus allowing them to react forming compounds of the MX_3 form, where M equals metal and X equals the substituent. However, a unique characteristic of this group is the *inert pair effect* where there are stable oxidation states, such as +1 below the main oxidation form of +3, thus allowing for the formation of more than one type of compound.

The elements of Group 13 of the educational periodic table represents those students in grades 4-6, the more advanced elementary or pre-junior high level. At this stage there is less conformity and more individualization beginning. Thus a mixed group of personalities and learning abilities exists [metallic, metalloid, and non metallic]. The environment is critical at this stage as personalities and learning abilities are amphoteric in nature and not all environments provide equal opportunity for all. It is critical at this level, I believe, that attention be paid to the individuality of the "elements/individuals" and allow for differences in learning. Thus promotion to a higher level to allow for more interactivity and reactivity might be critical to maintain the stability of the individual but also to keep the child interested. Of course, there are always exceptions where students might be content [much like the lower oxidation states of the Group] to not interact or engage, to advance more slowly and cautiously. The variability at this level though warrants attention to individuality and this is often lost in the system as a result of various restrictions and constraints.

Group 14: The Carbon Group (C, Si, Ge, Sn, Pb) and Grades 7-9

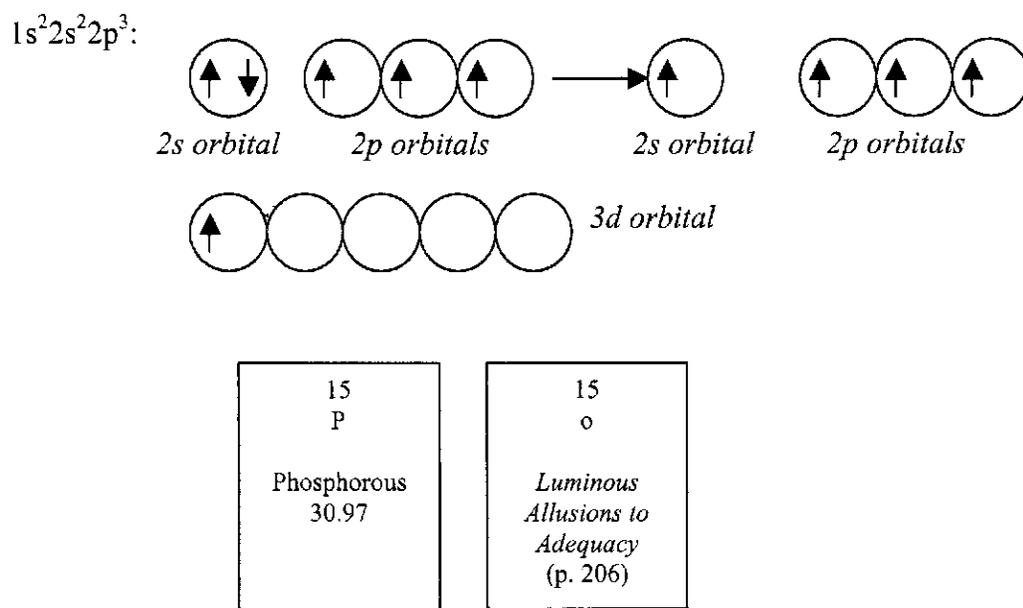


6	6
C	f
Carbon 12.01	<i>The Mighty Ms. E. and Her Students (p. 229)</i>

The elements of the carbon group have four electrons in their outer energy level [after electron promotion] and thus a +4 oxidation state. The inert pair effect applies to tin (Sn) and lead (Pb) in that they prefer to reside in the "expected" oxidation state rather than undergoing electron promotion, thus forming stable dipositive [+2] cations. The first two elements, carbon [the backbone of organic chemistry and the *life* element] and silicon, are very important in nature. The elements of this group include nonmetals, metalloids and metals and as a result there is much variation in chemical and physical properties of the elements as in Group 14. An important characteristic of this group is that the non metals of this group can exist in several different allotropes [forms], each having its own properties. For example carbon can exist in at least three very physically different allotropes commonly known as soot [soft, finely divided, very black], graphite [harder, found in sheets, greyish] and diamond [the hardest element, shiny and transparently clear]. Each is comprised of carbon but each has carbon simple arranged in different lattice structures.

This group is represented by the junior high level in education, those students in grades 7-9 where this is significant variation [allotropy] in learning and maturity level and oftentimes this is where interest in education or interest in engagement begins to change largely as a result of attitude. Thus there is much variability within this group which leads to all types of learning abilities or disabilities, as well as inter/reactability. Allotropy of ability, desire, personality, et cetera, of this group makes it a challenging group to teach.

Group 15: The Nitrogen Group (N, P, As, Sb, Bi) and Secondary/High School

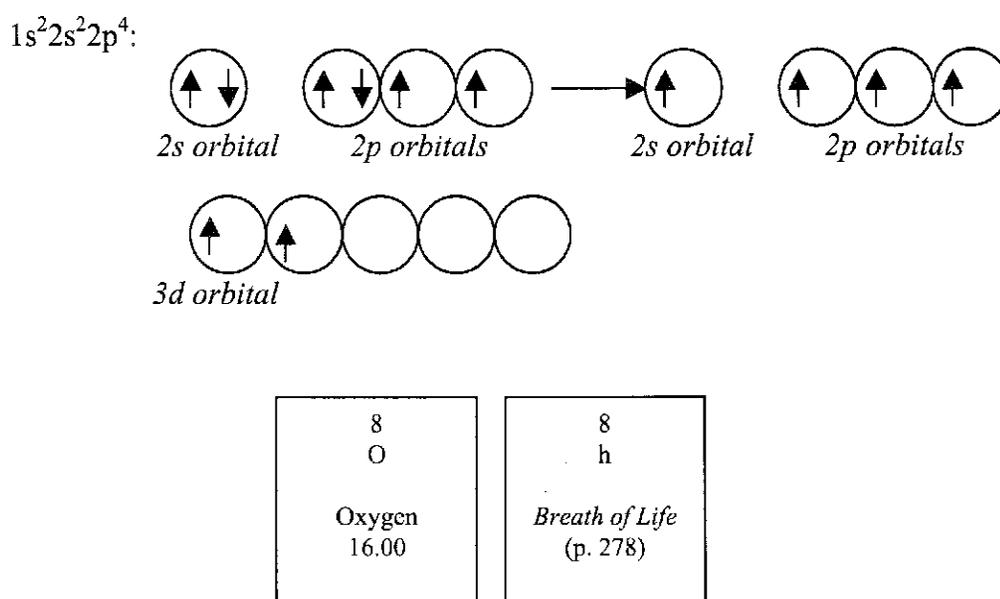


The elements in this group have five electrons in their outer orbit. Most of the elements of this group are non metals and promote their paired electrons such that there is an oxidation state of +5, the result of which the compounds formed from reactions are quite stable. They are quite ubiquitous in nature and form many important compounds.

This group in education is represented by the high school level, grades 10-12. At this level, more serious learning is beginning to take place as there is a well-established foundation [core] and students at this level are beginning to look more to the future, to

career paths, further education et cetera. Thus many important types [more stable] of relationships [compounds] are formed at this level.

Group 16: The Oxygen Group (O, S, Se, Te, Po) and Post Secondary Education

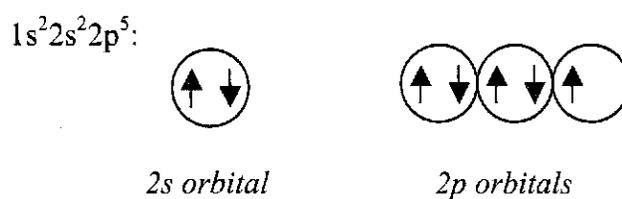


These elements are more like the halogens than the alkali metals and are consequently less reactive than the halogens. Their compounds can be foul-smelling and poisonous and they include sulfur, selenium and tellurium, the "stinkogens" (Sacks, 2001, p. 188) headed by oxygen [non stinky]; a vital component of air and life. Due to the variability of electron promotion, the elements of this group have different structures or allotropes and thus allow them to have a diversity of appearances and to become involved in a diversity of reactions. The compounds formed from reaction with the elements of this groups exist in many forms and have far reaching applicability.

Educationally, elements in this category fall into the post secondary level [technical or undergraduate education] and having an even number of six electrons, a significant amount of education [reactions] has been incorporated into base knowledge.

As a result, such elements have much versatility, much experience and are thus able to apply that knowledge and experience and exist or interact and react with great diversity. Post secondary education is where learned knowledge becomes applied knowledge as the elements/individuals build on core, learned knowledge by applying it in a variety of work/learning situations and observing cause and effect [much like observing a chemical reaction]. Thus there is much independent, although still guided, learning and thinking at this stage.

Group 17: The Halogens (F, Cl, Br, I, At) and Graduate Education

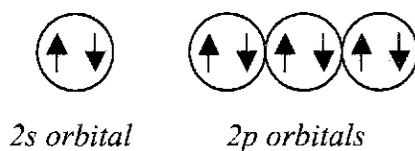
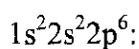


9 F	9 i
Flourine 19.00	<i>How to Extinguish a Flame (p. 204)</i>

These elements are the halogens and are the most reactive non-metal of the periodic table. With seven electrons [only one of which is unpaired resulting in a strong affinity to other unpaired electrons] in their outermost shell, rather than promote electrons, they readily accept electrons from elements willing to combine with them [particularly the alkali metals] and do so quite vigorously. In many cases they serve as electron scavengers until their deficit is readily stabilized.

Educationally such elements represent those at the graduate level. These individuals are continually seeking [scavenging] answers [knowledge] to questions and will readily accept input/information/electrons from other elements. Being so reactive they combine readily with many elements of the periodic table, especially the alkali metals of Group I [young and impressionable]. Of all the elements of the periodic table, they are the most reactive and interactive, getting involved in both the learning and teaching process.

Group 18: The Noble Gases: He, Ne, AR, Kr, Xe, Rn and Professional Status



10 Ne	10 j
Neon 20.18	<i>A Neon Light</i> (p. 279)

These elements are the noble gases and differ from the rest of the elements of the periodic table in that they are not chemically reactive. They have a filled outermost energy level, a complete octet [eight] of valence electrons. They are sometimes called inert gases because of their inability to react and rare gases because of their low abundance.

The noble gas state, that of a filled outermost energy level is equivalent to completion of formal education and the establishment of professional status. At this point there is a transition from that of learner to teacher. All energy levels are full and there are no unreacted, unpaired electrons. Professional status has the connotation of being “above

all” and unreactive/unapproachable [inert]. There is an image attached to professional status and because there are few individuals/elements relative to the whole who achieve such a status, they are also considered to be “rare”. This is not entirely true in that education is a continual process, but formal knowledge is complete and such knowledge is to be shared through practice and teaching

The periodic table is, therefore, a way of integrating the past with the present, a way of "meaning making" and it provides a format to predict, based on "experience" [the relationships and inter/relationships], the unknown. Nearly every element in the table has the capability of numerous different reactions and interactions. The effects of the chemistry of their interactions is illustrated through narrative tropes each related to its corollary chemical partner. These lay the foundation for meaning making and serve as a bridge to understanding the *chemistry of education*. Examples of such a table are given in Figures 19a, 19b and 19c; figures representative of an educational periodic table. Given the extensive nature of the table, only representative tropes are presented in this document; the rest will appear in a later document. Figures 19a, 19b, and 19c to follow are such a representation.

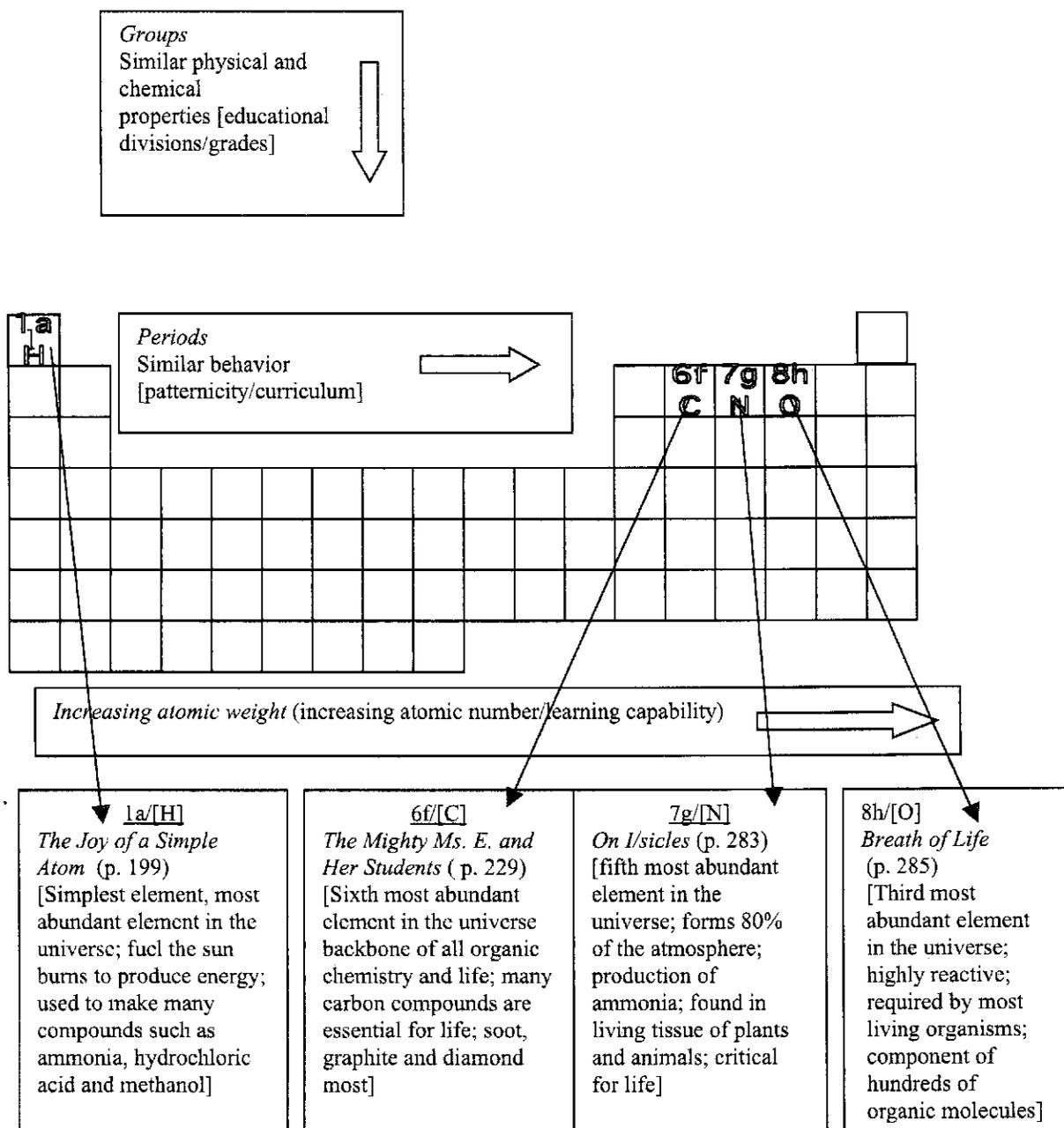


Figure 19a: The Educational Periodic Table of Narrative Elements [Tropes]. The first letter represents the educational element, the second letter in square brackets the analogous chemical element. The trope title is presented in italics and the chemical properties of the element are given within the square brackets.

The chemical periodic table serves as a relational metaphor for education. Each student [element] within the table belongs to a group or family and such an ownership of place allows for specific reactions and inter/reactability. The periodic table gives a sense of belonging and purpose. Just like the chemical periodic table, each element of the educational periodic table has its own set of unique relationships and abilities while at the same time being governed by the rules of the group [grade/class] and the whole; the overall table [curriculum and institution]. Each individual element has its own set of experiences [narratives] which are the qualitative results [observations] of the chemistry [reactions] of the elements within the table. Although the reactions themselves might be general, the experience is unique and is subject to many intrinsic and extraneous factors. The educational periodic table can do for education what Sacks/Pinar say the chemical periodic table does: provide a beautiful comprehensive symmetry to show the educational universe, with every student and teacher having his or her own place in order secure, no matter what. (Sacks, 2001, Pinar, 1998).

CHAPTER VI

CHANGING STATES

When we think of chemistry, we imagine all kinds of mixtures and reactions. Some reactions occur spontaneously; others require an input of energy such as heat before they are able to take place and while some reactions are very quick others take a long time. Transformations may be of the physical type, such that there is no change in the chemical composition of the substance but rather there is a change in its physical state, its way of being in the environment in which it is housed. The physical state of a compound, whether it is a solid, a liquid or a gas is dependent upon the environment in which it exists and although the physical state may change, the chemical composition will remain constant. Transformations may also be of the chemical type where there is a change in the chemical composition of the substance and it is no longer the same substance but is something new. Such a compositional change may or may not be accompanied by a physical change in the sense that a liquid may still remain as a liquid although it is a different liquid in composition and thus there is a difference in the arrangement of the compositional molecules [the structure] that is not apparent to the naked [untrained] eye.

When the particles of a substance do not have a lot of energy and cannot move away from one another the substance is considered to be in the *solid state*. The links/connections between the particles are very strong and the substance has a definite shape. Upon heating, the solid absorbs energy and the particles within begin vibrating and eventually break free from the attractive forces of their neighbors. When the substance reaches its melting point, it moves into the *liquid state* and it no longer has a

definite shape, its particles slide over one another and it assumes the shape of the container. When a substance is heated enough, it reaches another level, its boiling point and the particles, now highly energized, fly off in all directions taking up as much space as possible. This is the *gaseous state* and as long as the particles are contained, and not allowed to fly away, they will remain constant in number and kind as in both the liquid and solid states. All compounds, whether pure or mixtures, exist in one of the three physical states and the physical state of a compound is also a determining factor in its ability to inter/act and re/act with other compounds, either physically or chemically. For example, a compound in a gaseous or liquid state is more readily able to interact with other compounds than one that is in a solid state simply by mobility of the constituent molecules whereas molecules fixed into the solid state require other particles to come to them or some mechanical means of bringing them together.

Not only can a compound change in terms of its physical state, its way of being in a particular environment, so too can it change in composition, its chemical or internal state. This type of change often involves interaction and or reaction with another or other compound(s) and often results in a change in composition and a permanent transformation to another compound. For example, two compounds, liquids say, may interact forming a solid precipitate and another aqueous product resulting in both a chemical and physical change. The learning process, I theorize, also involves a change in both the physical state [the way of being] and the chemical state [the how of being or the ontological becoming of being] and both changes have a direct impact on the positive or negative outcome of the learning process. I suggest the physical state is equitable to the *learning readiness* of an individual and the physical transformations that take place

during that process. The chemical state, I propose, is equitable to how that takes place, the *engaged pedagogy*, the interactive and reactive processes that lead to the final physical state, the way of being, of the individual after the learning or educational process. As in any change of state, whether it is physical or chemical, there are many factors, extraneous and intrinsic, that will directly impact on that process and its final outcome. In order to fully understand the process, these must be taken into consideration.

Physical Transformations and Learning Readiness

Physical change, unlike chemical change, does not involve changing one kind of matter into another, or a change in composition, but rather it involves a change in one or more structural properties such that there is a change in the physical appearance or the way of being, but there is no alteration of the chemical composition. The educational learning process is in itself a process of changing states and the readiness to learn in education can be equated to the physical changing of states in chemistry, the movement from one state [way of being] to another, much like chemical compounds change their physical states depending on the environment at any given time. How the process of learning takes place differs for each individual and involves many physical transformations as one learns the curriculum, incorporates it and finally consolidates that information into the physical matrix of one's knowledge, one's own curriculum base.

Bloom (1956) developed three overlapping domains: cognitive, affective, and psychomotor to describe the learning process of individuals. *Cognitive* learning, that of knowledge and the intellectual skills, is much like the solid state of chemical compounds. It has a defined and solid structure, holds shape, is of a concrete nature and it involves comprehending information, organizing ideas [much like the organized structure of a

solid] analyzing and synthesizing data [much like building a solid], and as a domain it is based on the acquisition and use of knowledge. It provides the base, the solid foundation for the application of such knowledge to the rest of one's curriculum.

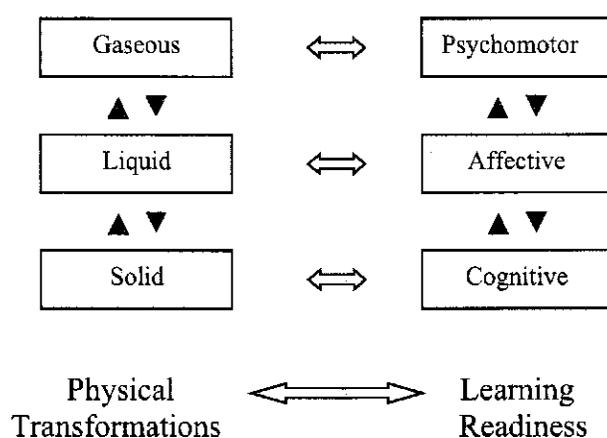


Figure 20. Transformations of matter that lead to a change in physical appearance analogous to transformations of learning readiness that lead to a change in one's ability to learn.

According to Vygotsky (1978), development cannot be separated from its social context, and it in fact serves to mold or solidify the cognitive processes. The cognitive processes therefore provide the solid foundation of one's knowledge.

Affective learning, according to Bloom (1956), is much more fluid in nature than cognitive learning and is demonstrated by such behaviors as attitudes of awareness, interest, attention, concern, responsibility, the ability to listen, respond and apply, interaction with others, and is essentially the ability to apply and test one's base or solid knowledge. Like the fluids of chemical compounds, affective knowledge has the ability to move through, over, around and to take on the shape of the container. Interaction is a feature of such a state. Vygotsky (1978) suggests that learning leads to development and

that they, learning and development, are two different processes. If one thinks of learning (cognition) as the solid state, development then could be considered the fluid state, or according to Bloom (1956), the affective state [taking that learned knowledge and moving it around; applying it].

Psychomotor learning is demonstrated largely by fine motor skills; skills that involve dexterity, manipulation, grace, speed, precision; skills that involve bending, grasping, handling, operating, reaching, relaxing, expressing, performing; skills that require movement and space in which to do and move. Such a domain is equitable to that of the gaseous state of chemical compounds where the atoms require room to move freely unencumbered, unrestricted or not bounded by their neighbors. It requires space for application and expression of one's curriculum in an individual and free way. Like the gaseous state where the atoms or molecules although individual maintain their purity, the skills of their composition are individual and pure. Vygotsky (1978) suggests that language plays a central role in mental development and is the actual mechanism or tool for thinking that takes one a step further providing the ability to move outside one's learned base, "to think outside the box" in an applied fashion and to go beyond known boundaries. Language allows one to create, and like a gas, such creation does need freedom and space to apply learned knowledge and concepts to something more.

The movement from solid (cognitive) structured thought patterns learned in the structured teachings of early education [of all sorts] to the liquid more fluid (affective) thought processes willing to move and interact, to flow with others, other ideas, other ways of being and thinking, move one's thought processes away from the "ingrained" early taught and somewhat biased thought processes to the gaseous, hyper/interactive

(psychomotor) state, the state of not being afraid to move away from the whole and think, learn and be on one's own. Such physical change is the physical readiness to learn, to intake the curriculum at hand. Such domains are governed by the physical transformations of crystallization, melting, solidification, evaporation, condensation and sublimation.

Crystallization

In chemistry, the process of crystallization occurs when the dissolved solute comes out of solution and forms crystals, the solidified pure form of a compound is sometimes referred to as a liquid solid. The atoms or molecules of a crystal are arranged in a definite pattern that is repeated regularly in three dimensions and crystals tend to develop forms bounded by definitely oriented plane surfaces that are harmonious with their internal structures. Crystallization involves taking on a definite structure, a definite form, to become crystalline in structure.

In education, crystallization could be considered the "*getting it*" or heuristic "*Eureka*" (Moustakas, 1990, p. 9) of learning. When we finally learn something well enough that it becomes part of the fabric of our knowledge, rather than rote memorization, we can say the concept has crystallized, has become clear, we see how it fits into whatever knowledge framework we are working with at the time. Crystallization of a particular piece of the curriculum, a piece of knowledge, extends even further; it is a deeper kind of knowledge such that it gives us the depth to think outside the box. But how does one get to the point of crystallization, the point of "*getting it*", of deep, understanding knowledge that becomes ingrained within the fabric of one's knowledge - so that it is "*crystal clear*"? What is the process that leads to crystallization?

Melting

Such a physical state, I believe has to begin with a slow melt of our current learning process, the "warming" to the idea. To melt is to thaw, dissolve, soften, dwindle disappear, vanish, fuse, liquefy or blend. Melting is the transition from a solid state to a liquid, more fluid, flexible state, that occurs at the melting point, the temperature when the solid and the liquid phases of a substance are in equilibrium. In general, substances expand when they melt because the atoms move away from each other, and they contract when they freeze because the atoms move closer together, slow down, consolidate and conserve energy. In extending that to the learning process, learning must begin with melting, the waking of the mind or the reaching of the melting point. Thus the curriculum being presented must be stimulating such that one becomes interested, engaged, excited, wanting to learn. Like atoms of the solid that begin to vibrate upon heating, moving around, leaving the safety of their neighbors [allowing for movement to view things from a different vantage point], so too does the individual become ready to learn. How that melting occurs is not only dependent on each individual's interests, desire, drive, but it is also dependent on the material, the curriculum, and how it is presented as well as on any extraneous interactions. Melting of old ideas, old philosophies, practices of teaching and learning leads to more fluidity of thought, and new ways of teaching and learning.

Solidification

Once the melting point has been reached, such that there is a stimulated interest, a desire to learn, a cognition [movement and fluidity of thought], then reception to new ways of being is possible. It is difficult to maintain a constant state of hypersensitivity or hyper-reception to learning and at some point, the individual needs to go away, digest and

solidify the learned information into some semblance of understanding within her own physical knowledge framework. *Solidification* therefore occurs when a substance goes from the liquid state to the solid state as it cools down. This is what happens to water if you put it in the freezer. Melting and solidification often exist in equilibrium and the controlling parameters of their physical change is temperature.

In extending that concept to education, the melting (desire and receptiveness to learning) should exist in equilibrium with solidification (the incorporation of the learned material into one's solid knowledge base). In Vygotsky's (1978) approach to education, he suggests that the two different processes of learning and development are interrelated and he suggests there exists an equilibrium between the two, that learning impacts development and development impacts learning. Metaphorically then, the melting/learning and solidification/development exist in equilibrium and each has a great impact on the other.

Evaporation

Evaporation occurs when a heated substance goes from the liquid state to the gaseous state. In such a transformation, the atoms are very high energy, so excited they escape the liquid, very fluid state at the boiling point, and move out on their own, far away from their neighbors. They no longer need the assurance of their "peers". Such an evaporation when translated to the learning process might be considered as "thinking outside the box", having the ability to apply learned knowledge to another layer, to extrapolate learned knowledge. Such high energy might be the passion, the desire, the driving force to learning more, to continued learning, to pursuing more than the basic curriculum. Theorists and researchers in any field have the ability to "think on their own",

have a passion for learning in their field and outside and are not afraid to have their own ideas. This physical state requires a great input of heat to keep the molecules in such a highly energized state, to fuel such a desire. Such a high energy state is at risk for getting out of hand, for spiraling off, getting lost or losing focus particularly if not contained. Just like in a chemical compound there is no change in the composition of the compound as long as it is contained. But as soon as there is a leak in the system, a way for the excited atoms to get out or get lost, then there is the potential of loss of vision, loss of focus, loss of intent, and possibly the beginning of difficulty particularly in burnout, both in teaching as well as in learning.

Condensation

This change of state from a gas (vapor) to a liquid (droplets) is called "condensation" and such a state occurs when the concentration of the vapor molecules in the excited gaseous state exceeds the holding capacity of the container such that they accumulate forming droplets, thus becoming a liquid again. Such droplets may find their way back to the main body of the liquid or they may accumulate somewhere outside that body, possibly as extraneous "liquid" droplets removed from the whole. When you take a hot shower, for example, the air in your bathroom becomes very humid. A fine layer of tiny water droplets forms on the walls and mirror. As these droplets join and become larger, they end up flowing down the walls and the mirror, pooling with the original body or more often than not in another body of liquid. *Focusing* in the learning process is in itself a condensation process whereby one takes the learned bits and pieces and condenses or consolidates them into more compact, concise information capable of being integrated into the framework of learned knowledge. When evaporation occurs, such high

energy is often difficult to focus and much is lost in trying to garner all that energy into a productive frame. Condensation, or the slight cooling, allows for this to happen.

The equilibrium between evaporation and condensation may lead to different ways of thinking and learning, and may in fact be what separates individual learning styles.

The cyclical effects of melting [warming to learning] leading to the high energy of evaporation [the ability to think differently and by oneself] followed by the condensation of the vapors and the formation of pure droplets [new learned knowledge] and finally to the cooling of the condensate which eventually leads to solidification [understanding that knowledge rather than rote learning] all lead to the final physical stage of crystallization, "the getting it" [integration] of the learned knowledge or curriculum such that it becomes the core of one's knowledge. Such a cycle, I suggest is the physical change of the learning process.

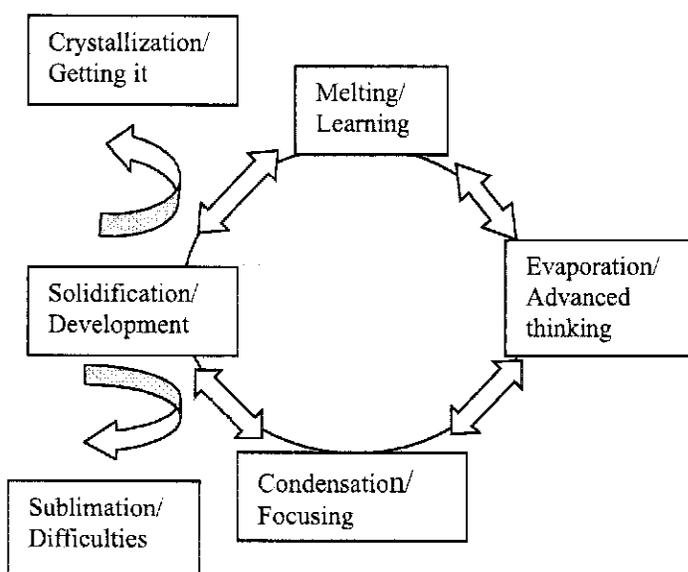


Figure 21. The physical changes of the learning process.

Sublimation

Sublimation is a physical state that occurs when a heated substance goes directly from the solid state to the gaseous state. Mothballs used to discourage moths from damaging clothes in storage disappear [sublime] after several months leaving behind only the olfactory traces of their vapor are an example of sublimation. In the chemical sense, sublimation is a process that leads to purification in that the molecules that escape to the gaseous state do not go through the intermediate liquid phase so they do not interact or react with other molecules on their way through. In other words, they do not "pick up baggage" along the way. In education, sublimation might represent those individuals who move through leaving in their wake traces of their being, traces that have a dramatic impact, either in a positive or a negative fashion, on the system or components of the system such as the teachers, students, the curriculum, et cetera. Possibly they are the "pure thinkers" or the "idealists" who are "way beyond the pack" or whose ideas are "way out there" and may represent "the gifted," either gifted students, or gifted teachers, theorists, administrators who simply see beyond, who have a vision. Such individuals or ideas are often criticized by others because they are so removed from what is considered normal but it is often these individuals who move through, disrupt the system in some fashion such that change, positive or negative, occurs. The impact of such individuals appears to have the most profound effect in times of difficulty.

Fowler in *Curriculum Intertext* (2003) states "our entire education system is in deep difficulty" (p.166). She refers to Caputo (1987) when she further states "experienced teachers straddling fault-lines at the borders of self and system in their professional lives ask questions that call for a radical hermeneutics" (p. 166). Sublimation, I suggest, is the

transition or the process that occurs in difficulties within education, it is the fault-line or border of difficulty where at one moment one is in the solid state, possibly questioning: "*Who in the world am I by now? Where am I and how did I get here? How do I go on from here? What interpretations can I make of my professional being and practice?*" (Fowler, 2003, p. 166) and then in the apparent next moment in grave difficulty. There appears in such cases to be no intermediate or transitional state, and the common theme of the individual is: *I just couldn't handle it any more and I lost it. I snapped. I crashed. I burned out.* Colleagues or peers who witness the difficulty, the apparent sublimation often view it as a sudden change as well: *She just snapped. She lost it. We had no idea.* The increased heat and pressure, and often it is a slow steady, incremental process such that it goes unnoticed, causes the "snapping" or sublimation of the individual and thus there is no apparent transition to the change. This occurs to both students and teachers and in both cases leads to difficulty both in learning and in teaching and often to *burn out*.

In addition to a physical transformation, the learning process can also be a compositional transformation as a result of the reactions and interactions of the *elements* [the teachers, students] of the educational periodic table. The so-called chemical or compositional transformation is the end-product of the learning of the curriculum, the final product which is unique and based upon the individual experiences.

Chemical Transformations and Engaged Pedagogy

Science, the term of which is derived from *scientia* meaning to know, is a broad field that encompasses both the natural (physical, chemical and biological) sciences as well as the human sciences (education, psychology, sociology, et cetera). Wilhelm

Dilthey compared natural or physical science (Naturwissenschaften) to the human sciences (Geisteswissenschaften) (In *Selected writings*, Rickman, ed., 1976). The natural sciences study the objects or things of nature and how they behave while the human sciences study persons and how they exist (through meaning and expression) in the world (van Manen, 1994). In postmodern thought, the lines between the sciences have blurred and the discourse and metaphors of each discipline have begun to transfuse and inform other bodies of knowledge. No longer is the language bounded by the discipline. For example, the interaction of people, how they exist and interact in the world is a chemistry in itself and involves many reactions/interactions. The reactions involved are indicative of the type and strength of the relationships between the reactants [those involved in the inter/intra-reactions] and the products are the results of those reactions. Chemistry is itself a relational science: It is the relationship, the inter/intra-reactions of the reactants, the elements of the periodic table, which lead to the formation of products. Education is also, perhaps especially, a relational discipline (a blend of science and art) and like chemistry the interaction of the reactants (teachers, students, curriculum, system) leads to the formation of products (learning, constructed knowledge, acquisition of skills, development of attitudes and opinions). The use of thought and language in chemistry, can, I suggest, be informative, even enlightening for education. There must be a chemistry of relational reactions for education. I argue for a chemistry of education as a useful way to enlarge our understanding. The following is an analogous description of chemistry in education. I use tropes and stories written as narrative data to study those concepts of the chemistry of inter/reactional and ¹³*relational education*.

¹³This is a term synthesized by Fowler to describe education in terms of relationships.

Inter/reactional and Relational Education

Given the right environment, the right assistance and the right mix of reactants, reactions, favorable or unfavorable, *may* [although not always] occur when two or more species come together. In chemistry, a reaction is the mutual action of substances undergoing chemical and often physical change and is the process that involves changes within the nucleus [central core] of the atom resulting in products or the state of change as a result of such reactions (Websters Dictionary, 1976, p. 1181). Relations are the narrating or the telling, the account of what has taken place (Websters Dictionary, 1976, p. 1198). Reactions in chemistry are depicted simply by the chemical reaction formula and narrated in detail by the observations contained within the narrative laboratory notebook. In education, the complexity of the reactions that take place within the teaching and learning environment, although prevalent, for various, often personal reasons, are not commonly narrated or described in great detail. Such narration is critical data to understanding the chemistry of relational education but the complexity might, at least initially, be more easily depicted by developing a comparative educational reaction. The relationship between the reaction and the relation is critical to *understanding*, to "meaning-making" (Polkinghorne, 1988, p. 36) and is essentially the bridge between the two. Reactions, chemical or educational, are governed by many parameters [see Chapter VII]. In a successful reaction, as the reactants are being consumed, the products are being formed. Deviation from the ideal or optimum reaction environment may lead to the formation of unexpected or undesirable products [reaction difficulty] and even to little or

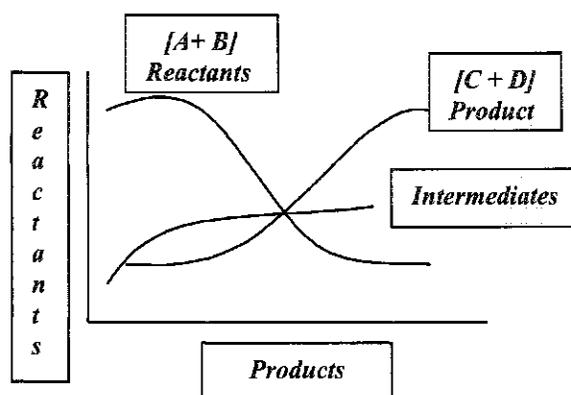


Figure 22. A graphical representation of a general reaction of two reactants to form products $[A + B \rightarrow \text{Intermediate(s)} \rightarrow C + D]$. The depletion of the reactants leads to the formation of the intermediates and/or the products.

no product formation [reaction failure]. Intermediate products may or may not exist for a period of time and are often paramount in a reaction as a resting place, a place to regroup, to garner energy, to make a decision whether to go forward to form the products or backward to reform the reactants. Figure 22 depicts graphically the formation of the products at the expense of the depletion of the reactants. There are many types of reactions and hence many ways in which this can take place. Figure 23 below, is a schematic representation of the main reaction types involved in this transformation of reactants to products. Each reaction is in itself a relationship as well; it is the relationship of the reactants and how they respond to each other and in response to the various external influences [the relationships] that determines the quantity and quality of the products formed. Such relational reactions are not dedicated to chemistry alone but can be extrapolated to other disciplines such as education. The following is a discussion of the various chemical reactions and how such reactions metaphorically bridge education. The bridge between the two disciplines is substantiated and augmented with teaching

narratives. In reading and analyzing the reactions and narratives, it is possible to see that many may fit into more than one category. This makes sense as so much of our experiences, chemistry or educational, are relational (inter- and intra-) and it would thus be expected the borders discriminating most experience is rarely concretely defined and is most often blurred.

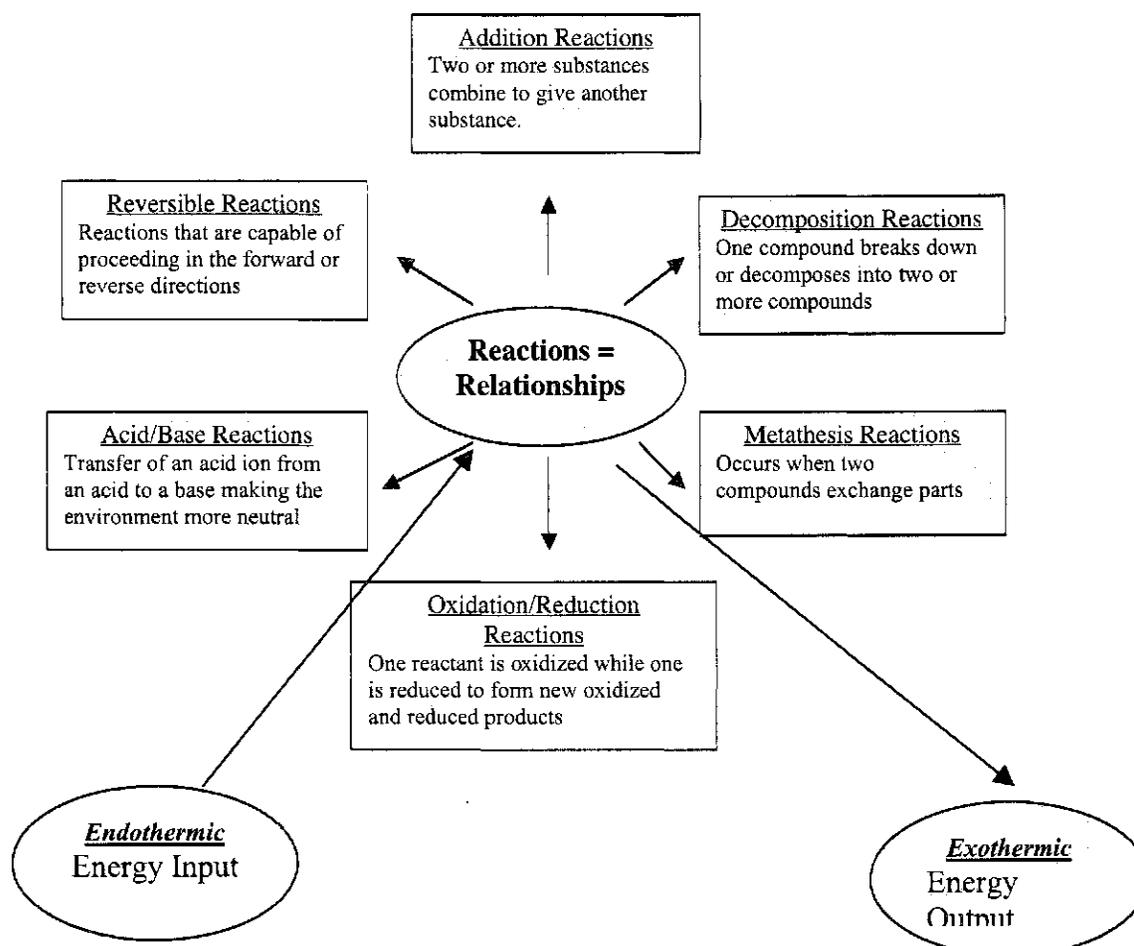


Figure 23. The basic reactions of chemistry and education. An exchange of energy either in terms of energy input or output occurs and will be discussed in the following chapter.

Through the Eyes of Ms. S.

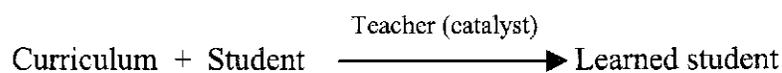
Chemistry at my high school was taught by two teachers, Mr. M. and Ms. S. Everyone wanted to take chemistry from Mr. M. because he was good looking, cool and very hip with a lively and fun personality. He had the reputation of being "a lot of fun, but not much of a teacher" among us students. With just a minimal amount of effort, a good grade was guaranteed. Ms. S., on the other hand, had a reputation for being tough with very high expectations and was rumored to be somewhat of a tyrant. A good grade in her course was very hard to come by and was well-earned if one had such luck. As misfortune, or fate, would have it the only chemistry class that would fit into my schedule was the one taught by Ms. S.. I remember being terrified of taking chemistry from her.

In looking back though, I would have to say that chemistry with Ms. S. was pivotal to my career choice. She turned me on to chemistry and science in general. The fact that Ms. S. was a female doing science was in itself inspiring. Her passion and enthusiasm for chemistry were intoxicating and through her eyes, it was fascinating, not intimidating, as I had once been led to believe. She had a way of getting a person excited about all aspects of it and she never showed any bias in terms of gender and ability. I never at any time, felt that I was in out of my league, simply because I was the only female in the course; it [the course] was challenging and fun for all. In fact, I liked being one of the few females in such a challenging course, most likely because it put me on an even playing field with my male peers.

I can't say this was always the case in my later undergraduate years, but those initial experiences of making it fun, exciting and equitable, went a long way to establishing for me a positive image and perception that girls can do science. I think one of the greatest criteria for any girl to initially choose science, is believing in her ability to do science and to succeed at it. This belief is greatly instilled by seeing examples of success in like-gendered others--mentors.

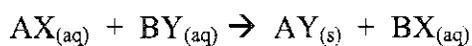
The student learning of the curriculum is critical to obtaining the skill set required but sometimes the reaction is slow to start, possibly due to a large learning curve. For every elementary process in a mechanism, whether it is a chemical mechanism or an

educational mechanism, there must be an energy barrier [activation energy] that must be overcome in order for the reaction to proceed. The higher the activation energy, the less likely the reaction will proceed without either a large input of energy to initiate the reaction or a means of lowering that energy barrier to make the reaction more feasible [accessible]. In chemistry such an initiator is a *catalyst*, a substance that increases [or decreases through inhibition] the rate of a reaction without itself being consumed. The teacher in an educational reaction is such a catalyst, bringing the perceived [by the student] difficulty of a particular curriculum to the level of the student such that learning the curriculum is feasible. The above reaction might therefore more correctly be depicted as;



Metathesis Reactions

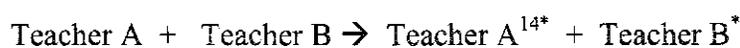
Metathesis reactions occur when two compounds exchange parts resulting in a change in chemical composition and physical state [gas, weak electrolyte, non electrolyte or a solid]. The physical change alters the composition of the system resulting in an irreversible reaction. Those reactions producing a solid are referred to as precipitation reactions



And once the precipitate is formed, the regeneration of the reactants is impossible because there has been a physical and compositional change.

Reactions of the metathesis type in education occur with exchanges between reactants occurring at many levels. Such exchanges can be both beneficial or detrimental

to the parties involved. For example, teaching is considered to be a cooperative environment, where ideas are exchanged as part of teacher collegiality.



Each exchange of ideas and knowledge alters the knowledge base of each individual such that he/she is changed in a fashion that has an impact on their teaching and relational approaches to education. Beneficial exchanges may lead to the growth and development of the teacher(s), to the way in which curriculum is taught, to the inter and intra-relationships of teachers and students. Less than positive exchanges may lead to teaching difficulties that have a negative impact on teachers and students and their respective teaching and learning. Positive and negative metathesis reactions also apply to teacher – student interactions and student–student interactions.



Metathesis reactions are illustrated in the following narrative.

¹⁴ The symbol * refers to a changed condition; in this case, a changed teacher.

¹⁵*The Joy of a Simple Atom*
[Hydrogen]

1 H	1 a
Hydrogen 1.008	<i>The Joy of a Simple Atom</i>

Being comprised of a single proton and a single electron, hydrogen is the simplest and most abundant element on the earth. It is the first element of the chemical periodic table and is probably the most interactive element combining with other elements to form many important compounds.

I will often steal a few minutes for myself and stop for a coffee after work. I like to be alone to collect my thoughts and wind down without having to engage with anyone for a few minutes before attending to the demands of my "after-work" life. One afternoon I was deep in thought and my writing when I was interrupted by a bright, cheery voice. "Hi, how are you? What is your name? What do you do?" I irascibly looked up saying to myself, "Go away and leave me alone", into the smiling face of an obviously mentally-challenged young girl who was spraying the table next to me with cleaner and wiping it with a meticulous thoroughness, a sharp contrast to the usual quick sweep given by others in her position. "I'm fine, thanks," I said, rechecking my demeanor. I told her my name and that I taught at the university "You must be very smart to teach at a university," she said. "I'm not smart and when I was in school the kids always teased me because I wasn't as smart as them. I'm slow, you know, so they always called me stupid. I liked school because I got to learn things but I was glad when I finished because the kids were so mean. I never treat people that way. The bible [a crutch I often think of it as] says that you should treat others as you would like to be treated. I like to be treated nicely so I always try to be nice to everyone, even if they don't look like they are nice. My name is Joy. It is very nice to meet you. I hope you come again. I like working here because I get to meet nice people like you. Sometimes people don't like to talk too much to me so thank you for talking. Have a nice day. Come again." And then she was off

¹⁵ Where ever applicable, the chemical and educational periodic table blocks will be used to represent the analogous element for chemistry and trope for education and their position within the periodic table.

cleaning the next set of tables and as I returned to my writing, I heard her say to the next person "Hi, my name is Joy, how are you....."

Over the next number of weeks, I would watch Joy as she interacted with the customers, some of who were clearly uncomfortable with her outgoing, somewhat loud but enthusiastic personality, and her simple, often-repeated conversation, much like that of an elderly person in the beginning stages of memory loss. But she treated all people the same, regardless of whether they responded to her in kind or not-so-kind. "I like this job", she told me one day. "I get to meet so many nice people. I love that. I like clearing and wiping the tables. I'm good at it don't you think?"

"Absolutely!" I agreed without hesitation. Having learned I taught nutrition, she asked me how she could go about losing weight. "Exercise and good nutrition, meaning no A&W hamburgers and fries or doughnuts everyday," I coached her. Now every time she sees me she repeats my instructions but the amazing thing is that she has probably lost ten pounds in the past month because she is working very hard at it. "I need to learn good nutrition myself because even though I am slow doesn't mean I can't take care of myself properly" she told me. "I'm twenty-six you know, an adult, and even though I am slow my parents shouldn't have to take care of me anymore."

For some time now I have been frustrated with teaching students who seem to think that it is my responsibility to ensure that they are happy, that they succeed in their courses, and that they get the most from my efforts without much input on their part. To me there very often seems to be little ownership of responsibility and certainly little reciprocity of effort in today's generation of students. "I couldn't be bothered" was the response a complaining student recently gave me when I asked why he didn't come for help [I have an open-door policy]. "What can you do for me?" a student asked me in a private conversation, saying he needed an A in my course, without so much as a hint of any effort he might put into the work himself. "I started my paper a couple of days ago and I'm not done it yet. Could I have an extension?" asked a student of me at the end of the term. The paper had been assigned at the beginning of the term and when questioned as to why she left it so long she replied, "I couldn't get motivated to start it." A student with whom I had spent many extra hours tutoring accused me of "setting her up" for the final exam because she was unable to do the question and I [who set the exam] "knew

that question was going to be on the exam” [never-mind the hours I had spent tutoring her because I did know what was on the exam]. I felt like I had been punched in the stomach and was sick at all the time I had invested for such little thanks. How did it become my fault?

I watch Joy in her job. Not only is she is the best “bus-person” I have ever seen, she is one of the best and finest people I have met. Many consider her “simple” and even seem uncomfortable at her outgoing simplicity. I think of the hydrogen atom, the apparently simplest of all the atoms that in its uncombined form it consists of one proton in the nucleus and one valence electron in the 1s orbital [the orbital closest to the nucleus – the heart of the atom]. At room temperature, it is essentially non-discript, existing as a colorless, odorless, tasteless gas composed of diatomic molecules. Yet in spite of its simplicity, it has probably the most varied and complex chemistry of all the elements of the periodic table and, in fact, is so unique that although it is often associated with groups I and 18 of the chemical periodic table it almost deserves its own position. It is certainly the most relational of the elements and is capable of forming bonds with virtually all elements of the periodic table owing to the fact that it is willing to share its single electron in covalent bonding or gain an electron from another element, thus taking responsibility in the workload.

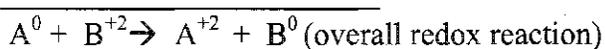
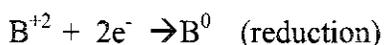
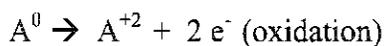
When I watch Joy at her job, at how much care she takes in making sure the tables are spotless, her care in stacking the cups and plates, in picking up the garbage from the floor, in removing clutter from customer’s tables as they are eating, and how she always does it with a smile, I am in awe of her work ethic and pride. It is matched by none I have ever experienced, mine included. My students could learn so much from her “simple” attitude and pride toward her work. Her ownership of responsibility and how it is her responsibility and not her parents to care for her is something I wish my students possessed. Her intrepid motivation in caring for herself is exemplary. Joy resembles a small child in her enthusiasm and approach to everything she does. She is undaunted by the difficulty of something that might come easier to others. “I might be slow,” she said to me one day, “but that doesn’t mean I can’t do it. I just have to try harder and it might take me a bit longer, but I can do anything I put my mind to”.

Like the hydrogen atom, that even in its most complacent state at room temperature likes company and exists partnered at the very least with a like atom, Joy likes to be with people. Her innocent and open personality is like that of a small child at times. She doesn't see the insalubrity or malevolence of people, or possibly she simply chooses to ignore it. Whatever-the-case, she treats all people well and is totally giving of herself forming amazing relationships with people. I left one day while she was busy doing something else, and she ran out to my car and knocked on the window. "I forgot to say good-bye," she said, "I didn't want you to think I was being rude." On another occasion I heard her say to one of her co-workers, "I'll pray for your mother in church so that her operation goes well." Another more-mentally-challenged young lady comes for coffee daily and Joy will stop whatever she is doing and make sure the young, often-confused girl finds a seat. I have yet to see her ever be rude or unfriendly to anyone and I have never seen her without a smile on her face – a very simple, but stark, contrast to most people, myself included.

My after-work coffee is no longer a respite to collect myself after teaching and interacting with students all day long, but rather it has become a sanctuary where I have learned the simple meaning of doing your best, trying your best and being your best from someone whom I would consider to be the most elemental of beings. Like the hydrogen atom, which owing to its complete absence of nuclear shielding of its sole electron, thus exposing its simplicity, Joy does not shield her soul; she simply bares it for all to see and is a joy learn from.

Oxidation/Reduction (Redox) Reactions

Oxidation and reduction reactions involve the exchange of electrons. When a reacting species is oxidized there is a loss of electrons from that species that are picked up by the second reacting species. This gain in electrons subsequently reduces the second species. Thus the gain of electrons by one species is at the expense or loss of electrons by the other species but the process always occurs simultaneously.



Such analogous relationships occur in education where the loss of electrons is equitable to giving of oneself in the teaching process; giving of one's knowledge, one's way of being; the engagement of the teacher with the student in the learning process. It may also be equitable to the loss of self, loss of principles, loss of philosophy [on the part of both the teacher and the student] all of which can lead to burnout or difficulty in teaching or learning. *Reduction*, or the gain of electrons in education is equitable to being the recipient, benefiting from someone else's giving (loss) of electrons. Such reductions might include taking on responsibility for one's teaching self, practices, relationships and could also refer to the benefits gained from the intra and inter reactions of teaching. Someone who is neutral or who does not participate in the "reactions of education" may become reduced such that they engage and become active players when stimulated or influenced by another who does engage. Oxidation/reduction relationships may also refer to the loss of one's self, principles, et cetera to the gain of someone else. This is not a reciprocal relationship and may be self-limiting.



How to Extinguish a Flame

9 F	9 I
Flourine 18.998	<i>How to Extinguish a Flame</i>

Flourine is one of the most reactive of all elements. Having a negative overall charge it is capable of reacting with many elements forming compounds that are incapable of being freed from chlorine. Its negative nature makes it highly corrosive, so much so that it has been phased out of compounds such a dichlorodiflouromethane used as a coolant because it damages the earth's ozone layer.

They were all assembled, my students, four to a straight row, eyes forward, waiting for the beginning. I sat on the sideline, having relinquished my customary position at the front, to allow this young and upcoming scientist the chance to "gain some teaching experience". After all, he needed such experience to be listed on his resume when he moved on to bigger and better academic endeavors. He, this soon to be Masters graduate of Biochemistry, walked to the front of the class, white lab coat buttoned to the collar, a red and blue pen perfectly protruding from his pocket, chalk in hand, poised and ready to start.

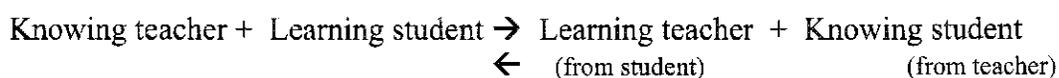
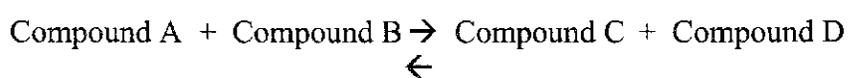
"Quiet! Quiet! I want to get started," he said, tapping the chalk on the board. It echoed of my grade-one teacher, Ms. Erickson, tap tapping on the desk to get the attention of her little charges. The chatting stopped, and all eyes focused forward.

"Today we are going to begin with..." and he was off. The chalk flew across the board, and structures materialized from beneath but soon evaporated with the whisk of a brush. Periodically he would turn and face the class, as he had been told that all good teachers make eye contact to get the point across. A student on the back bench put up her hand, but in his incessant desire to teach the material, he missed it. It didn't matter in a minute anyway, because he had long gone past that crucial point. He would periodically interject with, "Are there any questions? Put your hand up." The command, I am sure squelched any desire to ask a question. I looked out at the sea of stone faces frantically trying to transpose his knowledge from the board to paper, and wondered about the transition from the relaxed faces I was used to looking at. He continued on, coming to a

critical point where acute knowledge of the theory was essential to understand the concept. He posed a question, as all good teachers should do to instill independent thinking. "Put your hand up if you know the answer," he commanded. After a few seconds a couple of hands timidly poked into the air. He selected the best of the choices with a "yes" and a finger point. The somewhat less than eager student began with an answer. "Wrong! You are wrong!" came the cut off. "On we go." "Anyone else?" I looked at the face of my young student and saw the flicker of light go out. My heart sank. I knew the damage that had been done. I too had once been in her shoes, eager to learn and eager to respond to learning. I knew the fragility of self-confidence in putting oneself on such a spot, and I knew she wouldn't be putting herself in that position for a long time. It is amazing how easily that eagerness and self confidence can be nurtured and molded into an exquisite mind or snuffed like a flame of a candle with only one statement. After that day, I vowed to never let someone gain experience for their resume, at the expense of the self-confidence of one of my students.

Reversible Reactions

Reversible reactions are those reactions that can proceed in either direction with the forward reaction yielding products from the reaction of the reactants, while the reverse utilizes the products as reactants to regenerate the reactants.



Such reactions are often equilibrium reactions. In education equilibrium reactions or reversible reactions are recipricol reactions, or give and take reactions, whereby both parties involved benefit from the equal and recipricol exchange. The ultimate reaction depends on the situation but would be expected to be the reversible reaction, one where

there is total reciprocity, give and take, where the forward reactions equals the reverse reaction, reciprocity. My point is illustrated in the following story.

Luminous Allusions of Adequacy
[Phosphorous]

15 P	15 o
Phosphorous 30.97	<i>Luminous Allusions to Adequacy</i>

Phosphorous' Greek origin means light bearing. Originally isolated from urine, phosphorous is now largely obtained from phosphate rock in the form of $\text{Ca}_3(\text{PO}_4)_2$. Phosphorous has three main allotropes [see definitions]; white, red and black. The white allotrope is poisonous and ignites spontaneously in air. Red is not poisonous nor as dangerous as white although it does sublime to become white in extremely hot conditions. Black phosphorous being the least reactive of the three forms has no commercial uses. Some phosphorous compounds glow in the dark and as a result are used in paints, fluorescent light bulbs and television sets.

CRASH!!! The box of glassware--beakers, graduated cylinders, flasks of various sorts, chemical apparatus as it is called, hit the floor shattering glass sending some of it flying but the box itself remained intact and served to contain most of the pieces in broken forms somewhat reminiscent of their original shape and from randomly lodging into the unsuspecting legs of the surrounding students. I love the sound of shattering glass and find nothing more satisfying than to "slam-dunk" a chipped or cracked piece into the "broken-glass-box" at the front of the laboratory classroom further shattering it and the already accumulated pile into even smaller shards. Shattering glass has an almost melodic ring, harmonic, unless of course it is an eight-hundred-dollar-box of laboratory glassware which then translates into a sickening sound, one that makes my stomach drop like the descending plummet of a roller coaster not only because of the replacement cost, but more importantly because of the potentiality of serious physical damage to the student.

"Anyone hurt?" I asked quickly grabbing the broom and dustpan as I made my way to the back of the classroom where the sound had originated.

"No, just a small cut on my finger," nervously replied a very embarrassed young man, trying not to look up at me as he picked up the broken pieces. "I'm really, really, really sorry. I bumped the box with my elbow. I am so stupid and such a klutz. Boy do I feel like an idiot".

"I'm sorry, I don't know your name yet," I said.

"R," he replied his voice trailing into nervous self-consciousness.

"O.K. R. First, the most important thing is that you are not seriously hurt," I said as I examined his wound. "Now let's get you over to the sink and rinse out your cut to make sure there is no glass in it and secondly your elbow is connected to your brain by the nervous system...not to your intelligence. You are neither stupid nor an idiot. You simply had an accident."

As water mixes with blood it interrupts the agglomeration of the red blood cells with each other thus spreading them into a thin mono-layer which has a way of appearing to voluminize even the smallest drop and which doubly serves to frighten many and make even the toughest feel queasy and faint. R's face went from the crimson of acute embarrassment to ashen-white, the tell-tale sign of the impending loss of consciousness. I gently eased him to the floor as his world went black for him and ordered the girl standing next to me to quickly get a cold, wet, paper towel. "Lean forward and keep your head down I said to the [coming-to] R. "You just fainted so give yourself a minute to regain your faculties."

"Now I really feel stupid. What a way to begin a class," he moaned, the color coming back to his face much more quickly as a result of his embarrassment.

"Well," I said with a little chuckle. "The good thing is I now have a face to go with the name." He looked confused for a second and then smiled sheepishly.

Aside from a name attached to an insignificant number on the class list, unmatchable to a distinguishable face in a sea of blank look-a-likes on the first day of class, that was my first introduction to R., a less-than-confident eighteen-year-old. Throughout that first semester of introductory chemistry he tempted every fate possible from his initial glass-breaking incident, to cutting himself numerous times, to flooding the lab, and to repeatedly spilling his experiments. "I am sorry I am such an idiot and a klutz," he would apologize at the end of each class for what he perceived as his ineptness

at chemistry, to which I would reply, "The arm-bone is connected to the shoulder-bone which is not connected to the intelligence bone." This elicited a timid smile at first to which he would ask,

"Really, you're not mad?" he would say with surprise. My reply was always the same,

"What did you learn today?"

Whenever he had a question he would begin with "I'm sorry to waste your time. This is a stupid question," to which I would respond,

"There are no stupid questions in my class." Initially this caught him off-guard.

"Oh???????" he would say, more as a question than a statement before continuing with hesitation. I wondered about his lack of self-confidence and nervousness and worried that I intimidated him. I later learned his high school teacher made him feel stupid and inadequate because he perpetually asked questions in trying to truly understand the material.

"I need to know how it works," he once told me. "I don't have the brains to memorize things. They usually go in one side and out the other [a sign of true intelligence] but I love chemistry."

Over the next couple of years I would see R. in a number of my classes. He struggled with his grades, not because he lacked the ability, in fact he was incredibly insightful and bright, but because he lacked confidence in his own ability. He would spend hours in my office asking me an interminable number of questions, much like a three-year-old who wants to know the "why?" to everything, but unlike a three-year old, R. really did want to know the why. But he would freeze on an exam, his mind unable to thaw and what he knew inside and out going into the exam would somehow get crystallized in his mind and he could not transfer it, his pen becoming an icicle, frozen unmovingly to the paper stuck with cold fear which then often translated into a poorer-than-deserved-grade. It was painful to watch his struggle but I was continually amazed at his persistence and perseverance. He never gave up and because of that neither did I. We would spend hours going over questions and the chair at the side of my desk became affectionately known as "R.'s chair".

R. wanted to be a science teacher in the worst way, a secondary chemistry teacher specifically, but was refused entry the first time he applied to the Faculty of Education because his marks were borderline owing to a few “bad” classes. In his initial devastation, he asked me if I thought his dreams were stupid and unrealizable, if he had what it took to be a teacher or if he was simply wasting his time.

“I have wasted your time,” he said. “You have spent so much time with me and I still didn’t cut it. I feel like a loser and I’m sorry for wasting your time.”

I remember seeing red and I’m not sure if I was more mad at the Faculty of Education’s blind-sightedness for being so stringent about the mark bar and not seeing R.’s ability or at R. for what I considered to be a personal insult. I was rude and sent him away with a dismissal that still echoes in my ears,

“You are anything but a loser. I’m sorry you didn’t get in this year, but it’s not the end of the world and that doesn’t mean you can’t try again. You have never wasted my time until now. Come back if and when you want to work together again.” To this day I nearly lose it whenever the ghost of the look on his face as I closed the door that day haunts me and it is a continual reminder about the proper terms of engagement.

A couple of days later there was a timid knock on the door and a white carnation appeared around the corner followed by a sheepishly smiling face and a “Can I have my chair back?” And so began the hardest year of R.’s academic life. He worked harder than anyone I have ever seen and with each achievement whether it was just grasping a concept, getting an answer right, or acing an exam I watched him gain confidence and begin to shine. I went to his Education 2500 class when he gave a chemistry demonstration and was amazed at his presence in the classroom, how the students responded to him but most amazingly how he shone, how he seemed to be in his element. He truly had what it takes to be a teacher.

Some time towards the end of the last semester that I was to see him for a few years, I was struggling with my own inadequacies and very much second-guessing my worthiness as a teacher. On one particularly bad occasion, the culmination of many incidents over the previous months, I decided to throw in the towel. I was burnt out, fed up and had had enough. The defining moment occurred after having spent countless hours helping a struggling student who was, I later found out, an unmedicated Bipolar

Schizophrenic whom I believed to have both the intelligence and capability and who, at the time, I felt was worth my time but who then later turned on me with unfair and unjust accusations. It was the final straw after which I closed the door to my office with the full intention of tossing in the towel. I was drained and was calling into question the worth of it all, my abilities, my desire, my integrity--everything. Upon returning to my office after a soul-searching weekend, still ready to pack it in, I found a card innocuously slid under my door from my former R. thanking me for my countless hours, for the gift of my time and the gift of my chair, for being the one person who believed in him even when he didn't believe in himself. He had been accepted into the Faculty of Education and he was finally going to be a teacher, "simply thanks to you," he wrote. I didn't throw in the towel that day, or the next or the next. I've pinned that card to my bulletin board and now, some five years later whenever I feel like throwing in the towel, I look at it and remind myself it is possible to make a difference.

I had the wonderful opportunity to teach with R., now a colleague, just a little while ago. I watched him with his students, how they respected him, how he treated them fairly and as individuals, how he listened to them, how he respected them, and how he paid attention. I watched as he taught, and he really did teach. But the amazing thing to see and experience was the transformation of the yester-R. to the today-R.

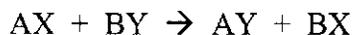
I'm reminded of the element phosphorus, how it is commonly misspelled "phosphorous" and often equate it to the misunderstanding [misspelling] of R.'s ability as both a student and a teacher. One of my colleagues suggested I was wasting my time on someone with such delusions of adequacy. Allusion, would be the correct spelling of the word in my opinion. Phosphorus is an essential component of all living systems found in everything from nervous tissue to bones to the cytoplasm of cells. It is structural in its being, providing essential integrity to bones, teeth, and even the integument of animals and insects alike. R. is representative of the type of teacher that is elemental to the system, he participates and works hard for his students. I think of his integrity, his ability to stand strong and persevere and I think of the incredible example he provides to his students and colleagues. Like phosphorus, that exists in several allotropic forms the most stable of these being red phosphorous, which when heated sublimates to become the dangerously reactive and self-igniting white phosphorus, I think of the stability of R., how

he was able to navigate through some incredibly difficult classes to follow his dream when it seemed like all the strikes were against him and he didn't have the support. I saw him sublime in the heat of the situation and become reactive and interactive, take charge of his path and make it happen for himself. I saw the slow burn of desire and passion. I know he will pull through in the heat of any situation for his students.

One of the unique characteristics of white phosphorus is its inexplicable ability to glow, luminesce, give off light; a form of radiant energy, a beam, a ray, to glow, to shine, to brighten, to radiate, to shed light, to illuminate, to be luminous. As I watched R. teach that day I saw a luminous light, the quiet glow of confidence, an actinic inner light, a most definite allusion [lum/allusion] to adequacy.

When he introduced me to his class he said, "The greatest gift you can give yourself is to take a class from this lady." His greatest gift...teaching me to become a teacher.

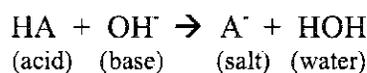
Reversible reactions are similar to *double replacement reactions* in that two compounds exchange ions with one another resulting in the formation of two new chemical compounds. For example,



In the above reaction, both the student and myself exchanged much in terms of learning from one another. The reaction/relationship was reversible or reciprocal but the exchange [the interaction/reaction] left us both permanently changed.

Acid/Base Reactions

Acid/base reactions involve the transfer of a hydrogen atom (H⁺) atom from one Bronsted acid to a Bronsted base resulting in a neutralization reaction that produces a salt and water.



hit with it as it is thrown across the diameter of the circle from one player to the next. Generally Mr. H. our teacher always played on the popular team.

I had gone to the equipment room just before class to get the ball as I was the ball monitor for the week. The equipment room was a small closet-like, pitch black windowless room situated in the middle of the long North wall of the gym. The balls were kept in the far inner corner of the room and the path to the corner was generally littered with equipment not put away. I switched on the light in order to see and was shocked to see Mr. H. with one arm straddling S., the most popular girl in the class, and the other down the front of her shirt fondling her ample breasts. I stood there staring, the bright light glaring, making me squint not really sure what to do.

"Oops, I'm sorry," I stammered. "I didn't know anyone was in here."

"Shut the light off and get out now," Mr. H. ordered in a tone I didn't dare challenge. I shut off the light and closed the door quickly and as I stood trying to make sense of what I had just seen, knowing full well what was going on, the class began to arrive and Mr. H. came out of the room with the balls.

"O.K. Let's get the show on the road," he yelled. "Same teams as last game. My team will form the circle first." We organized ourselves as we had been ordered and my team was on the inside of the ring.

"Let the game begin," shouted Mr. H. The game began with furious ball throwing and one player after another in the circle being hit. Now I was quite agile and slight for my age and was really quite good at the game so after a few minutes there were only two of us left. Mr. H. threw the ball with a force beyond anything catchable by the other students. His aim was straight for my head and he threw true. I put up my hands to protect myself and the impact of the ball with my right forefinger gave a resounding snap audible only to me but obvious to others by its unnatural crooked appearance. The pain was excruciating and as I reflexively grabbed my arm I caught his smug look, daring me.

"Let's have a look at this," he said, moving the other students out of the way. "It looks broken. You should never put your hand in the way of the ball. That is how accidents like this happen." he admonished me. "Let's get you to the nurse."

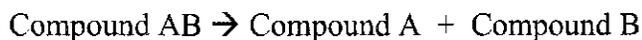
As we left the gym, I said, "you did that on purpose just because I caught you in the equipment room."

"Prove it, he said icily. "If you say one word, you will have more than a broken finger."

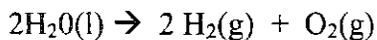
I never said anything that day, or the next, largely because I didn't think anyone would believe me and also because I really did believe Mr. H. would do more than break my finger the next time. But to this day I feel guilty because four years later he was finally charged with statutory rape when he got a thirteen-year-old girl pregnant.

Decomposition Reactions

Decomposition [breakdown], or analysis reactions, are the opposite of a synthesis reaction and take place when one compound decomposes into two or more compounds (products) according to the general equation;



The converse of the synthesis reaction of water above is the electrolysis or decomposition of it to form hydrogen and oxygen gases.



Such *decomposition reactions in education*, where there is a breakdown or a decomposition of one element into two or more resultant products or consequences, may be representative of *difficulty*. Examples of decomposition reactions might include;

Teacher → Burnout + Ineffective teaching

Student → Frustration + Ineffective learning

Losing the Focus

57 La	57 L1
Lanthanum 138.91	<i>Losing the Focus</i>

Lanthanum from the Greek word *lanthaneia* meaning to "lie hidden" is one of the rare earth elements used primarily in the motion picture industry for lighting and projector lights and in the glass of special lenses, allowing for clear focusing. It comprises about 25% of the Misch used in making flint for lighters as it readily sparks.

"How dare you!" she screamed at me, standing at my office door, hands on hips, face bright red. "How dare you set me up for the fall. You knew all along that question was going to be on the exam. You knew I didn't understand. How could you put that question on the exam? You are just trying to fail me."

With that last accusation she stomped away and I stood dumbfounded looking at the mirage of her presence in my doorway. An ache in my arms brought me back to reality and I put the two hundred exams I was holding down on my desk and plunked myself into my chair numbed by what had just transpired. I thought about the hours that tolled into days I had spent over the last couple of weeks coaching S., helping to prepare her for the upcoming final chemistry exam. She suffered from Bipolar Schizophrenia, a condition that resulted in unexpected outbursts of temper and difficulty in focusing particularly when she wasn't medicated, but she was incredibly bright and wanted desperately to be a doctor. She came to me with her medical history and asked if I would coach her throughout the semester as she sometimes needed extra help and really wanted good marks. I agreed and over the course of the semester she would stop by weekly for help with either the course work or the lab work and I was inspired by her dedication in light of her condition, this mature, returning student. She persevered and never gave up even on incredibly difficult-to-focus days for her and so I was willing to go the distance to help her and stayed many nights after work, sometimes going over the same problem ten times until she grasped the concept. Once she had it she was away and she had the incredible ability to make the connections and relationships to other problems many students take years to learn.

The end of the course is marked by a final chemistry lab exam, which is prepared by myself and the other instructors teaching the various sections of the course. One of the questions on the exam was one S. had been struggling with for some time and knowing this I had spent many extra hours on similar problems, helping her learn various approaches to tackling them. Still, she had difficulty with it. On the night of the final exam she was quite nervous. I felt for her having been in that position many times myself but I was confident she was prepared. Some time after the exam had begun I walked around the classroom. As I passed her desk I saw she was on the problem we had spent many hours studying and seemed unable to do anything. I encouraged her to move on to the next problem and come back to this one later. When the time was up, I called for the exams to be brought to the front. She flung hers at me as she passed it in. I had a sinking feeling, knowing she was angry at the question and must have had difficulty with it. I felt awful for her.

Sitting in my office after she left, her accusations still hanging in the air, I wondered about all the time I had spent with her. Why did I spend the hours I had coaching her? Perhaps I saw myself in her, struggling with difficulty and took it upon myself to rescue her? I was inspired by her perseverance and persistence in light of her condition. Perhaps I thought I could save her? For some time I had been unsure about my own teaching and had lost sight of what my focus was. This was the "icing on the cake". As I left my office that night, I closed the door not knowing if I would even, could even, come back the next morning.

Difficulty can occur at the level of the teacher, where the teacher begins to lose her focus or her desire to teach. Continued existence in this situation can lead to burnout and ineffective teaching. At the same time, difficulty can also occur at the level of the student, leading to frustration and burnout as well, and ultimately, ineffective learning. The combination of a teacher in difficulty and a student in difficulty can compound the level of frustration and be counterproductive to both teaching and learning.

Decomposition reactions do not only occur at the level of the teacher or the student; they may also occur at many other levels within the system;

Learning Institution → Politics + Frustrated teachers + Frustrated students

Curriculum → Failed curriculum + Failed learning

Although the results of decomposition reactions may initially be negative, such decomposition reactions, I believe are the underlying force that drives change. If something is not working, is continually decomposing, then in order to fix it or better the reaction there has to be change.

And so I stand on the bridge between chemistry and education, knowing that I myself need to understand the chemistry of education, the chemistry of teaching and come to my own education about the chemistry of my teaching. How do I do this? As a child I had an amazing toy, a long clear container comprised of a myriad of different colored, shaped and sized particles in a thicker-than-water solution, almost a gel. Because the solution was more viscous than water, it took fairly vigorous shaking to suspend the particles and often I would jump up and down for many minutes holding my toy to shake it vigorously enough. Once suspended the particles settled very slowly often gently [due to the viscosity of the solution] bumping into each other thus causing a deviation from their original course. Every time I shook it up and let it settle, a new and different layered pattern appeared. Much like my toy, *thixotropy* works in the same fashion. It requires the vigorous shaking of a gel-like solution such that the result is more fluid and then allowing it to settle out into a relatively fixed pattern the result of which is often very different from the original. Both my favorite toy and thixotropy are symbolic to me. Personal or professional change at all levels requires the shaking of our gelled situation, condition,

way of being, et cetera, such that the unsticking [suspension] results in change.

Encountering difficulty has thixotropic effects on any situation, the results of which can be positive or negative but which certainly results in a change from the original.

CHAPTER VII

¹⁶THIXOTROPIC ANALYSIS

The Gift

I slid the key into the lock for the one-hundredth-million time and the last time, turning it to the left, unlocking and opening the door simultaneously. I was only coming in for a few minutes, and even that was too long. Exhausted and having hit the wall, I simply couldn't do this anymore, put myself out on the limb only to have it snap in the storm of teaching, my own self falling into the abyss. I needed some time off, maybe even permanently. Teaching was not something I had ever planned on anyway.

The card was barely visible, stuck under the carpet runner at my door. I picked it up puzzled and wondering who it could be from and thought about J.'s outburst in class last night. Maybe it was an apology card? The card was simple, a blue hill with a lone flower on top bending slightly in the wind. The simple message inscribed on the front said,

Sometimes it takes another person to help us appreciate what we have, and to show us that nothing is impossible if we believe in ourselves.

Turning the cover, I read the inscription "Thank you for believing me" and the note

Michelle,

On the first day that I stepped into the lab, I knew I belonged there. But I also knew that I would need some help to reach my goal. I heard that once you reach university you are on your own. My eyes wandered for a while until I saw this pretty, smiling lady and I thought to myself that maybe this would be the one, the one that would help me.

As we both know, as time went on you had to deal with me more and more. We were becoming more and more comfortable with each other. You

¹⁶ The word thixotropic, although not synthesized by Fowler herself, is a word I give credit to her introduction to. She uses this word throughout her doctoral thesis and it is a mainstay of her philosophy of understanding difficulty. For me, my initial introduction to the word was in my grade nine literature class and later in the chemical world [the property of shaking a gel such that it becomes fluid again and allowing it to resettle and gel each time in a more settled form] and like Fowler, it serves as a metaphor to my approach for the analysis and understanding of difficulty, to agitate and suspend the difficulty and allow it until the desired product [answer] is obtained.

helped me almost each and every week and I appreciated that as I was so frustrated. I certainly felt I wasn't worth your time but you just sat there and patiently helped me for hours. It was incredible. If I never had a teaching goal before I started I do now and it is to be a teacher like yourself, a true teacher. It is a person like you who makes an education for someone like me. This department is the best department on campus because of you. And because of you, I have been accepted into the Faculty of Education and I am going to be a science teacher. My goal has been reached. But I know I could not have done it without your incredible patience and help. I find it extremely difficult to express how much I appreciated your help, guidance and encouragement. I am the luckiest man on earth to have had someone like you believing in me.

Thanks a Million, Michelle,
R.M. (the very gracious student)

*Tears in my eyes, I slowly closed the cover and looked at the lone flower on the hill,
feeling very much alone staring at the verse,*

Sometimes it takes another person to help us appreciate what we have, and to show us that nothing is impossible if we believe in ourselves.

It certainly does R.M. I didn't leave that day, or the next and I look at that card every time I have the urge to leave.

The Reluctant Teacher

I came to teaching reluctantly. It was the only job I could get when I moved from a large to a significantly smaller city. Fortunately for me it was large enough to have a university where I landed a teaching job. Not really wanting to teach, I had planned to use the job as an interim filler until something better came along or until I got into medical school [my ultimate goal]. In my first semester of teaching I taught a mix of courses at the end of which, to my surprise [since I had never taught a full course before], I received

very good teaching evaluations. Since there were not enough course offerings in the following semester my teaching services were not needed so I moved on to a job in research with the government--a job I grew to despise much more than I had initially disliked teaching. Because I disliked that job so much, I jumped at the opportunity and took a full-time teaching position at the university when it was offered to me the following year. This turned out to be a path I would, reluctantly [initially, at least], build a career upon.

Over the next number of years I worked hard to find my place, the only female in an all-male department - *the token skirt*, as I was most often referred to in the earlier days [that is until I took extreme exception to the title]. In this professional environment, I struggled with much gender-based difficulty, an "old boys' school philosophy" that excluded females. My own educational training had not really prepared me for this and aside from quitting, I was at a loss as to what to do, but I knew I needed to do something. I fought a continual battle and years of frustration in this position brought me to a precipitating point where I could no longer work in the same capacity and something needed to change. My initial gut reaction was to leave, move on, find my niche somewhere else. But I did not leave.

Identifying the Re/action

So why did I stay? I was the only female teaching in an all-male context and was experiencing a profound sense of alienation, itself an existential difficulty. I had reached a point in my teaching career where it seemed, over the course of many events, that things were falling apart rather than thixotroping together. I was frustrated at the lack of teaching philosophy [and the lack of support] at the post secondary level in the "pure"

sciences: the fact that research was paramount to everything and teaching was only secondary. It turned out to my surprise that I cared deeply about my own teaching but the traditional dynamics at that time made collaboration nearly impossible. My concern was considered to be just a *woman's way of doing it*, and I was continually told I was *too concerned, too easy, too emotional, too everything*, and because this was a university, the curriculum *just needed to be delivered* [the rest was up to the students]. That archaic approach to curriculum implementation frustrated me, particularly because I had been fighting a long gender-based battle alone and I was weary to the bone.

Falling into teaching by circumstance rather than choice I think is the case with many researchers who come to teach. But surprising to me, my initial resistance to teaching had been replaced by a desire to learn how to teach more effectively and more importantly a desire to make a difference, an impact on my students, as many of my teachers had on me. I had arrived at a crossroads where it would have been much easier to close the door and move on, but for some reason I simply couldn't do that. I wanted to try to understand how I could bridge the two disciplines of chemistry and education effectively and how my formal academic studies and experience contributed to my "*way of being and philosophy*" of teaching. To do this, according to Pinar (1994) in his *Method of Currere* originally published in 1975, "one returns to the past, to capture it as it was, and as it hovers over the present" (p.19).

Being a scientist, for the most part means that one thinks factually and linearly in that asking a question means carrying out experiments in which the quantitative answers provide the factual, concrete data to support or disprove the hypothesis. Asking questions about my teaching self and practices does not lend itself well to quantification in terms of

research but I felt the need to find the answers and being a researcher I felt there must be a methodology that supported such research. The methodologies of heuristic research (Moustakas, 1990), allows for the formalized study of human experience.

The root meaning of *heuristic* comes from the Greek word *heuriskein*, meaning to discover or to find. It refers to a process of internal search through which one discovers the nature and meaning of experience and develops methods and procedures for further investigation and analysis. The self of the researcher is present throughout the process and, while understanding the phenomenon with increasing depth, the researcher also experiences growing self-awareness and self-knowledge. Heuristic processes incorporate creative self processes and self-discoveries. (Moustakas, 1990, p. 9)

The heuristic methodology of Moustakas, coupled with Fowler's *Seven Interpretive Fields of Narrative Analysis* (Fowler, 2003, p. 166) provide the framework for my own analysis methodology. As a scientist, I look at teaching and teaching difficulty as a reaction. What factors influence that reaction--result in its success or failure? What is the impact of that reaction on the rest of the environment and its components?

I think about the chemical periodic table; how each element within the table is capable of many *ways of chemical and physical being*, how such ways of being allow the elements to engage in different fashions with other elements within the table, and how the endproduct result of those reactions and interactions can be either positive or negative. Teaching is a test of endurance involving many reactions, inter/reactions and side reactions at multi layers: at the site of the curriculum, the teacher, the student, the institution and the system, much like the chemistry of the periodic table. As teachers we wear many hats, hats that require more from us than just daily teaching. This makes it difficult at times to focus on the moment and often we end up *going through the motions* such that at the end of the day we feel we have accomplished little in terms of making a

difference or fulfilling some aspect of a dream or a passion for ourselves. Continued living and working in such conditions puts strain and stress on individuals and we don't realize it is too late until the time has passed and we are in difficulty, often both personally and professionally. And then what?

There are stages to teaching much as there are steps to a chemical reaction and each of these is affected by many parameters. When the reaction [chemical or educational] works, it is beautiful, fulfilling and the endproduct [reward] whatever that may be is worth the effort [endothermic energy]. Positive outcomes can lead to an overall production of energy [exothermic energy] that can be fueled into other educational reactions but that can also be used to fuel teachers. Failure to meet a critical parameter, to carry out the reaction removed from the optimum can lead to unexpected [not always negative] results or even failure of the reaction. What happens when the reaction fails, when there is no endproduct or there is an undesired product; when the product produced is unexpected or the energy produced results in or has negative effects? How do we understand the reaction?

Narrative Sense-making

We get used to the chains we wear, and we miss them when removed... Unpleasant because meaningless activities may get agreeable if long enough persisted in. It is possible for the mind to develop interest in a routine or mechanical procedure if conditions are continually supplied which demand that mode of operation and preclude any other sort. I frequently hear dull devices and empty exercises defended and extolled... Yes that is the worst of it; the mind, shut out from worthy employ and missing the taste of adequate performance, comes down to the level of that which is left to it to know and do, and perforce takes an interest in a cabined and cramped experience. (Dewey, 1964, p. 355)

It is easy to get lost in everyday life and to become complacent with the way things are particularly if on the surface at least, everything appears to be running

smoothly. I used to think the ideal reaction was an oscillating reaction, one that proceeds forward and backward at equal rates with the reactants giving rise to the products and the products giving rise to the reactants such that there seems to be a harmonious and equal relationship. But an oscillating reaction is a finely tuned reaction, one that is easily disrupted by even the slightest change in a parameter which causes a shift in the equilibrium and even at times, complete failure of the reaction. Thus careful attention must be paid to the factors that can disrupt the system.

The desire and need for change, the desire to know and understand, particularly of the self, often begins with difficulty. It is easy to get lost in difficulty and it can be Sisyphean work to find one's way out, to try to make sense of the difficulty and to move forward from it. From the time I was a child growing up in an abusive environment, I have tried to make sense of difficulty through writing about it. Each difficulty became a short narrative compiled into a folder tucked far away from prying and judgmental eyes. Polkinghorne calls this meaning-making (1990, p. 1-12), I call it survival. It would have been easy to bolt from teaching, particularly in the environment I was in. But I have always dealt with difficulty by marathon running and writing. Both provide a safe place, a haven in which to think, to put into context the difficulty [the question], a place to formulate my thoughts into some semblance of order [much like a chemical reaction], some logical pattern. This way of making sense, along with my scientific grounding in research, has always re/enforced my desire to understand and has provided the necessary template with which to start. The final validation of such thinking and analysis, the meaning-making is the written narrative.

Fowler (1997) in her doctoral work, *(Re) Constituting the teaching self: Narrative explorations of difficulty in teaching*, and her writing, *Narrative plains of pedagogy: A curriculum of difficulty* (Hasebe-Ludt & Hurren, 2003, pp. 159-172), has developed a qualitative method of analysis that focuses on analyzing and understanding one's difficulty, beginning with narration and moving through steps of analysis to arrive at a place of understanding. Moustakas' (1990) method of heuristic research, "the process of internal search through which one discovers the nature and meaning of experience and develops methods and procedures for further investigation and analysis" (p. 9) is a more quantitative scientific-like method of analysis.

I have used my own quantitative and qualitative scientific understanding of reactions and the relationships and inter-relationships of the chemistry of the elements of the chemical periodic table of elements, coupled with both Fowler's and Moustaka's methodologies as templates for the development of my own methodology to analyze and understand teaching and teaching difficulty.

Narration, much like the laboratory notebook, provides the breadth and depth of the experience and goes much further in providing information about the reaction than the observation of whether or not the product was formed. More importantly [or at least it should be, in my opinion] it gives insight into the how and is an explanation of the quality of the product formed. Oliver Sacks (2002) states of Mendeleev's book *The Principles* [a more formal, published reiteration of his laboratory notebook],

The Principles grew like a living thing in Mendeleev's lifetime, each edition larger, fuller, more mature than its predecessors, each filled with exuberating and spreading footnotes [Mendeleev's narrative] which became so enormous that in the last edition they filled more pages than the text. (p.195)

The laboratory notebook in the chemistry lab is thus a narrative and includes the qualitative description of the "experience" of the chemical reaction. Narratives [stories of teaching and learning experience] in education are part of the "research of education" [the lab work] and like the laboratory notebook are a record of the research. Fowler (2003) states,

Some of my narratives explore the underside of teaching, and some are "counter-narratives" [side reactions, competing reactions]...which the teaching community of readers may find difficult to hear or accept and which they may prefer to leave untold. Other stories of mine are memories of ordinary, often preconceptual, difficulty as I try to retrace my own epistemologies. Some are deliberate products of literary craft meant to create openings for more study, multiple tellings, and diverse interpretations. All have their roots in some form of autobiography, although they may blossom into fiction. (p. 165)

My own narratives provide the data to substantiate the analysis but as in any reaction there is much varied data that either supports, augments or re/enforces a reaction, or that serves to negate or dispel a reaction. Mine are only *one* set of narratives for any of the reactions.

So here I am again in difficulty, trying to make sense of myself in the difficulty and find a way of moving beyond it to a place where I can use it as a tool not only for myself but possibly also for others. The following steps of thixotropic analysis are my own sense-making steps of understanding the marathon of teaching and its difficulty.

Defining the Reaction Parameters

The basic premise of any reaction, chemical or educational, is that the starting materials, the reactants, proceed through the reaction mechanism to form the products. Every reaction of chemistry or education is affected by many parameters, the ideal of which will favorably enhance or support the reaction. Deviation from the ideal or

optimum can have a significant impact on the reaction, sometimes for the better; often at some sacrifice or expense of something else and great deviation can cause reaction failure. The inter/action and re/action of the reactants of either chemistry or education occurs optimally when the environment is the most favorable and many factors determining the success or failure of a reaction are controllable while many are not. The following section describes the parameters that may influence and have an effect on a reaction, either a chemical or an educational reaction.

In my early years in small-town Saskatchewan, there were no early childhood education programs so much early learning was either done at home under the guidance of the parents, generally by mothers who worked in the home, or it waited until one entered school. Grade one thus, was one's first exposure to the educational reactions and experiences. Given the lack of an early childhood education program, our class was a blend of Groups 1 and 2 of the Educational Periodic Table (preK/K and grades 1-3) with individuals entering at varied levels. Much like the simplest elements of Groups 1 and 2 of the Chemical Periodic Table we were highly reactive. We were young, easily impressionable, enthusiastic reactants [children] ready and willing to engage and like the elements of Groups 1 and 2 we were in need of much guidance and individual attention. Ms. E. was the stabilizing reactant, the core, in that.

One of the greatest experiences a student can have, particularly in the primary grades is a good teacher. Ms. E., my grade-one teacher had a significant impact on me, and my experience in that grade one class was the beginning reaction of my educational desires and drive. She was a very tough teacher and many were afraid of her initially but we all grew to love and respect her deeply. The environment she established in the

classroom and the attention she paid, seemingly to know the individual needs of each of her students [much like a shepherd of a flock of sheep], enabled each of us to learn to our own ability. She made the classroom a community for all and a safe haven for each of us as individuals to learn. I relate many of the parameters that affect reactions in the following section to my initial learning experience with Ms. E. simply because my inter/reaction and relationship to learning began with her. The products of that initial educational reaction have been the foundation for the rest of my chemistry of education but are also the foundation of my own philosophies about teaching and learning. The following section thus uses narratives from that experience as relational data.

The Reaction: The Mighty Ms. E. and Her Students

6	6
C	f
Carbon	<i>The Mighty Ms. E. and Her Students</i>

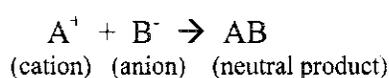
Carbon is the sixth most abundant element in the universe. It can be as soft and black as graphite, leaving its mark on anything or as hard as diamond, unyielding to pressure, reflecting a spectrum of color. It comprises nearly ten million compounds and forms the backbone of all life.

September 3, 1968...my first day of school. It had taken me forever, it seemed, to turn six years old and with that "coming of age" came the escape of school and the honor, some would disagree, of spending an entire year with Ms. E. who was not your typical grade-one teacher, soft spoken, gentle, beautifully dressed, someone with a gentle demeanor that most small children adoringly look up to. No, Ms. E. was exactly three feet tall, with an almost cartoon-caricature appearance enhanced by her bright orange hair and black, round glasses which, when perched upon her nose, made her eyes have a perpetual astonished look. She was small but her presence was mighty. When she entered

a room, it was with a vengeance. She would march straight up to the front of the classroom, step up onto the raised platform she had constructed and look out over her young charges with a No-Nonsense look that one dared not defy. Breathing was risky business in her class, while talking often won you the not-so-coveted spot kneeling in the corner with the DUNCE cap on. I came to learn over the course of the year that her tough, external demeanor could soften periodically and underneath existed one of the most beautiful and caring souls and as the years went by, I appreciated the products [gifts] of the reactions of that first grade; strengths and philosophies I still carry with me.

The Reactants

With the exception of decomposition-type reactions, all chemical reactions involve the reaction of starting compounds or materials called reactants, two or more species that interact/react. Whether the reaction takes place or not is dependent on whether the reactants interact. For example,¹⁷ ionic reactions are those reactions involving charged species. Cations are positively charged species and anions are negatively charged species and because opposites attract in chemistry [and in life in general], cations and anions will react to form a neutral product as in the following reaction equation.



As is the case in all reactions, how and if they do react is dependent on the reaction environment as well as the physical state of the reactants. Two solids are not as readily able to interact or react as are two liquids or a liquid and a solid where contact is

¹⁷ Ionic reactions are not the only type of reactions in chemistry but are used to illustrate reactants, particularly cations and anions. Other reaction types will appear in a later section.

much more integrated thus allowing for all the particles comprising the reactants to come into contact with each other [increased surface area] providing more points of reaction. The physical state of the reactants of education is critical as well. For example, some teachers are more fluid, have very dynamic personalities and are interactive and reactive with their students whereas others are very strict and do not budge. Such a solid state makes interaction of the comprising particles difficult and this sets up a gap in interaction and creates relations of power that are intimidating to students. Physical states [as seen in Chapter VI] are subject to change and what was once solid and contained can melt and become more fluid or vice versa. This is seen in difficulty, where once a teacher who was all-engaging [fluid] becomes withdrawn and more solid. The same is true of students. Many students change over the course of their education. Part is due to maturity [learning readiness] and part is a result of the learning process. One cannot learn and not be changed.

Ms. E.'s Philosophy on Reactants

My first introduction to the educational differences between boys and girls was in that grade one classroom. Ms. E., on the first day of school, took a roll of bright yellow tape and stuck a line straight down the middle of the classroom floor much to the astonishment and puzzlement of us all. She then aligned the girls' desks on one side of the yellow boundary and the boys' on the other and unless she said otherwise, each had to stay in their respective territory. She advocated that the girls needed to learn with the girls and the boys with the boys and mixing simply caused everyone to become "mixed up" and unable to think. At the time I thought it was just her way of keeping control of a group of unruly farm boys but in retrospect, I think she had the insight and foresight to know that girls and boys behave and learn differently.

Ms. E.'s Philosophy on "Girls' Things"

Part of my grade one curriculum was to study the "life" of an animal. Our teacher Ms. E. chose a rabbit for such study and the first project as a class was to build a rabbit hutch. In the planning stages, we drafted the plans for the hutch, decided on what materials and tools we would need for the building, planned what we would include for comfort accessories for our pet, what type of food we would need, et cetera and began to allocate the various tasks. The boys had decided they were going to do the building as they, as boys, knew how to do this and the girls could do the interior comfort and food stuff as those were "girls' things". Ms. E. was intolerant towards such stereotypes as she said it diminished the worth of one group at the expense of the apparent elevation of another group. She decided that such ignorance required an education and assigned the boys the "girls' things" and the girls the "boys' things". And so the rabbit hutch was built by the girls [and not so badly I might say] and the pillows, blankets and comforts of home were sewn and assembled [under great vocal protest] by the boys. Walking in someone else's shoes, Ms. E. said, was the best way to educate oneself about different shoe styles and sizes, and that it is possible to wear more than one style but that the shoe may be difficult, although not impossible, to fit. [As in chemical reactions, there is often more than one approach to a reaction, some of which are easier than others.] Every time I am faced with the "girl thing" mentality, I am reminded of Ms. E.'s philosophy on such a topic and now realize that my own philosophy and intolerance of gender stereotypes was largely grounded in that grade one classroom.

The coming together of the reactants is a critical first step to any reaction. How successful this is, is influenced by many external and internal parameters but failure of the reactants to come together and interact/react will most certainly lead to failure of the reaction.

The Limiting Reagent

The limiting reagent or reactant is the reactant present initially in the least amount and is thus consumed first in the reaction and if not replenished in some fashion the reaction will cease and there will be no further formation of products. The limiting reagent thus has a great influence on the outcome of the reaction. In an educational reaction, the limiting reagent can be the student, the teacher, policies, the curriculum, the administration, the system, et cetera; any reactant which when consumed totally causes the reaction to stop.

Ms. E's Philosophy on Becoming the Limiting Reagent

A short, rather overweight and very rude boy, F. would always be waiting for me at the gate of the playground after school. He had moved in two doors down from me in the middle of the summer and had taken it upon himself to engage me in daily verbal and sometimes even physical battle. Today was one of those days but unfortunately for both of us I was not in the mood. He was waiting in his customary place by the gate and I tucked my head into my torn jacket, protection from the cold wind and his biting words and started on my twelve block trek home bent on ignoring him.

"Hey ugly," he shouted. "Where you going? To that barn you call a house. Must be cold, all those cracks and broken windows. Probably eat dogfood or slop for dinner don't ya."

I ignored him at first and keeping my chin down kept walking.

"Hey ugly. What's the matter. Cat got your tongue?" he said, he and his constant sidekick, L.. blocking my path. L. echoed, "Ya cat got your tongue, ugly?"

"Get outta my way F. or ...", I said in an even tone.

"Or what?" he asked sneeringly, poking at my arm over and over, each poke harder than the one before. "Or what? Come on tell me? Come on. Come on. Come on."

"Yeah, come on," mimicked L. poking at me from the other side.

My balled up fist, hidden in my coat pocket, seemed to have a mind of its own and before I knew it, it was out and trying to connect with F. somewhere in the midrif. But F.

being more than twice my size just gave me one big shove, sending me flying and landing on the ground.

"Ugly wimp", he sneered giving me one last shove as he walked away.

Tears stung my eyes yet once again and I told myself not to cry but they came anyway. As I struggled to get up I saw a familiar pair of black oxford shoes with one heel higher than the other [to compensate for her shorter left leg], in front of me and looked up to see Ms. E. I wondered how long she had been standing there. She extended her hand helping me up and gave me a pat on the back.

"Don't stoop to his level honey. You are way beyond that. If you just walk away and don't engage pretty soon he will leave you alone. He only continues because you engage. Like most living things in life honey, if you don't feed it, it will fizzle and die. Walk away. It gives you all the power."

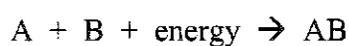
As Ms. E. walked me home that day, chatting and pointing out all colors of the changing leaves [she loved the fall], I wondered what it must have been like for her. Was she bullied too? Did her knowledge come from experience? The next day and the next and the next, F. was at the school gate again, and each time I kept my balled fists tightly in their pocket-cages and walked as fast as I could home, never once saying a word or even looking at him. And then not too many days later, F. wasn't at the gate after school. I was surprised but didn't trust it to be real. But F. never showed up after that and for the rest of the year pretty much ignored me. To this day, I have found much power in not engaging in such negative reactions.

The limiting reagent entirely controls the reaction. As soon as it is depleted, the reaction stops, no more products are formed and unless there is a new input of the reagent into the system, the reaction can no longer continue. In education there are many limiting reagents, the teacher, the student, the curriculum, the system, even drive and desire are all limiting reagents. The most profound and probably the one having the greatest impact is the teacher. As soon as the teacher becomes the limiting reagent whether it is from lack of knowledge, experience, teaching style but most particularly in cases of difficulty, then

the teaching-learning reactions stops or even fails. Such failures can lead to change in a positive fashion or to difficulty in a negative fashion. As in many chemical reactions, the insidious problem is that the reaction will continue without any obvious indicators that one of the reactants is becoming depleted until complete depletion and as such there are no obvious indicators until it is too late. The reaction may slow initially but then stops until replenishment, if it does, occurs. It is critical therefore that when the limiting reagent is consumed in its entirety there are ways of refreshing or influxing that reagent into the system to prevent complete cessation or failure of the reaction.

Energy of Reactions: Endothermic and Exothermic Processes

Energy is involved in reactions of all types. It is either taken into the system to drive the reaction, or it is produced as a product of the reaction and can be used to drive other reactions. In all reactions the Law of Conservation of Energy applies, in that energy, although it can be changed can neither be created or destroyed; the total quantity remains constant and therefore can only be moved about the system or the universe. Some reactions may require an input of energy from the system to drive the reaction and in taking energy from the system, the system undergoes a temperature change and becomes colder as energy is lost to the reaction. Such reactions are referred to as *endothermic* reactions and may be represented by the following general equation:



Many reactions of education require a significant input of energy from the system. Teaching requires energy input from the teacher sometimes so much so that the overall

cumulative effect may lead to failed teaching or burnout. Learning, as well, requires energy input from the student. The interaction of the two, teacher and student, requires an input of energy on both parts but the input may not be balanced by both parties resulting in energy input in some cases that may be only one-sided.

When energy is given off to the system, the reaction is *exothermic*, meaning that energy goes into the system to provide fuel for other reactions. Energy in the form of heat results in a temperature increase of the system. In education the interaction of the teacher and the student may be such that there is much energy produced [stimulation] that can be garnered and used to further drive other reactions. Exothermic reactions can be illustrated by the following equation:



In a reversible reaction the energy put into and taken from the system is essentially recycled energy and in the overall reaction it is balanced. Failed reactions, when reciprocity no longer exists in education or when the energy is lost [escapes] from the system, lead to teaching or learning difficulties or other conflicts within the system.

Ms. E. Fuels the Reaction

Red is both the antagonist and protagonist of my early childhood. Grade one seemed to be a red year, a color I initially loathed but one that eventually became a symbol of a very deep love, not the red symbolic of romantic love, cupid, red valentine hearts or red roses, but the love of opportunity--the love of words.

Ms. E., with her almost elf-like appearance and flaming red hair, was my three-foot grade-one teacher. Her no nonsense demeanor gave me the initial perception of a

tough, strict and unforgiving personality, but even in my early years, I was able to read between the lines and saw the contrasting gentle demeanor she tried to hide.

On the first day of school, Ms. E. passed out red workbooks, not orange-red but deep blood red, with smooth matt covers unblemished by fingerprints or uncreased by opening, each person's different only by the black letters that identified the owner in the top right hand corner. I had never had a new book before and I caressed its newness with anticipation of what lie between the covers. The excitement of it took my breath away.

Grade one, in my time, was not preceded by kindergarten as it is today, at least not in the rural setting of my early school years, but still, Ms. E. expected that we know our alphabet and have a basic understanding of how the letters formed words before we entered her class in September. Unfortunately, this was not something my parents spent any time teaching me in my pre-school days at home. It was something I had learned pretty much on my own but consequently lacked self-confidence about. So when she handed me and a fellow male classmate the red workbooks to pass out to each student, I could not match the black letters to any face I knew in the room except mine. I stood blurry-eyed, trying to get my brain to make a connection to what my eyes were seeing, but to no avail. I stood there, stupefied, my eyes watering, my face bright red and my ears threatening to burn off. My embarrassment was so great.

Ms. E. snatched the pile away from me and handed them to the blond, curly-haired little girl sitting next to me. "If you can't read simple names then just sit there", she said. "There is no room in this class for lazy people. You were supposed to know your alphabet before you came to my class." I sat in my desk, embarrassed and feeling incredibly inadequate, jealous and seething as the little blond girl sitting next to me handed out those beautiful red workbooks with barely a glance at the name. I sat still, trying to control my anger, seeing red before my eyes. "How dare she!" I thought indignantly. "I'll show her." That night I went home and stayed up late into the night learning every single child's name in the class. I dreamed them in my sleep. The next day, Ms. E. asked for volunteers to hand out the red workbooks and I quickly put up my hand. She looked at me and said, "Are you going to make a fool out of yourself again today?" NO, I shook my head, so she passed me the pile of books and I nearly ran around the

room as I passed them out. I finished and sat down, barely looking at her. "Hmmm," she said. "I see you can work hard. Good for you!" A compliment, and a victory.

Ms. E.'s critical assumption that I did not know my alphabet and could not read names stimulated the anger reflex in me, anger at the fact that she assumed I did not have the appropriate knowledge when my real problem was fear; fear of making a mistake in front of all the other students who might make fun of me. Staying up all night to learn the names required a great amount of energy [endothermic] input and the anger channeled itself into becoming a catalyst and providing the necessary energy for learning to read the names for the next day. It could, however, have had the opposite effect in that it could have shut down someone who was too shy and timid, and rather than stimulate an anger response, it might have stimulated a negative self-esteem response. Such a response could have a far reaching and long enduring negative impact. The energy garnered at that time and the positive feeling of self-satisfaction was paramount to establishing my own self confidence in that class; a self-confidence that enabled me to overcome other more difficult things later in my education.

Catalysts

Many chemical reactions have a high reaction threshold [an energy barrier; the amount of energy necessary to overcome in order to convert the reactants to products] and therefore are slow to start. The addition of a catalyst, a substance that increases the rate of the reaction by lowering the threshold energy, aids in initiating that reaction and as such the chemical or learning reaction proceeds more quickly and efficiently.

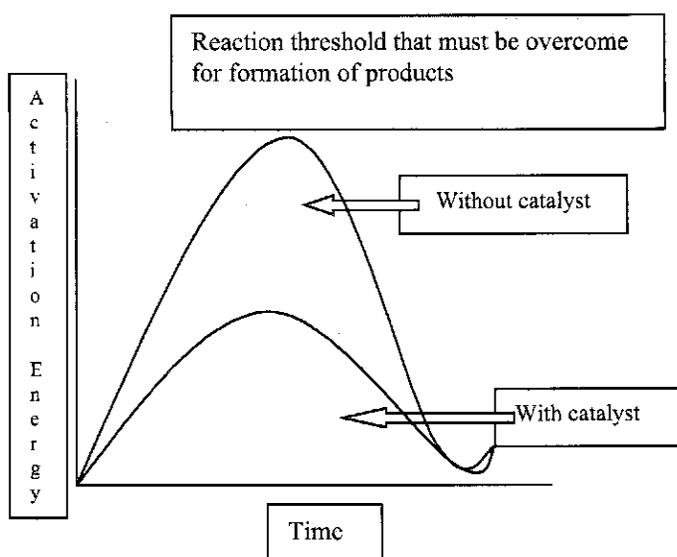


Figure 24. Graph of the activation energy [the amount of energy required to overcome the initial reaction threshold]. The addition of a catalyst to the reaction lowers the amount of energy required to start the reaction thus increasing the rate at which the reaction occurs but it does not change the overall reaction mechanism.

The teacher is a catalyst in the learning process of a student, initiating the learning process through teaching style, stimulation, engagement et cetera, thus lowering the activation energy for the student making the learning process less difficult, more stimulating, engaging et cetera. The learned student is the final product who then goes on thus leaving the system while the teacher becomes the catalyst for the next reaction; the next student or group of students.

Ms. E.'s Philosophy on Catalysts - Mind Over "I can't do it"

Every time one of us, either a girl or boy, said we couldn't do something Ms. E. would ask, "Why not? Is it because you don't know how to?" If that were the case, learning was

in order. "Is it because you don't want to?" would always be the next question, in which case Ms. E. would tell us there were many things in life to do and not all were pleasurable or desirable but they still needed to be done and the best way to do them was just to do them. "Is it because you think you can't?" she would lastly ask, to which Ms. E. would ask "why not" if we answered in the affirmative. It really didn't matter what your answer was, she always said,

You can do anything you put your mind to. If your mind is telling you that you can't do it then you need to trick your mind into believing that you can and so you say over and over to yourself...I can do it, I can do it.... If someone tells you that you can't do something, or you are incredibly nervous about doing it, then you stand straight, pull your shoulders back, hold your head high, toss your hair back and in your mind you say, "I amand I spit in your face.

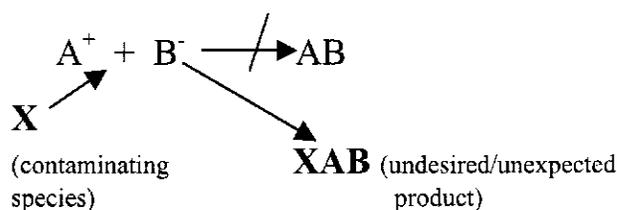
And it was an amazing thing, despite fits of tears and frustration in her class we usually did do whatever the difficulty was and felt good about our accomplishment in the end. That one has been a bit of a problem for me over the years because, much to my astonishment at times, those words did not remain caged within my mind and have served as a catalyst to fuel the voice of my opinions.

Some individuals have a natural ability to learn quickly such that each new challenge, physical or mental, of the learning curve seems effortless and the individual soars through easily and apparently [on the surface at least] unscathed. For others though, the curve is steep, requiring continued exposure, practice and effort. The learning process for those who require more effort may seem to be more painful and slower requiring a greater input of energy or even a catalyst, someone such as a mentor *to show one the ropes*, to lower the activation energy [the amount of energy required to start the reaction]. Regardless, in the learning process there is a reaction threshold that must be overcome,

and a learning curve that ensues thereafter. The height of the reaction threshold and the slope of the curve are very individual.

Contaminants and Inhibitors

Chemical reactions will sometimes fail, or give unexpected results, even side reactions that are seemingly unexplainable. It can be especially frustrating when the reaction is tried and true and then all of a sudden for no apparent reason it fails resulting in an undesired product as in the following reaction equation.



The chemist then begins to look for extraneous factors, contaminating species or inhibitors that might be interfering. Sometimes it is as simple as dirty glassware or an impure starting material [reactant], other times it is more innocuous and difficult to figure out, but whatever the contaminating species might be, it can have a deleterious effect on the outcome of the reaction and an undesirable resultant product.

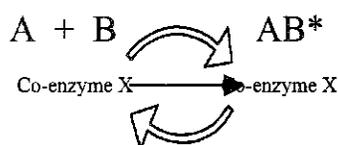
Ms. E.'s Philosophy on the Contaminant – Stupidity

I remember some of my male classmates informing a group of us girls one day we were just "stupid girls" and really, what could we possibly know? Ms. E. happened upon the conversation and we abruptly ended our heated discussion in her ominous presence although not before she perceptively picked up the trailing threads. After the bell rang and we had all reassembled, each boy was required to stand and define "what is a stupid girl?" and conversely each girl to define "what is a stupid boy?" We all had our own opinion, I am sure, but dared not voice it for fear of repercussion. For the most part, we

just mumbled "I don't know", to which Ms. E. would ask, "well...do you think you are a stupid girl?" or "do you think you are a stupid boy?" Of course we answered "no" and when queried as to why we thought not, Ms. E. would respond "Hmmm" or simply nod her head to our child-logic. After we each had our uncomfortable turn in the lime-light, Ms. E. said, "Actually, you are all stupid boys and stupid girls. The boys are stupid for thinking that they are better than the girls simply because they are boys, and the girls are stupid for letting the boys treat them that way." Stupid, she went on to explain, was a lack of normal intelligence and the brains you got were the luck of the draw [genetics she said] and had absolutely nothing to do with whether you were a boy or a girl. Ignorance, on the other hand was a lack of knowledge or education, which in itself could be quite dangerous and the fact that the boys thought the girls were stupid really meant they just weren't educated about girls. Stupidity she could deal with she said, but ignorance in her class was an unacceptable contaminant and something to be worked on. The ignorance of prejudice, was an intolerance I learned in that classroom and is one that did not end with grade one. It has become an enduring part of my own life's philosophy.

Reaction Co-factors/Co-enzymes

Many chemical reactions proceed more effectively or are enhanced by a co-factor or a co-enzyme, a substance that does not actually take place in the reaction and is recycled to be used again, but that makes the reaction environment more favorable, conducive to taking place with greater ease and often yielding a much better [higher quality and quantity] product. Such co-factors or co-enzymes are often intrinsic to the environment of the reaction thus remaining innocuous such that their contributions often go unnoticed [at least until they are no longer there].



In the above reaction, the co-enzyme serves to enhance the environment in some fashion such that the product formed (AB^*) is of better quality and quantity than if the co-enzyme were absent.

Ms. E.'s Being

I often think about how difficult it must have been for Ms. E. to get where she did, a physically challenged individual, a dwarf, in a society that ridiculed the different long before laws to protect them were in place. Not only was she a ¹⁸ dwarf, she was a female dwarf and I can only imagine the prejudices at both the physical and gender levels she must have endured. By just being who she was, Ms. E. stimulated my desire to learn. More importantly, she taught me one of the most important life lessons; that of the right to achieve--that no matter how difficult it may seem to be, you can do anything you put your mind to and no one has the right to tell you that you can't, you just have to have the internal strength [co-enzyme] of perseverance and the companion of faith. I am sure I wasn't the only student who flourished as a result of her unconditional support.

Intermediates

An intermediate is a compound or substance that is formed part-way through the reaction. Instead of going directly from reactants to products. This might be thought of as a resting place for the reaction. In teaching and learning there are many intermediates formed, places where both the teacher and the student rest. Partial understanding, partial learning, partial relationships or engagement, et cetera are all intermediates. The

¹⁸ I realize "dwarf" is no longer an acceptable term but it is a term I grew up with. I do not use it in a derogatory or demeaning sense and no harm is intended. It was a term Mr. E. used in reference to herself.

formation of intermediates often leads to a higher yield of a better quality product as it gives time for the reactants to catch up, to rest, to garner energy and it is also a place where there can be an infusion of something of assistance say a catalyst, a co-enzyme, a secondary reactant, et cetera. Many of the transition metals serve as catalysts.

Learning to Read With Ms. E.

"You can't go out in this!" my mother said. "It's storming, Michelle. You will get lost and freeze. You can't even see two feet in front of your face out there."

"I'm going Mom, " I replied, my jaw set in determination fearing she would really put her foot down preventing me from the only sanity in my days. "I'll just keep walking straight ahead until I run into the school. How hard can it be to keep going straight. I'll be fine and besides it's not even cold out." She hesitated, I imagine weary from arguing for the last hour, and finally said, "I suppose. But you keep going straight. No turns." My screaming baby brother got her attention so she couldn't continue. I left quickly before she could change her mind, the peeling green door slamming behind me as I went running out not bothering to make sure the door was shut completely for fear she would change her mind. It was one of those Saskatchewan blizzards that always seem to hit right around Halloween when fall isn't quite over and winter not yet begun, not really cold but having a biting wind that blows ice-snow so hard it stings the face. I loved the penetrating cold that broke through the numbness making me feel.

I was small for my age but determined so I arrived at school a bit late after much Tug-a-War with the wind. I noticed all the familiar noises were missing; the usual morning hall-din was replaced by an eerie silence. "No school," I thought, disappointed. I couldn't bear the thought of spending the day at home confined to my room, the alternative to not being at school. The door to my classroom was open and the light on. Thinking I would just get a book, I was surprised to see Ms. E. working at her desk. She looked up when I entered.

"Ah. Good you, Michelle. Come in and have some hot chocolate and we will do some work this morning. Since you walked all this way in the freezing cold, I imagine you want to be here. Do you?" I nodded.

"R. made it in as well and has just gone to the washroom. So we will wait. It looks like it is just the two of you today. What would you like to do?" she asked plugging in her kettle to boil water for the hot chocolate.

"Learn how to read," I replied immediately surprised I had a choice.

"In one day? That's pretty ambitious for one day don't you think?"

I shook my head NO. "I really need to learn to read, Ms. E. Please". I'm not sure if it was the earnestness in my voice or the pathetic look on my face that made her agree. "O.K., let's learn to read then," she answered. When R. came back she said, "Michelle wants to learn to read today."

"Me too," he said in agreement.

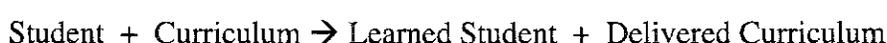
Ms. E. picked up a book and for the next five hours we sat on the floor, our backs propped against the book cupboard, isolated and cocooned in the wintery whiteness of the blizzard outside, drinking hot chocolate, eating our lunches and reading. And I learned to read. It was the most amazing experience, the combination of the letters I knew and words I had been learning came together in a structured way to make a story. Until that day, I had struggled with reading, not quite getting the patterns. I was nearly there [intermediate step] but had no one to spend time with me to help me put it together. Just sitting there with Ms. E., her quiet interjection as I stumbled my way through the vocabulary and sentences was a comfort, and provided me with the security and confidence [the intermediate infusion] to try without the eyes and ears of others. And then it clicked and by the end of the day I was reading quite fluently. Everything made sense and a door sprung open. I was enamoured. My love affair with the written word began that day and has continued throughout my life.

Much like the intermediate step of a chemical reaction, having the time with Ms. E. provided an infusion of confidence, an infusion of energy that enabled the reaction to take off. And like many reactions, the more there is a fresh input at the intermediate

stage, the greater the amount and quality of product produced. The quality of the product formed that day and my desire to engage with the text has fueled my passion for literature for a lifetime.

Secondary/Side Reactions

The reaction equation for the above narrative might be represented as;



However many reactions also have one or more simultaneous secondary reactions and often in chemical reactions, and educational ones as well, they may even be more important although often significantly less obvious than the parent reaction. Such side or secondary reactions may be beneficial, harmful, or innocuous. In many cases though they serve to augment and substantiate the learning process. We can all remember being drawn to certain teachers, wanting to learn what they know, not only by their love of the topic but also because of their way of being. In the movie "Dead Poets Society" (1998), Robin William's love of poetry, his reading and presentation of it mesmerizes the students, seductively draws them in, entices them, and transmission at a more qualitative, experiential level occurs. They begin to love poetry as well. Like chemical reactions, full engagement means participation.

Sunday School with Ms. E.

Sunday afternoon was the day Ms. E. would tend to the church yard. She loved gardening and had the gift of salvaging even the most stressed and love-starved plant and nurturing it into beautiful blossoms and lush greenery. The yard of the Anglican church across the street from my house was never so beautiful as when it was under the loving care of Ms. E. She noticed me watching her from my front step one Sunday afternoon and

gestured for me to come over. I crossed the street and timidly stood by the white picket fence.

"Hi, Michelle. Would you like to come in and help me? she asked smiling at my nervousness. I nodded and she opened the gate leading me into the huge backyard where the grass was adulterated with hundreds of yellow dandelions. It looked incredibly beautiful to me, the contrast of the yellow button flowers against the green canvas, but the huge yellow pile in the middle of the grass made it quite evident that she did not feel the same way.

"Would you like to help? I have an extra little shovel you could use."

"Sure." I replied, happy for the attention and glad for the company. She showed me how to dig the shovel into the ground with a bit of a twisting motion while at the same time forcing the tip under the plant and scooping it up and out. "They have to be removed from the grass to the garbage otherwise they will re-root into the lawn and that would defeat the purpose," she explained. "Have you ever done any gardening?"

"Just pulling weeds." I answered.

"Well I guess that is what we are doing now but I have a whole bunch of planting to do and lots of cutting and pruning. How would you like to be my assistant on Sundays and maybe we could learn about gardening together?" Surprised I nodded my head in agreement, secretly delighted that I would be able to spend time alone with Ms. E.

So every Sunday we would meet after lunch at the church and garden until dinnertime. I learned about plants, what they liked and did not like, what they needed to make them grow, what their enemies were and I grew to love gardening. I learned about nurturing, a void in my own life, and I learned Ms. E., in spite of her tough demeanor, had a heart of gold. To this day, one of the natural beauties for me is a field full of dandelions, reminiscent of a time when I learned to nurture and to weed.

I was reminded once again of their beauty in another context when my daughter presented me with a bouquet of dandelions.

Dandelion Bouquets

$^{24}\text{Cr}/$ ^{79}Au 52.00/197.0	$^{24}\text{x}/$ ^{79}Li <i>Dandelion</i> <i>Bouquets</i>
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Chromium is a metal that can be polished to a very shiny surface and when plated with other materials forms a very attractive coating. It forms many colorful compounds and is the main component of chrome yellow, the yellow pigment in paints.

Gold, the most malleable and ductile of all known metals is attractive and highly valued. It is often alloyed with other metals to increase its strength and is used to make jewelry, decorative items, dental fillings, et cetera. It is a good conductor of heat and electricity and does not tarnish.

Yellow...a color I have had no real love for except in dandelions and in fact have often had quite an antipathy towards in all my life-color choices. Being the unequivocal, dogmatic person that I am, I have always found yellow to be a fence-sitter even as a primary and necessary color in the spectrum. Although its Greek roots mean "to gleam" [to shine or reflect; to be manifested briefly; to appear or reveal suddenly], it also has lesser aspiring affiliations such as when attached to "-belly" thus transforming itself into a contemptible coward, something I at times equate to myself. As an adjective: flaxen, mongolian, Mongoloid, jaundiced, jealous, envious, cowardly, craven, fearful, lily or white-livered, afraid, unmanly, pusillanimous, lurid, sensational, scandalous, melodramatic, yellow paints a rather unflattering picture. Many things of "more pure color" become yellowed with the chemical process of aging making them look less-than-perfect. Skin yellows with age and with it is gone the pure unadulterated innocence of childhood, replaced by a more veritable perception of the world. Cheaply sensational can be said of certain newspapers whose written word is printed on yellowed paper. The yellowing of the leaves of plants is indicative of viral or fungal infections, much like the jaundiced eyes of humans is symptomatic of not only physical ailment but can impede

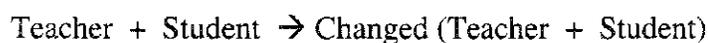
true vision and perception. Yellow is a [catch-color]; an indicator, a symbol, a signal, an identifier, a signature and by its very nature it has credentials, but to me it was a non-descript color, one with little integrity.

With maturity, I find there are few things in life that I know absolutely and more and more, I look for the positive beauty in everything. Over the last number of months yellow has slowly made its way into my life and rather than reveal itself suddenly, it has gently and tenaciously whispered its introduction and taught me the beauty of its existence. Much like the yellow of the traffic lights, yellow has taught me to slow down, to yield to life, to relax, to mellow and to simply take my time. It is the base upon which many colors are built and thus like a true friend provides an unfailing foundation to the curriculum of color. It is the color of element gold [Au] in the chemical periodic table, a metal used in rings, the symbols of endless, circular continuity and of Chromium [Cr] an important mineral in the metabolic reactions maintaining the homeostasis of the human body. It is the preceding color to sunrises and last of the queue in the light at the end of the day. The beginning chemical transformations in the aging of white can lead to the most subtlest of yellow hues indicating its willingness to take the baton. It can be the most vibrant and intense of colors such as in a field of dandelions in the spring, sunflowers in the summer, Black-eyed Susans in the fall, and yellow spots on pure white snow in the winter. The yellowed pages of old and often-shelved books hold an entire world of life, one that endures time and one in which to escape with a cup of hot chocolate, a warm blanket and the yellow glow of a fire on a stormy night. It has the most amazing friends in its relationships with the myriad of colors in the rainbow and is their elusive and subtle anchor holding down their "end". It is the color of the gossamer wings of the angels I know to exist in this life.

I no longer think of yellow as being a color of little character or substance. It has a subtle but volatile nature and is its own person providing foundation and support, capable of working well with others, having a positive personality that provides levity and buoyancy to life and is able to indicate when things are not quite right. It is enzymatic in nature providing a means to stimulate reactions and effervescent in providing the positive atmosphere to keep them going; it has grace, form, elegance, charm, pulchritude, fairness, brilliancy, delicacy and magnificence, much like the

element gold and much like the Ms. E. of my grade-one education. It is immaculate, perfect and flawless. It is a color symbolic of a deep and true friendship I have developed with one of the truest people I know. It is a teacher, a teacher of time...time to slow down and enjoy the more subtle things in life....deep and true friendships, sunrises and sunsets, the quiet fire of inner strength, and acceptance of the quiet knowledge that lies on the yellowed pages of life. Today my youngest daughter ran excitedly up to me, arms clasped tightly behind her back holding a cherished gift I was not to see. "I love you Mommy!" she said, as she proudly presented me with a huge bouquet of yellow dandelions. Ah.....the gifts and [b/lessons] contained in yellow.

The interaction/reaction of two or more reactants does have an effect on both reactants although it might seem to benefit one substantially more than the other. Although the teaching reaction is seemingly one-way with the ultimate goal being the transmission of knowledge to the student resulting in the "changed" or "learned" student there are often many side reactions and as with all relationships and reactions, the experience can be either positive or negative and such side reactions can happen to both the student and the teacher. The secondary reaction to my Sunday gardening with Ms. E. might be represented by the following reaction;



We shared much on those Sunday afternoons and although I may have been the one to benefit the most from those gardening lessons, the friendship and companionship changed us both. I find much comfort in the garden to this day.

Failed Reactions

Many reactions in chemistry, particularly in research, when one is trying to get a reaction to work, fail initially and many times in fact. It is often difficult and time consuming to determine what is causing the failure. It might be something as simple as a dirty piece of glassware, a contaminated reagent, the temperature of the system, the wrong concentration of reagents, et cetera. Whatever the problem is, it often takes many trials and much varying of the reaction parameters to get the reaction to work and to work optimally. This is true of teaching as well. It is rare that an individual can get up in front of a class without some level of difficulty, at least initially. Experience comes from varying the reaction conditions to find what works optimally for the teacher and the student. Many times this is an ongoing process because the reaction conditions change with each new batch of reactants [students] and are dependent on the environment [the class and classroom] at any given time. Like all reactions, there is a possibility the reaction may not work as expected; it may not yield the desired product. "Failed reactions", ones that do not produce the desired product, the learned student, may be the result of difficulty at many levels or layers.

Biting Ms. E. and the Hand That Feeds

Ms. E. ruled her grade one class with a strictness one did not dare challenge. Talking out of turn resulted in ten lines of "I will not speak unless spoken too" written in the best penmanship during recess. Coming late to class meant one had to stand at the front of the class and apologize to the whole for being so rude as to interrupt the process of learning. Disturbing the class by fooling around resulted in one leaving the classroom to sit on the chair outside the door until Ms E. found sufficient time to come and discuss

your inappropriate behavior. [In comparison to the lack of manners I see in many of today's children I am not so sure Ms. E.'s strict rules were so wrong.] We certainly had manners by the time we graduated from grade one.

The "Dunce" cap was reserved for the particularly bad behavior, such as swearing, hitting or not listening numerous times. T. H. sat behind me in grade one. He was mean and cruel and would pinch my shoulder, spit eraser balls at the back of my head or pull my hair. This went on all year and I being a scared rabbit never did anything in retaliation or said anything. After one particularly cruel recess where T. H. persisted in making fun of my torn and dirty dress, my scabbed knock-knees and my "sniveling" as he called it, I sat at my desk, ram-rod straight, fists balled in anger barely able to contain my tears. And then T. H. pulled my hair yet once again. I turned around before I could even think and pummeled him with my balled fists, a mistake for sure in Ms. E.'s eyes.

"Michelle!" she yelled at me. "Stop it right now!" I stopped frozen, my fist in mid swing, halfway between T. H.'s face and myself and sank into my seat. She marched right over to my desk, yanked me out of my seat by my arm and I knew I was going to the front of the class. I was angry she was only taking me and embarrassed and frightened, so much so that I peed my pants. This was cause for a look of disgust on her face and as she dragged me past her desk she grabbed her twelve inch wooden ruler, the kind with red numbers marking each inch and little ticks marking each eighth of an inch and whacked me on the bare arm with it. Surprised by her action, I screamed out in pain and she, in her wish to silence me, put her hand over my mouth. How was she to know that I was phobic about such an action, fear of suffocation and memories of other silencing making me do what I automatically did, bite down. And that I did. She let go with a yelp of surprised pain and I ran out of the classroom as fast as I could straight to the girls' bathroom and hid in one of the cubicles, tears streaming down my face, my own breath and fear threatening to choke me.

After what seemed like an interminable period of time, I heard the door of the bathroom open and a very quiet voice say, "Michelle are you in here?" I didn't answer but my hiccuping gave away my hiding spot and Ms. E. gently knocked on the door.

"May I please come in?" she asked. As I moved away from the door, she opened it gently and gestured for me to come out. "Can I please talk to you?" She sat on the floor and motioned for me to sit on her crossed legs. "I am so sorry," she said. "I don't know what got into me and I was very wrong. I need you to know that how I handled that was wrong and I will figure out how to do that better. In the meantime will you forgive me, please?"

I nodded my head, my six-year-old brain not able to fully comprehend what she meant by "figuring out" and quite confused because in my little world adults never apologized whether they made a mistake or not. I was humiliated by my own behavior but my respect for her went up enormously that day. Ms. E. didn't come to school for two weeks after that. I missed her terribly and felt somewhat responsible. It wasn't until I was a teaching adult did I realize that Ms. E. was in difficulty.

But an unexpected reaction is not necessarily a failed reaction and may in fact lead to a more interesting and positive outcome. It is, for example, how many great inventions or discoveries are founded. In 1928, Alexander Fleming accidentally made a crucial discovery that led to the production of the "Wonder Drug" of the twentieth century, that of penicillin, simply by leaving a culture out on the counter that became contaminated with fungus [mold]. The mold [later named *Penicillium notatum*] found to inhibit the growth of bacteria (Franklin & Snow, 1985) was later purified and produced on an industrial scale for widespread use as the antibiotic penicillin.

Thus even in teaching and learning, reactions that do not work as expected, that yield unexpected results or that fail completely, may possibly turn out to be even more beneficial as they may lead to reflection and praxis and thus change and growth of the teacher or the student. However, continued failed reactions may reveal unexpected results

in teaching or learning for the student or the teacher and a continuum of this can lead to severe difficulty.

There is a need for change and for growth even at the post secondary level where there is a certain arrogance that exists, one of *all-knower*, based largely on credentials and attitude. Having a doctorate in a particular area means one has much knowledge and experience [is an expert] in that area. It does not, however, insure that one can teach. In fact from my experience I would have to say this arrogance actually shuts down most individuals' openness to constructive criticism about teaching. Many of my colleagues do not take their student evaluations seriously and in fact feel they are not valid given the source; that they should have the right to teach what and how they feel as that is the auspice under which universities operate. I believe this arrogant attitude does a disservice to post secondary education and certainly does not contribute to a good learning experience for the student. I take the negative comments of my student evaluations seriously, not necessarily as failures but certainly as failed reactions in that I failed to connect and engage the student in a positive manner because even though it might not be their favorite area of learning they should still have a positive experience and come away having learned something. Reactions which do not work as expected, particularly if there are continued failed reactions may reveal unexpected results in teaching or learning for the student or the teacher.

The Optimum Environment

Many parameters determine whether a reaction will be successful or not and how long it will continue optimally. Often even the slightest change in a parameter can have a significant impact on the reaction. The slightest change in temperature for example can

have a major impact on the physical state of a compound which can have far reaching implications on its ability to interact with other reactants. pH can affect the conformation of an enzyme such that it can no longer bind to the active site of the substrate and consequently cannot partake in the reaction and as a result no product is formed. Something as simple as dirty glassware can contaminate a reaction causing interference and even failure. But changes in the reactions, sometimes even failure of a reaction are not necessarily a bad thing. Growth, development and learning come often from challenging an "ideal" system. Such challenges to a reaction system require a period of readjustment in which the system reaches a new possibly better equilibrium and a better yield and quality of products. Even failure of a reaction can lead to growth and development when one learns from it.

Bored to Tears

After teaching for twelve years, I am able to walk into any one of my courses and start teaching with little or no preparation. It is a comfortable place to be after many years of having the stress of preparing for a new course, learning the curriculum sufficiently that one is able to proficiently teach it rather than being just one step ahead of the students. And for each course I now have a set of notes that I can grab-and-run with. In fact the other day I grabbed a set of notes for my course, arrived at class with just a couple of minutes to spare, stood at the front of the classroom and began teaching. At the end of the nondescript fifty minutes, as I was packing up my materials, I realized I hadn't even turned the first page of my notes over. Now one could say I was so well versed in the material that I didn't need my notes. True, I suppose, but I honestly couldn't tell you what I had talked about, what I had covered or what I had said. I simply couldn't remember; my mind was blank. I was frightened that my teaching was so ritualistic that it was robotic. What I once found comfort in, the ability to walk into any class able to teach at the drop of a dime, now scared the hell out of me. Why? I realized how bored I was

and that in my memory lapse, my comfort zone had shifted to the uncomfortable. Ritual was replaced by complacency and I no longer cared to become engaged. Something was shifting in my equilibrium of teaching and I somehow needed to find a way of re-establishing an equilibrium. My own teaching reaction was failing.

Behind Closed Doors

I closed the door to my office, tired to the bone and for the first time in my life I didn't think I could go on. I certainly couldn't open the door, put on a happy face and walk down the hall to my classroom yet again. As I sat in my chair watching the river flow by, the geese swimming, bathing, conversing in the daily-ness of their lives, I thought about the daily-ness of my life, my teaching life. Tears streamed down my face and I sat, for how long I don't know, probably only minutes, maybe an hour, it felt like forever. I simply could not get out of my chair. A knock on the door startled me to reality and for the first time in my teaching life, I didn't answer the door.

Understanding Dis/Equilibrium

The ideal reaction is that of the oscillating reaction where the reactants and products are in equilibrium with each other. Even when this happens though, there are many factors that will disrupt that equilibrium so that in order to maintain the synchronicity there has to be continual attention paid to the reaction and continual adjustments made to re-establish the equilibrium when it shifts or fails. My life has been much of a marathon of difficulty, a series of various chemical reactions, some of which are more difficult at times than others. As a marathon runner I have learned that continued training is critical to conditioning so that one has the endurance to pass through various stages to successfully complete a marathon. But like a chemical reaction, there can be a shift in the equilibrium resulting in setbacks and readjustments. I see teaching to be a metaphoric marathon, one that begins in its infancy with a learning curve and that

progresses through various reactions [stages] some significantly more difficult than others, but all that are critical to understanding oneself, one's philosophies and practices about one's teaching. Most often however, coming to understanding is a difficult process, a long journey that involves much self-reflection. I believe all learning and understanding is a reaction mechanism that begins with a question, possibly of something we have observed, possibly of a difficulty, possibly of an experience. Much like a chemical reaction, one asks the questions: What happens when...? What if...? How do I...? et cetera. Moustakas (1990) in his stages of heuristic research says, "within each researcher exists a topic, theme, problem, or question that represents a critical interest and area of search." (p. 27)

I believe coming to understanding of one's teaching and one's way of being is a heuristic endeavor and a mechanism or path of its own. Such a reaction often begins with looking at difficulty or at the very least the questioning of one's current situation, philosophies, way of being et cetera. Sense and meaning-making (Polkinghorne, 1990) is much like researching a chemical reaction, looking at the parameters that affect the reaction and is a progression through a series of stages as discussed in the following sections. Figure 25 is a summary of the stages of understanding or sense-making of the disequilibrium and reestablishment of the equilibrium of the chemical-educational reactions followed by an explanation of each stage of the process.

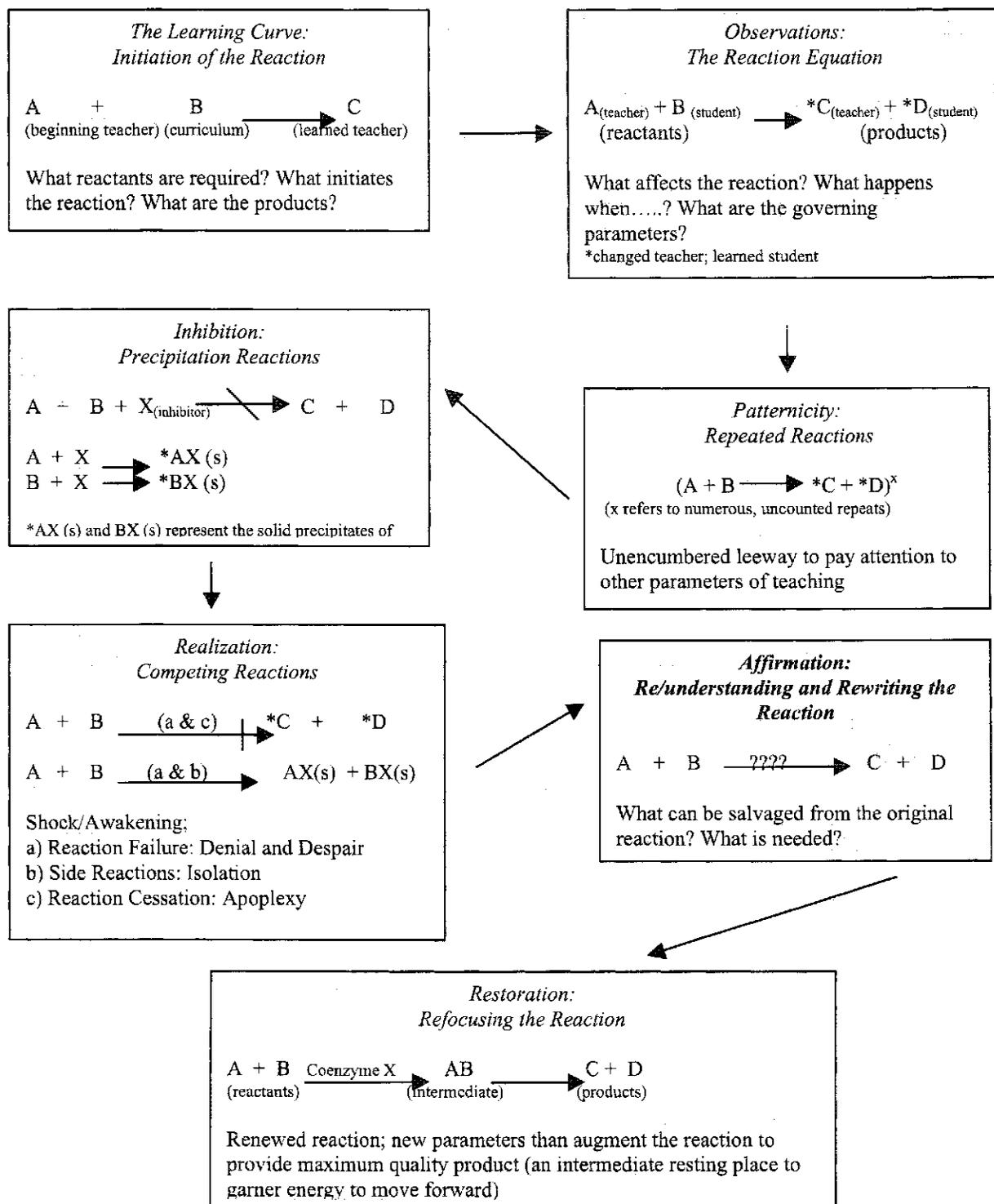


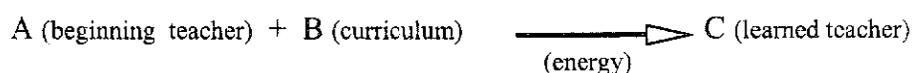
Figure 25. A schematic representation of the understanding of dis/equilibrium

The Learning Curve: Initiation of the Reaction

All reactions begin with an initiation of the reaction, the coming together of the reactants in the appropriate environment. First there has to be a general understanding of the reaction mechanism. What reactants are required? What initiates the reaction? What energy is required? What are the products? Understanding the reaction mechanism and how it is influenced allows the researcher, oneself as is the case in heuristic research or sense-making, to modify the parameters such that there is maximum product formed. This involves much careful qualitative observation.

No matter what the curriculum may be, in order for a reaction to occur the reactants need to be brought together. There is always a *learning curve* for any reaction, the slope of which varies for each participant and is influenced and affected by many extraneous factors [see previous section, Thixotropic analysis] many of which may have a significant impact on both the time and activation energy of the learning curve/process.

The initial stage of learning to teach, much like a chemical process, is an endothermic reaction requiring a great amount of energy [in the form of heat in a chemical reaction and in the form of time and effort in the reactions of teaching] input into the system. The final product is the learned teacher at least such that the teacher is able to teach the curriculum.



But what is a learned teacher? Is it someone who knows the curriculum, someone who can deliver the curriculum, or someone who can engage the students with the curriculum? How does one teach effectively? The more I stay with teaching, the more I find I am

continually questioning and the more I search for answers. Very little of the questioning has to do with the quantitative aspects of the curriculum [the *how much*] and mostly with the qualitative aspects [the *how* and *why*] and the effects of that. More and more they are questions about myself and my engagement in my own teaching and how the impact of that engagement affects my students. Such questions have arisen largely out of my experience of continued teaching--both the positive and negative experiences. Such experiences seem to perpetuate more questions. Like the chemical periodic table, teaching is relational; every aspect interacts and impacts on some other aspect, sometimes positively and sometimes negatively.

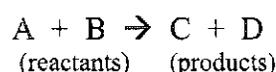
Pinar (1994), in his "*Method of Currere*" written in 1975, talks about the relationship between the "temporal" [short-lived or transitory] process and the "conceptual" [long lived and understood] process when developing a point of view and the possibility of coming to know the *evolved Self* and education. In looking at one's life, according to Pinar, one can look regressively in a linear fashion or look at it from a multidimensional facet, one with many layers and steps [this event has led to that response]. This is analogous to a chemical reaction, where the reaction of chemical species [the reactants] leads to the formation of the products [this event has led to that response], which may further react with other species thus producing further products. How that takes place is greatly affected and may be altered by extraneous factors in the reaction system [see previous section]. Pinar says that if one plots the events, the choices and circumstances [extraneous factors] on a time scale then one is able to describe the sequence of learning [the chemical reaction] with a certain coherence. The point where there is coherence between the temporal and the conceptual is the "biography as it is lived

the "*lebenswelt*" (p. 20). Such lebenswelt is the qualitative description of the reaction: the laboratory notebook in chemistry and the narrative short story in education.

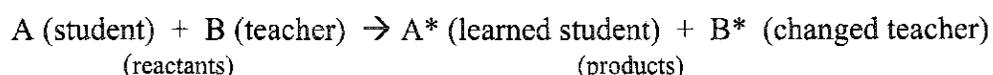
Observations: The Reaction Equation

I think about Fowler's (2003) "*Seven Interpretive Fields of Narrative Analysis*" in terms of the *chemistry of teaching*. The first field, that of *naïve storytelling* of a teaching/learning experience, "requires breaking silence, finding language and voice to (pre) consciously tell an experience, image, event, conflict, or puzzlement about a difficulty that exists in the common world or the private world" (p.167). This is equitable to *initial engagement* in Moustakas' (1990) heuristic research where through self-dialogue the researcher (self) discovers a topic or a question such that "one encounters the self, one's autobiography, and significant relationships within a social context" (p. 27) [much like the relationships of an element with other elements within the social context of the periodic table].

A chemical/educational reaction equation can be equated to breaking that silence and finding the language [the equation itself] to relate a particular experience, image or event [past] or to predict or hypothesize [(pre) consciously tell] about a conflict, puzzlement or difficulty. For example, a general reaction equation might be represented as such;

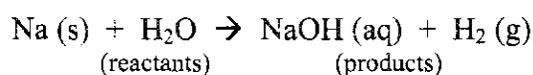


And a general educational reaction might be represented by the equation;



The reaction equation thus allows one to translate the experience or hypothesis into a logical format, something that makes sense. In terms of a story, it is the "underlying theme". The setting down of the story, the actual story of the reaction [the characters/reactants, the setting/environment, the protagonists/inhibitors, et cetera] are all the parameters [factors] that can affect the outcome of the reaction and are not depicted by the bare structure of the reaction equation. It is a bit simplistic in that it tells nothing of the effects of influencing parameters on the overall reaction. Qualitative observations, the note-taking, are critical to truly experiencing and understanding the reaction.

Thus in the learning process it is critical to write down one's observations, all of them no matter how insignificant they may seem to be, because in retrospective (Pinar, 1994) looking back [the analysis] something that seemed to be insignificant or unimportant may be critical to the overall reaction and might be the point of understanding. Unlike naïve storytelling, that might be adulterated with some fiction (Fowler, 2003), one cannot go back and fill in the blanks or fabricate the observations of the chemical reaction. For example, in the chemical reaction of sodium metal with water,



if one did not write down one's observations of the reaction, it would be impossible to know from the reaction mechanism that the sodium metal bounces around sizzling and dancing on the surface of the water rather than sinking to the bottom as might be

expected of a metal placed in water. The heat of the exothermic reaction ignites the extremely combustible hydrogen gas produced which results in the production of a bluish flame and a loud popping noise [proportional to the size of the sodium metal piece used]. The chemistry laboratory notebook is thus a blend of narrative and biography; the lebenswelt (Pinar, 1994, p. 20) and is the naïve story (Fowler, 2003, p. 166). It is a point of initial engagement (Moustakas, 1990, p. 27) allowing the observer to participate in [experience] the reaction. Good qualitative observations provide much information when one is looking back and trying to understand (reflection and praxis) the outcome of a reaction. What are the patterns? How was the pattern changed? How was it broken?

Patternicity: Repeated Reactions

Unconsciousness perpetuates itself. Hence the formation of habit, of habitual responses to seemingly characteristic stimuli, responses that are to varying degrees (we say) adjustive or not. The habitual is the surface is the public, the outer and its strength or force of habit is probably positively correlated with unconsciousness and captured by the past. (Pinar, 1994, p. 22)

The periodic table of chemistry is in itself a relational pattern. Each element within a group [column] of the periodic table exhibits the same reactional characteristics to a more or lesser extent, a pattern that is repeated with every eighth element. This provides some security to performing reactions in that one knows what to expect to some degree as long as the reaction environment remains constant for a given reaction.

This applies to teaching as well. Once the bulk of the learning to teach has been done, and one has a plethora of stories [experience], one arrives at a place of ritual [or habit], a place of comfort considered to be that of discipline, the stage where teaching [lab work] becomes so ritualistic or second-nature that after a period of time one can do it without really thinking about it. This leads to a place of comfort and security in the

knowledge that one can walk into a classroom and teach without much thought, effort or preparation. Much like the periodicity and patternicity [repetition/ritual] of the periodic table, it becomes so familiar and second nature [predictable] that one can carry out the process with one's "eyes closed". This is a good place to be as it allows one to concentrate on the engagement [reactions] of teaching without having to concentrate on the curriculum [the periodic table] as heavily. The researcher or the teacher retreats from the initial engagement (Moustakas, 1990) the concentrated focus or naïve story to a place of comfort where the inner processes are working while outwardly one is engaged in other things. The problem occurs when one forgets the basics such that she becomes so ritualistic there is no longer any passion [chemistry] in it and one is simply going through the motions. It is critical at this point that the teacher change the mix [some variable of the reaction] in order to remain motivated and stimulated [more interesting reactions, the formation of new products]. Much like an oscillating reaction, ritual or stagnant patternicity [the same old reactions] can lead to complacency and boredom, both of which can lead to the lack of desire, lack of focus, lack of engagement and eventually to teaching difficulty [failed or unexpected reactions]. One of the reactants changes or decomposes and the reaction fails or stops.

In looking at one's teaching and arriving at a place of difficulty, retrospective reflection (Pinar, 1994) on the leading events often helps one to distill where the turning point [often lost in the ritual of teaching] was. It is most often a series of experiences [steps] such that the *precipitating* reaction is quite innocuous and unexpected with the reactants being transformed into permanently changed [negative or positive] products. Fowler (2003) talks about *psychological construction* [her second interpretive field] as

including *affect* and *cognition*, a process that examines the knots in the narrative [recognizing/cognition the process to the difficulty/affect]. One could think of such a process as examining the parameters [knots] that affect the chemical/teaching reaction much like the stage of *incubation* in heuristic research (Moustakas, 1990) where it “allows the inner workings of the tacit dimension and intuition to clarify and extend understanding on levels outside the immediate awareness” (p. 29). The ability to rely on the patterned or the known allows one unencumbered time and leeway to ask the persistent and important questions such as: What are the reaction conditions? What are the inhibitors? What are the promoters? What are the contaminants? Such questions provide *openings* for evaluation allowing one to look at what works and what does not. This is particularly important when evaluating difficulty or when change is required.

Inhibition: Precipitation Reactions

In the third stage, inhibition of the reaction occurs particularly when the holding capacity of the solution or individual is exceeded and solubility [focus] is lost. The result is precipitation where things begin to precipitate or fall out of solution resulting in difficulty. This most often happens quite insidiously, much like a sneak attack the result of which is shock, that condition that causes a sudden disturbance to the emotions, a disturbance [surprise] that occurs when one realizes she has lost the desire, lost the passion to do the chemistry [teach]. One might be shocked at her own behavior in the classroom, possibly having done things *out-of-character*. Shock at the realization that one is capable of doing the unimaginable or not doing the imaginable is probably the first time one actually realizes things are not right, possibly even bad, and one is usually taken by complete surprise. While illumination in the heuristic steps of Moustakas (1990) is

considered the more positive of suddenly "getting it", precipitation would be equitable, a "breakthrough into conscious awareness of qualities and a clustering of qualities into themes inherent in the question."(p. 29). This stage requires much reflection in trying to understand the precipitation process.

"Psychotherapeutic ethics", according to Fowler (2003, p. 168) "asks the reader to engage in issues surrounding professional ethics and morality, as each of us confronts our own potential for harm in teaching and research. "In reading and rereading one's narratives or in looking at the reactions of one's teaching self she says, often I am startled by how each story reveals more than I intend about the legislative, executive and judicial branches in the country of my own (teaching) consciousness" (Fowler, 2003, p. 168). She continues, "reflective practitioners need to become knowledgeable about the possibilities of transference, projection, and shadowy behaviors in times of the unexpected or of deep stress."

The shock of precipitation is the awakening stage [the illumination] for which we must pay attention [psychotherapeutic ethics]. Unfortunately such attention leads often to very deep, often negative, precipitating feelings and it is only through reflection and praxis (Friere, 1970) that one is able to make sense of the past. Until that happens, it is difficult for progression (Pinar, 1994) to take place. Like all precipitation reactions, it is difficult if not impossible to go backwards; to get things back into solution. Rather it is easier and often better to salvage what is possible [collect the products and discard the waste] and to move forward from there.

Realization: Competing Reactions

Realization is the arrival at the understanding that one has encountered a place of change, either of difficulty or growth and that one cannot go further without re-evaluating the parameters that have caused the precipitation. There are often conflicting and competing reactions and feelings in this process as one tries to distill what is from what was and what should be. This process of explication in the heuristic sense of the analysis (Moustakas, 1990) tries to understand and explain the meanings behind the reaction. Narrative craft (Fowler, 2003) allows one to look at the competing and conflicting reactions safely, while one hermeneutically uncovers and reveals other interpretations and understandings of the reaction. Such realization and analysis progresses through the following stages.

a) Reaction Failure: Denial and Despair

The shock of precipitation is often replaced by denial, the stage of *this can't be happening to me*. One might deny her own situation, might deny that she has *lost the edge, or lost the focus*. We have all heard of colleagues who have suddenly *lost it*, were wonderful in their day but have *lost their edge*. We have all, as teachers, been in the situation where we have done or said something out of character, been in a situation where we wonder *how did I get here?*; been to the point where we are only going through the motions, where we simply no longer care, where there is no longer any endothermic energy to drive the reaction. At this point the reaction slows such that there is little product formation and eventually it stops.

b) Side Reactions: Isolation

Denial and despair are often coupled with or linked to feelings of isolation, the stage of; *This can only be happening to me. What is wrong with me? No one can find out?* Denial of teaching difficulty and feelings of isolation may lead one to pull away from colleagues so that no one finds out. One suffers in silence [isolation], after all no one wants to admit to being in difficulty; such an admission is commensurate with feelings of failure: *This is all I know. What should I do? Where should I turn? How do I go on?*

c) Reaction Cessation: Apoplexy

The stage of apoplexy is the one of paralysis, the stage of immobilization or the partial, complete, or temporary loss of function; the point where one is at the fork in the road or at the crossroad and is paralyzed [frozen] in the decision of direction. Reflection and praxis (Freire, 1970) are characteristic of the latter parts of this stage. Pinar (1994) describes the progressive phase as the one in which we look the other way. In this stage, we close our eyes and pay attention to breathing and we do it for as long as it is comfortable while at the same time paying attention to its quality and content without forcing the process. We do this for as long as necessary and in a way it is a process of regrouping. We stand still and refocus and like a chemical reaction, we allow it to proceed naturally without interfering and pay attention to the quality and less so, the quantity of product formed.

This is the point where through reflection our narrative craft comes into play, where we refocus ourselves "on those elements of convention, structure and craft which constitute the safe container (temenos) of story" (Fowler, 2003, p. 168). As we regroup,

we can narrate or put into context our story. Thus we place our elements within the periodic table and look at the various reactions that have taken place. This requires that we don a hermeneutic philosophy and look at the messages that might lie beneath the surface of the text and look towards more open and deeper meaning; "careful interpretive exploration of what is "uncovering" and "revealing" returns the reflective practitioner to original difficulties of Being and self" (Fowler, 2003, p. 168).

So we look at the actual chemistry: What is taking place? What are the side reactions/"what other interpretation of the story in question can be provided" (p. 168)? What are the interferences and what are the inhibitors/"what is too difficult to talk about?" (p. 168). What is the ideal environment?/"what is too difficult to hold is of critical interest, as we open ourselves to mystery and play in the community of mortals?" (p. 168). What parameters must be changed so that we maximize the quality and quantity of the yield?

Affirmation: Re/understanding and Rewriting the Reaction

Reflection and praxis (Friere, 1970) coupled with narrative craft and hermeneutic philosophy (Fowler, 2003) the latter part of the above stage, lead to the point of affirmation or predication, admitting and acknowledging there is a problem. This is the beginning of reclaiming of the "teaching self", not in the fashion of one's previous teaching self but in a new light where "one takes photographs and sets them aside" (Pinar, 1994, p. 25) and looks at what is left. It is easier and often better to salvage [collect] what is possible [the good products] and move forward [discard the waste] from that point.

Like most precipitation reactions, one cannot go backwards but one can go forwards or change the patterns. This is often seen in teachers who return to school after

teaching for many years. Affirming there is a problem, that one's philosophies [ideals] have changed and what was once important no longer is leads one to search for something more, another way of approaching teaching, another way of being in teaching, more passion and such a self [teaching] search is the result of an affirmation of the worth of the self. "Curriculum pedagogy," according to Fowler (2003), the "pedagogic phase of research is the site of careful thought about the implication that arise for one's own practice." (p. 169)

Whenever a chemical reaction is modified, whether it is to maximize the yield of a product or to determine the failure of a reaction, only one parameter at a time is modified to obtain the most informed data. If too many parameters are modified at once then it is impossible to distill which parameter is effective and which is ineffective or detrimental to the reaction. As Fowler (2003) says of teaching,

One examines possible explanations and ways of thinking differently about difficulty in teaching. The goal is to find generative lessons from those difficulties. (p.169)

This is the point: to pay attention to how one is thinking about the issues in a story in terms of the foundations, theory, and practice of teaching. Here, one discovers even more about what it means to teach, to be human and to learn. (p. 169)

If we juxtapose the reactions, good and bad, one learns more about the "chemistry of teaching".

Restoration: Refocusing the Reaction

The final stage of teaching difficulty is renewal, a renewed view of teaching born of reflection and praxis (Friere, 1970). Such a renewal of the teaching self is critical to becoming an effective teacher, on with a new, different and renewed focus. This involves

creative synthesis (Moustakas, 1990), the putting together of one's learned and understood knowledge such that it allows one to move beyond restrictions defined by the data itself and open inward reflection in order to reveal the essences of the phenomenon investigated. In the poetics of teaching (Fowler, 2003) it is "the conscious reconstitution of our selves..." (p. 169). It is the refocusing of the reaction, with careful attention paid to the reaction parameters such that the reaction is in continual oscillation. It is the re-establishment of the oscillation reaction at a different [better] level such that the reciprocity and equilibrium continues. And so preparation for the next marathon teaching begins with restored and refocused strength and hope.

The Marathon of Teaching

*The early morning sun lovingly caresses the air,
 Strokes of gold filter through the frosted haze.
 The horizon, a glittering mirage. Hypnotizing silence.
 Running in silence my thoughts swim to the surface,
 Finding a voice they echo in my head.
 My bruised brain argues back,
beginning to think again.*

*There is not a breath of wind,
 My every exhaled breath hangs little clouds in the air,
 like the smoke puffballs my uncle blows to entertain small children.
 Cold aching fingertips, pain interrupts my subconscious. A touch of reality,
beginning to feel again.*

*The blue-glassed river lightly blanketed with freshly fallen snow,
 teased into a kaleidoscope of patterns by the winds of yesterday.
 Steam rises from an open wound in the smooth surface, weeping,
 a glimpse of the life-blood underneath.
 A doe trapped between the encroaching intruder and safety,
 The beauty of the painter's frost-tipped winter landscapes.
beginning to see again.*

*In and out, in and out, slow at first and faster with labor,
 Crisp cold sweet air, devoid of the acrid smells of summer.
 Warmed as it reaches my lungs, fuel to run, to live,
 Without it, death. In and out, in and out. One breath at a time.
beginning to breathe again.*

*The impediment. An insurmountable hill interrupting my journey,
 defying and daring me.
 Legs like lead refuse me. Impotence.
think
feel
see
breathe
The Top.....PASSION*

CHAPTER VIII

EPILOGUE

The periodic table is a unique metaphor for understanding the external and internal relationships of teaching and learning and of education as a whole as it looks both outwards "to manifest the properties of the elements, and inward to some as-yet-unknown atomic property which determined these." (Sacks, 2001, p. 211). It contains the "invisible world" (p. 211) of the educational atoms. At the end of the day, I wonder what happened to my enthusiasm for teaching, my desire to affect change in terms of teaching and engaging authentically. Like a fire, does one's enthusiasm burn hotly for a while and then given the extraneous factors [the reaction parameters] does it exhaust itself, fizzle or burn out and is gone? How does one rekindle the flame? Refuel the reaction of burning; find new sources of fuel? Pinar's *Method of Currere* (1994), the last stage, the syncretical stage, asks the question, "what conceptual gestalt is finally visible?" (p. 27). In other words, what is one's point of view? In trying to understand my own teaching and in developing my own teaching philosophy [point of view], I realize there is considerable difference between "*the world of the curriculum-as-a-plan and the world of the curriculum-as-lived experience*" (Aoki, 1991, p. 9). Aoki calls that gap, or the discrepancy between the two the "*Zone of Between*" (p. 9). What happens in that zone is critical and makes all the difference [in my opinion] in the educational experience for both the teacher and the student. The beauty of the periodic table of education is that it contains both the planned and lived educational matter of the chemistry of teaching and learning.

Precipitating Cations

12 Mg	12 1/ 20 t	20 Ca
Magnesium 24.31	<i>Precipitating Cations</i>	Calcium 40.08

Calcium is the fifth most abundant element in the earth's crust while magnesium is the seventh most abundant element in the earth's crust. Neither are found free in nature and both form insoluble hydroxides with water. Magnesium burns brightly as a white light but goes out rapidly. Calcium also forms insoluble hydroxides with water and has much widespread application due to its high reactivity with common materials. It is a critical component of teeth and bones.

The phone call came in the wee hours of the morning, 3:15 a.m. to be exact. At first I was not sure there was even a person on the other end; there was just silence when I picked up the receiver saying, "Hello."

"Hello," I said into the receiver for the third time. No response. I was about to hang up when a choked, barely audible voice on the other end answered,

"Michelle... This is R. I'm calling to tell you S. won't be in class tomorrow. I'm at the hospital right now but she won't be in. I won't be in either." Confused, wondering why he wouldn't wait until the morning to phone me I asked,

"Are you O.K? What is the matter? Why are you phoning me at this time?"

"She's dead," came the reply.

"Who's dead?" I asked, my stomach contracting.

"S. S is dead. She blew her head off with our Dad's gun tonight. I found her in the bathroom. I tried to hold her but there was so much blood. I wasn't even sure it was her. There wasn't anything left of her face but I knew it had to be her. Who else could it be, right? I just wanted you to know S. won't be coming to class tomorrow. She would want you to know. She really liked you and talked about you all the time. She loved your class and you made a big impression on her." His voice trailed into nothingness and I could hear him trying to gain control on the other end. I was trying to process and listen at the

same time but the processing part wasn't working and my ears were ringing so loudly I could barely hear what R. was saying.

"Where are you R? Can I come and get you?"

"Ah, Michelle. It's really late. I'm O.K."

"No. I don't think you are. Why don't I come and get you and take you home," I said with more firmness. "We can talk if you like. Or not. I think you should have someone drive you home. O.K?"

Only rapid breathing was the answer for a minute, interjected with small moans.

"O.K." came the agreement finally. "I'll wait on the step."

During the drive to the hospital to pick up R. I tried to focus, remember, recall the past weeks. What did I miss? Were there any signs? How did I miss them? I met S. at the beginning of the semester, a shy, nervous girl who sat at the end of the front bench in the chemistry lab. She would watch me like a rabbit and often I wondered what she was thinking. When she had a question, she would always start with,

"I know this is a stupid question...." or "I'm so stupid...", to which I would always say,

"You are not stupid. If you don't know the answer then someone else doesn't as well and, good you, you have chosen to ask. There are no stupid questions." She would most often be the last one out of the class finishing slowly but often just lingering, like she wasn't ready to go home. I caught glimpses of my younger self not wanting to go home, staying behind with Mrs. M., finding a safe haven at school and wondered about S. Her twin brother R. who had been in a number of my courses and who often sat in my office and chatted had a class in the next room and she would wait to catch a ride with him. They seemed to have an amazing relationship and were always together although R. was certainly the more outgoing of the two, not overpowering in the sense of diminishing S. but more in a protective sense. So while she waited, I would chat with her, ask her how things were going. She was shy and timid at first but eventually she began to talk. Her dream was to be a veterinarian, she loved animals and loved nurturing them, fixing them, making things better.

"It's important to make things better," she said to me one day. "Most people don't bother. They damage things and then don't fix them. Sometimes you can't fix them but you should always give it a try" [In retrospect, I wondered if that was my clue?].

I picked R up that night from the hospital and I held him while he cried. "It's my fault," he kept saying but offered no further explanation. I didn't know what to say so I just listened and held him. Eventually I took him home to be alone, something he wanted and needed. "You are amazing, Michelle. S. really cared about you and enjoyed all the time you spent with her. You made a difference for her. Thank you." I had a hard time accepting that in light of the situation, feeling myself like I too should have seen a clue, a sign....something. What precipitated her, caused her to quit, to just give up?

R. and S. were like calcium and magnesium ions, most often found together. S. like magnesium was the smaller of the two and R. always watched out for her. I often marveled at their relationship thinking it amazing. In the human body calcium and magnesium work synchronously together and loss of one eventually leads to non function of the other and affects the system as a whole. Together in nature they contribute to the harness of water when combined with the hydroxide (OH-) ion of water, becoming insoluble and precipitating out of solution, the result of which is the scale that builds up in the kettles and reduces the efficiency of soaps precipitating them out as scum or the films and rings seen in the bathtub. They are made more soluble by the addition of salt such that the chloride (Cl) ion from the salt combines preferentially with the calcium and magnesium making them soluble and keeping them in solution.

Their relationship was very much like that. They were inseparable in a good way in that they worked together rather than one overpowering or controlling the other. I suspect their relationship kept them in solution but the loss of S. caused the precipitation of R. For the next year, I rarely saw R. He dropped out of university and found solace in the bottle. I would often try to connect with him but he seldom returned my calls. And then one day towards the end of the Spring semester I received a letter,

Dear Michelle,

I want to thank you for everything you did for S. and me. You have no idea the anchor you were. S. was in a lot of trouble. We both were. Trouble we couldn't talk about to anyone. But we had each other. Now S. is gone and I have no one,

but I am O.K. I have decided to go into social work or counseling because I think that is where I can make the most difference. I want to help others who are in difficulty before it is too late for them too. First though, I am going to travel for a year and just find myself. I'll keep in touch. Don't worry.

Love, R.

I am not sure I ever felt like an anchor. I certainly suspected something was not right with S. and like me she was a very good chameleon so that on the surface everything appeared to be normal. Like Mrs. M. of my younger years, I felt I shouldn't intrude and I didn't want to project or interject my own experience into something that might be perfectly fine. So I didn't ask. To this day I wonder if that was the right choice. What if I would have asked? is a question that plaques me constantly. I pay more attention now. As a result, I am often criticized by my colleagues for being too soft, too open, too nice; that I leave my door open too much which is why I get all the "difficulties". But to me, even at the post secondary level, attention must be paid to all aspects of a reaction such that intervention by adjusting the parameters might alleviate reaction failure. Like the inter/relational reactions of the periodic table, there has to be a relational chemistry to education aside from just delivering the curriculum.

In bridging the disciplines of chemistry and education, the periodic table is equitable to the "curriculum-as-a-plan" while the actual reactions and inter/reactions of the elements within the table are the "curriculum-as-lived-experience". The discrepancy, or *Zone of Between* is the transition between the curriculum-as-a-plan and the curriculum-as-lived experience (Aoki, 1993). Much like the transition elements of the periodic tables, where there is considerable variability in oxidation state and reactivity, there is much variability in the Zone of Between. In understanding the reactions of both chemistry and education a type of content analysis allows for the generalization of values, histories or kinds of consciousness that characterize teachers. Narratives thus are used as a data source while the authors themselves are consigned to the status of data and thus become

the objects (Grumet, 1990). The hermeneutic process of interpretation therefore becomes the actual process of the chemical/educational reaction, the understanding of the inter and intra/reactions of the elements of the periodic tables.

But still there has to be something more. What is the one thing that drives all reactions, that is the commodity we exchange in order to make a reaction work, to convert the reactants to products? What basic component makes the periodic table work? *The electron*. It is the chemist's glue that holds the whole of chemistry together, the currency of chemistry, without which there would be no re/action or inter/action. More and more I know there are no quantifiable answers to the working of things, teaching in particular. The trends may be present but the success or failure of a reaction is influenced by many internal and external factors and what works in one situation may not work in the next. Teaching and learning is a continual changing reaction in that it oscillates for awhile but an ever-so-slight change in the parameters can have a great impact on the interaction and reaction of the reactants and the outcome of the products. The electron is education, the teaching and learning involved in the whole of education. The observations of the interaction and reaction of the electrons of the elements, the experience, are the narratives of that experience.

The Narrative Elements [Tropes] of the Chemistry of Education

They [narrative codes or tropes] give us a way to explore the qualities of auto-historical and allo-historical curricula that make possible understanding and generative co-dwelling on our shared lands [chemical/educational periodic tables] and languages [chemical/educational reactions] of being. (Fowler, 2003, p. 169)

narrative codes [elements/tropes] serve to bridge figurative understanding across differences, borders and ruptures (p. 169).

Thus such codes can be used to bridge chemistry and education and each narrative code can be simplified into a chemical equation that explains, simplistically, the “story”. Each element within the educational periodic table therefore is a narrative code [trope] that can be used to describe an educational experience [the chemical reactions, the periodicity and patternicity] of that element [the student] relative to other elements within the table [the curriculum]. It is a way of connecting stories [the combining, sorting, movement, exchange et cetera of electrons] and giving voice to the experience of all [good or bad]. “Experience is meaningful and human behavior is generated from and informed by this meaningfulness” (Polkinghorne, 1988, p.1). Narrative, according to Connelly and Clandinin, 1988b, p. 16) is “the making of meaning from personal experience via a process of reflection in which storytelling is the key element and in which metaphors and folk knowledge take their place.” Thus, narrative is “temporal, past, present and future, and, as in all storytelling, is a reconstruction of experience” (Clandinin and Connelly, 1990, p. 245) and are critical data.

Coming Full Circle

Meaning-making, understanding, and re/understanding bring me back full circle, back to the original reaction of understanding my own teaching, this time with a new focus or way of viewing it. When the equilibrium of the oscillating reaction is interrupted there is generally a cessation of the reaction or at the very least a slowing. Sometimes such a disruption can lead to precipitation at the level of either of the reactants or the products. It takes time to readjust or refocus such that the equilibrium can be re/established [to be re-framed] at a new and different level. Sometimes this is not possible to do this and one must salvage that which can be salvaged and move on, try a

different reaction completely. Narrative craft, as Fowler (2003) states "refocuses the author on those elements of convention, structure, and craft which constitute the safe container (temenos) of story. Narrative craft safely holds everything in one place" (p. 168). Sometimes it does require tossing out all the reagents and starting completely fresh and sometimes it is possible, and less costly, to salvage some things, the things that work and only toss out the ones that do not.

Skipping Lessons

19 K Potassium 39.10	19 s <i>Skipping Lessons</i>
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Potassium is the eighth most abundant element on earth, and a large component of the earth's crust. Never readily found free in nature, it reacts readily with water and oxygen and is critical to electrical balance within the body.

"It's easy Mom," she said with five-year-old experience, "all you do is hop and at the same time put one foot in front of the other. Of course you have to be careful not to trip or fall over. But if you practice lots, it gets to be easy and after awhile you can skip without thinking. Come on, give it a try."

Skipping is a way of movement intended for young children, one that projects a happy-go-lucky, carefree image. I learned to skip, as do most young children in my very young, less-encumbered days and I would leap, jump or spring lightly as I made my way to school or the corner store moving along by first hopping lightly on one foot and then the other, my auburn hair making mermaid waves behind me. There is a certain feeling of freedom, akin to flying, in skipping down the street. One feels light, without a care in the world. Unfortunately time and experience have a way of putting lead in one's shoes making leaping lightly difficult to do with any grace and soon one begins to trip over

one's own feet, even losing balance occasionally. Carefree skipping was shelved with age for the more purposeful version of navigation. Actually I am quite an expert skipper/navigator and from much practice can now skip without even thinking. In fact I am very capable of deflecting from the surface anything that might penetrate and cause internal damage. I allow it to ricochet off and in doing so I am quite capable of passing or directing attention, under the veritable guise of care and consideration for others, from myself to another either deliberately or inadvertently thus allowing for the omission of what lies between. I am a seasoned runner but if I look at running honestly, it is an excellent disguise for skipping [to leave or run away from].

I have recently re-visited the art of skipping both the (un)learning and (re)learning of it. Someone central to my core recently said to me, "It is hard to hear you skip," as she listened to my veiled words knowing the in-between. I caught my breath, lost my balance and faltered, one foot not quite making it to the front of the other. Both my mind and heart skipped in fear. Admission was cloaked by the shroud of omission...admission to my own vulnerability, my own limits, my own inadequacies. It scared me that in skipping I was losing the focus. Much like the alkali metals, such as potassium, that sizzle and skip around on the surface, like a drop of oil on a hot griddle, their exothermic reaction with water produces heat resulting in sparking and even ignition of the hydrogen gas produced. Eventually the skipping slows and the product, a base is slowly formed.

I am now (re) learning skipping from my five-year-old who takes my hand coaxing me, a forty-year-old grown woman not to feel silly and encourages me when I get it right, "Way to go Mom! You did it! I knew you could!" Such [Pandoric] encouragement. So now when I skip, it is to leap over my fear trying to land in a new place.

The periodic table is a way of integrating the past with the present, a way of "meaning-making" in the education enterprise and provides a format to predict, based on "experience" [the relationships and inter/relationships], the unknown. Fowler states the "poetics of teaching is a conscious reconstitution of ourselves" (p. 169) much like paying

attention to an oscillating reaction and varying the parameters such that the reaction works at its optimum providing the maximum amount of quality products. We must be continually adjusting the equilibrium so that we do not become complacent and lose focus. Like oxygen we breathe life into our teaching by our continual reconstitution of the self.

A Breath of Life

8 O	8 h
Oxygen 16.00	<i>A Breath of Life</i>

Oxygen is third most abundant element in universe comprising about twenty-one percent of the earth's atmosphere. It is a component of hundreds of thousands of organic compounds, highly reactive and capable of combining with most other elements, and is critical to the survival of most living organisms.

BAM!

BAM!

BAM!

We all looked up, startled, and then at Mr. T. who had the angriest scowl on his face one could imagine. It was obvious whoever had such audacity as to interrupt his class was in big trouble. He marched over to the door and flung it open with a vengeance

"What the..." he began but before he could continue Z. breezed past him to the front of the classroom, taking no notice of Mr. T. standing at door with his arms crossed in anger. Something orange looking like a mop more than a facsimile of his missing hair was perched on his head. He stood on a chair, pirouetted around a couple of times and said,

"So what do you think? Is it me, or is it me?"

Silence. And then a snort and pretty soon we were all laughing so hard even Mr. T. cracked a smile. Then Z. took off the orange spider-mop revealing his bald head with

only a few wisps of hair remaining. "My mom thought I should get it but it makes a better cap than hair. I'll wear it for her though." And then he sat down.

The room went quiet, all of us lost in our thoughts. Z. had a way of facing reality and making each of us do it as well by his raw honesty. He had been diagnosed with leukemia in grade ten and by grade eleven had been in and out of remission twice. In his third attempt at treatment he had accepted that he would likely not make it to our grade twelve graduation; knowledge he shared with us. But he tried to maintain as much normalcy as possible. He came to school every day he could and he worked and studied alongside us. He made it O.K. to grieve and there were many conversations about death, dying and ultimately living. He was open and honest with us about his pain, his fears, and his happiness. He was most concerned about leaving his Mom, a single parent, and he worried about her loneliness but about dying he seemed to have no fear. He saw life in death.

He died in early spring of our final high school year. He was wrong though about not making it to graduation at many levels. Each of us took him in our heart and when the final waltz of the dance came, we passed his picture around and each of us danced singularly with it. We ended the dance with his favorite hymn, Amazing Grace sung acapella at the top of our voices. Z. was like oxygen, he breathed life even in his dying breath.

Reconstituting the self means trying to find the light--the positive in the negative and re-framing or refocusing so that one doesn't spiral down. Re-establishing the equilibrium of the reaction allows one to begin again at a different level, a fresh start, thus allowing for possibility.

A Neon Light

10 Ne Neon 20.18	10 j <i>A Neon Light</i>
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Neon is the fourth most abundant element in the universe. It is highly inert and forms no known compounds. It does however have the capability of producing light and is thus used as a gas in lights.

The first day I met D. she was sitting in the hall outside my lab, her head back against the wall breathing shallowly. I came around the corner in a rush and caught her off-guard. Startled she sat upright, adjusting the clothes that hung loosely on her thin body but not before I saw how blue her face was. Alarmed, I asked,

“Are you O.K.? Are you ill?”

She drew in a breath and using the wall for support stood up. She was much taller than I, very lean and not well-looking.

“I’m O.K., she said. Today is just a bad day. My meds are still being adjusted.

“Medication for what?” I asked, not wanting to pry but feeling compelled to make sure she was O.K.

“I have Marfan’s Syndrome and right now my medication is in flux. I hope they get it fixed soon. I just get tired quickly and I haven’t slept well in a couple of days. I will be O.K. soon.”

“If there is anything I can do in terms of the class just let me know,” I said, “but you take care of yourself first.” I marveled at her strength. Vaguely I remembered learning about Marfan’s Syndrome in my genetics classes that it is an inherited connective tissue disorder that affects many parts of the body and often there are severe heart and blood vessel problems. Those with Marfan’s syndrome are often characteristically tall and thin having slender, tapering fingers, long arms and legs, curvature of the spine and eye problems. I knew heart failure and aneurysms were the typical causes of death at a young age. I also knew that a long life was rare and only in the mildest of cases. D. appeared to be in difficulty to me.

I had D. as a student for the next two years and I was awed not only at her sheer strength and tenacity but mostly at her outlook on life. She would come to class sometimes so blue and breathing with such difficulty I wondered how she did it. Of ten she would miss class or lab but would always come in and make it up, staying late. Her persistence was inspiring and I would stay with her. We had many talks. She was always happy, even on the days I knew she could barely function.

"Every day is a gift," she would say, "Even the crappy ones."

One night I walked out with her, as I often did, to the parking lot, afraid to let her climb the staired hill by herself; she was breathing so shallowly. It was one of those perfect early winter nights...you know the type, the snow falling in big flakes, coming straight down not a breath of wind, the air so quiet you can almost hear the snow falling. She stopped in the middle of the road and just stood quietly breathing, head tilted up to the sky catching snowflakes on her tongue. She looked like she was ten-years-old.

"God is amazing. Imagine...not a single snowflake identical to another, much like people. Can you imagine his capacity, his creativity. Amazing the gift of life, isn't it?"

I stood watching her, this young girl-woman who would likely not see her thirties and certainly not her forties and marveled at her perspective on life. She lived it.

D. graduated with Great Distinction and moved to a larger city to go to Graduate School in medical research much to her parent's concern.

"I want to be involved in finding the answers," she told me. "I might be able to make a contribution some day."

I got the news early one late October morning. D. had been going back to the lab after dinner to check on a reaction and when she hadn't arrived home by midnight her roommate began calling her cell phone to no avail. She was found dead in her car; a heart attack that killed her instantly at the age of twenty-three. Such a short [amazingly full] life.

I went to her Memorial service, something I never do but felt the necessity to. I guess I wanted more, more connection to such a bright and beautiful light. It was held in a small town not far from the city, her town where she grew up. I arrived in what I thought was more than sufficient time and was astounded. It was impossible to get anywhere near the church for more than a four-block radius. There were hundreds of

people [I later heard somewhere around a thousand] and loud speakers broadcasting the service. Like a neon light, D. had touched many people. Her way of being, her demeanor, her ability to make an apparently one-way reaction into an oscillating reaction was a gift few people have but one we all experienced because of our relationship with her. The front cover of her Memorial card was a lighthouse with the sun setting over the ocean and the phrase "in the darkness there is light." Like neon, D. was light.

So in coming full circle, one does not necessarily repeat the same things but looks at the situation with a different light, a different frame of reference, such that one is most often forever changed.

On I/cicles

7 N	7 g
Nitrogen 14.01	On I/cicles

Nitrogen is the fifth most abundant element in the universe comprising about seventy-eight percent of the earth's atmosphere. It has many physical forms and applications. In the solid form it used largely in the fertilizer industry. As a liquid it appears in nitric acid and liquid ammonia. As a gas, it is largely inert and thus has many applications where inert, non reacting gases are required. When cooled in its liquid form, it is a cryogenic that can be used for preserving biological samples, flash freezing and for low temperature experiments. Upon warming to room temperature it evaporates readily into the environment becoming part of the atmosphere.

Icicle (is, ice + gicel, piece of ice) - a tapering, pointed, hanging piece of ice formed by the freezing of dripping or falling water.

On the wall at the back of a coffee shop where I like to sit by the fire and warm my icy fingers, drink a good cup of coffee and sometimes just be, there is the most exquisite photograph of an icicle melting. I wonder at the beauty of icicles, perfectly formed spears of ice-glass anchored in their own identity, independent and unique. How do they form?

Perhaps it is an initial drop wanting to be free but clinging tightly, not able to let go, fear of falling, fear of the unknown, fear of risk, its fear freezing it into place, immobilizing it into rigidity. Deceptively anchored, it grows slowly, not outwardly but downwards, possibly reaching for more, never quite able to attain it.

Or is it is a drop that has managed to extricate itself from the whole, moving quickly away, like a free radical in a chemical reaction, excited by the challenge of freedom, the lure of dreams and desires, until it gets trapped in some unforeseen spot, arrested at a critical point, dreams transposed, becoming falsely complacent, obligation freezing it into stagnation? It grows slowly away from its dreams and desires.

Possibly it is a drop saved in a fall. Other drops coming to rescue it, lovingly and obsessively covering it, protecting it, saving it. The false security blanket of rescue wrapped so tightly it transpires into entrapment. Identity is lost, the soul trapped.

You were a beauty once, not a physical specimen so much as an inner beauty of light and desire for life, love and laughter. A small drop on your own, you were secure in your individuality, private in your inner life. You soared like an eagle, ran like a deer. Life made you laugh.....And then the seduction of the anchor. The freedom of your flight pattern changed, your run became a pace. Bolting was not an option so you became a caged tiger, pacing, pacing...waiting. And then somehow, sometime, somewhere you became an icicle. So slowly at first, you didn't know it was happening although you felt yourself becoming lost in an abyss. You let the tears freeze over your central core, each disappointment or hurt becoming frozen into another layer, each providing a coat of protection. Soon you were encapsulated in your ice-armour, your central core so well protected it was lost somewhere inside, frozen in time. Circumstance was an excuse, life a guise. You became a facsimile of yourself frozen, immobilized by the liquid nitrogen of your life. A prevaricator, it was much easier to keep up the pharisaical image, the central core buried so deep, so protected from the outside extremities, it could only look out through the frosted integument. But the kinetic energy of your inner core was never stilled. It kept moving inside, screaming out at you for freedom, its energy sometimes warming a channel for a tear to escape, trickling down the outside, tickling, tingling, providing the itch you couldn't scratch, reaching the bottom only to be frozen once again,

each tear accumulating, elongating the tip, slowly growing it further away, the protuberance of frustration.

Sometimes the solid-state weight of the icicle is so heavy that even the risk of shattering into a million irreparable pieces can no longer keep it attached. Sometimes it is the slightest of shakes that jars the release, other times it requires the strongest of quakes, but no matter how the icicle is formed, what anchor it has grown from, if it lets go it will fall. The distance and speed of the fall, the layered protection of the ice-armour, the cushioning of the terra firma on to which it lands all determine the remaining integrity. You've experienced the fall, you know the strength of armour required to maintain the foundational structure on impact and you also know if strong enough, layered enough, you are impenetrable, you can withstand any fall with only a repairable chip or two. Resiliency you call it.

And then the unexpected. Possibly there was a crack in the armour allowing in a faint glimmer of light, possibly you didn't have the strength or desire to patch the last chip or crack or simply you didn't expect the warm gentle breeze to blow your way. You most certainly didn't expect the gentle thaw. Initially it was just a slight change in temperature, innocuous warmth, a soft light, a glow on the horizon, refracted through the prism of the outer frost-shield, broken into a multi-colored spectrum, a myriad of color so beautiful it took your breath away. You smiled. It was reciprocated. You cried. And so it began, life from the inside, kindled by the fire of desire and love melting you slowly at first, each layer of vulnerability revealed with reciprocated love and trust, melting the ice, building a different foundation. Gentle streams of water running down, warming as they flowed, rivulets and streams of happiness, life, love, laughter gently tear-dropping off the softened tip. Learning to cry. Trust, belief, desirability, love, friendship, reciprocity, worthiness; dictionary words, such hollow concepts now make sense. You, the writer, have lost all vocabulary as you melt into a pool of water, nourishment, life-force to the garden of ever-changing bloom below, its own myriad spectrum of light and color.

And you know the impossibility of re-freezing a thawed icicle no matter how deep and dark the cold...it has been forever melted.

Each time a reaction [chemical or educational] occurs there is a chance of predictable and unpredictable products. I see education, the teaching and learning, as a chemical reaction, each embedded within the framework of the periodic table, where the reactants are the students and the curriculum, the teacher is the conduit to the product, the learned student [learned curriculum]. How that process occurs therefore can be a positive or negative experience for both the teacher and the student, one that is constantly shifting and that needs continual attention such that the reaction doesn't fail.

There is a chemistry to the education, a periodicity and a patternicity of relational re/actions and inter/actions. The experiences of the inter and intra/relationships of the reactions and the coming to understand how and why they work is metaphorically represented by a *Periodic Table of Relational Education* which is best explained and voiced through qualitative observation and narration.

So in coming full circle I now know that in order to teach effectively at any level, elementary, secondary or post secondary, one has to pay attention to the chemistry of the education, the reactions and inter-reactions at the site of the teacher, the student, the curriculum, and the institution. The Education Periodic Table provides a frame for understanding the reactions and inter-reactions of the constituent elements not only allowing one to understand past and current reactions but also to predict the possible outcome of future reactions. In coming to the end, I have arrived at the beginning, the beginning of understanding the *true* Chemistry of Education. As T. S. Eliot said,

What we call the beginning is often the end. And to make an end is to make a beginning. The end is where we start from. (<http://www.brainyquotes.com>)

We shall not cease from exploration and at the end of our exploring,
Will be to arrive where we started
And know the place for the first time. (<http://www.brainyquotes.com>)

The education periodic table has enabled me to come to know education and understand my in teaching for the first time. It is

neither arbitrary nor superficial, but a representation of truths which would never be overturned, but would, on the contrary, continually be confirmed, show new depths with new knowledge, because it was as deep and simple as nature itself. (Sacks, 2001, p. 211).

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(<http://www.brainyquotes.com>) *BrainyQuotes*.

(http://www.acs.appstate.edu/~davisct/temenos/creation/loiterary_temenos.htm)

Exploring a Literary Temenos.

(<http://memembers.tripod.com/~junojuno2/words.html>) *Montessori Wise Words-Quotes*

APPENDIX A

The periodic table of elements including their element symbol, name and brief description of some characteristics.

Element Atomic number	Symbol	Element Name	Element Characteristic
1	H	Hydrogen	Simplest element; most abundant element in the universe; fuel the sun burns to produce energy; used to make ammonia, hydrochloric acid, methanol and many other compounds
2	He	Helium	2 nd most abundant element in the universe; inert gas and doesn't combine easily; found in sun's gases; used in deep-sea diving or to inflate dirigibles.
3	Li	Lithium	Not found free in nature, used to treat manic depression disorder; used in batteries
4	Be	Beryllium	Transparent to x-rays, used to make windows for x-ray tubes, used in alloys for aerospace; forms poisonous compounds; found in emeralds and aquamarines
5	B	Boron	Used in pyrotechnics to produce green color; used in the nuclear industry; forms several important compounds
6	C	Carbon	6 th most abundant element in the universe, basic element of life and forms the basis of organic life, most versatile element
7	N	Nitrogen	5 th most abundant element in the universe; forms 80% of the atmosphere; production of ammonia, found in the living tissue of plants and animals, critical for life
8	O	Oxygen	3 rd most abundant element in the universe; highly reactive; essential to breathing and life; one of most common elements of every type of chemistry
9	F	Flourine	Most reactive element; cannot be freed from its compounds by any other element; used to help prevent cavities; component of freon used in cooling
10	Ne	Neon	Highly inert; forms no compounds; neon lights; high voltage indicator; refrigeration
11	Na	Sodium	6 th most abundant element on earth; forms many useful compounds; salt; lighting
12	Mg	Magnesium	8 th most abundant element in the universe; most abundant element in earth's crust; used in Epsom salts, fire bombs, mil of magnesia, alloys for airplanes and missiles, essential element in plant chlorophyll
13	Al	Aluminum	Most abundant metal in the earth's crust; never found free in nature, valued for its light weight and malleability,

			used in transportation, cookery, high tension wires
14	Si	Silicon	7 th most abundant element in the universe; 2 nd most abundant element in the earth's crust; found in sand, glass and most rocks combined with oxygen, used in computer chips
15	P	Phosphorous	Found in many commercial products; phosphoric acid; component of soft drinks; used in matches and fireworks
16	S	Sulfur	10 th most abundant element in the universe; forms many compounds; stinks; sulfuric acid; vulcanization – a process that incorporates sulfur into latex to make it tougher
17	Cl	Chlorine	Never found free in nature; combines directly with nearly every element; green, poisonous gas; used as a bleach and a disinfectant to kill bacteria in water
18	Ar	Argon	3 rd most abundant gas in the earth's atmosphere; used as an inert gas; used in lasers, light bulbs, fluorescent tubes
19	K	Potassium	8 th most abundant element on earth; earth's crust; highly reactive; never found free; used to make electric cells and fertilizer
20	Ca	Calcium	5 th most abundant element in earth's crust; reacts readily with oxygen and water, never free; essential element to bones and teeth; used to make mortar and cement
21	Sc	Scandium	Forms alloys with aluminum; used in athletic equipment; rare
22	Ti	Titanium	9 th most abundant element in earth's crust; strong, light metal used in alloys for airplane wings and prosthesis; forms many strong alloys; used as a pigment in paints
23	V	Vanadium	Forms many compounds; corrosion resistant; does not absorb neutrons readily, catalyst
24	Cr	Chromium	9 th most abundant compound in earth's crust; forms many colorful commercial compounds; dyes, photographic film and poisons
25	Mn	Manganese	Nearly 90% is used in the steel industry; important for absorption of vitamin B1
26	Fe	Iron	Cheapest and one of the most abundant metals; essential component of hemoglobin for the transport of oxygen in the blood; steel
27	Co	Cobalt	Widely used to form alloys, used to color many compounds; radioactive cobalt used in medicine
28	Ni	Nickel	Hard, corrosion resistant metal; alloyed with steel; used as a catalyst; electroplating; used in making coins and jewelry
29	Cu	Copper	Used in electrical industry in pipes and electrical wires; resists corrosion; used in coins; used in alloys (bronze and brass)

30	Zn	Zinc	1/3 used in the process of galvanization; used in alloys (brass); many commercial uses
31	Ga	Gallium	Melts at room temperature; one of the largest liquid ranges of any metal; liquid alloys; used in semiconductors
32	Ge	Germanium	Semiconductor industry; transistors in electronic devices
33	As	Arsenic	Occurs free in nature but found largely in minerals, poisonous; used in semiconductors, alloys and fertilizer
34	Se	Selenium	Conducts electricity proportionally to amount of light present; electric eyes; photography
35	Br	Bromine	Only nonmetallic element liquid at room temp.; hazardous; ethylene bromide use in gas; used in dyes, fire extinguishers, smoke generators, photography, and disinfectants
36	Kr	Krypton	Earth's atmosphere; expensive to extract; limited uses; photography – high speed photo flashes, combines with gases
37	Rb	Rubidium	Forms a large number of compounds; many uses; easily ionized; used in photoelectric cells and vacuum tubes
38	Sr	Strontium	Most used in manufacture of color television tubes; used in magnets; fireworks, signal flares
39	Y	Yttrium	Used in making garnets; used to form red phosphor in color televisions, lasers and high-voltage lines
40	Zr	Zirconium	Corrosion resistant; high performance pumps and valves; does not absorb neutrons
41	Nb	Niobium	Used as an alloying agent in stainless steel, to make rocket and airplane engines; jewelry; field of superconductivity; electron accelerator
42	Mo	Molybdenum	Molybdenite often confused as lead; high melting point; used to make electrodes; used to toughen steel alloys
43	Tc	Technetium	First artificially produced element; never found to occur naturally on earth, radioactive
44	Ru	Ruthenium	Used as an alloying agent; added to titanium to make it 100 times more to corrosion; used as a catalyst
45	Rh	Rhodium	Used to make electrical contacts, jewelry, catalytic converters; alloying agent in materials; high precision mirrors
46	Pd	Palladium	Used to make springs for watches, surgical instruments, electrical contacts, dental fillings
47	Ag	Silver	Silver and silver compounds have many uses; pure silver best conductor of heat & electrical; used in jewellery photography, and to make alloys

48	Cd	Cadmium	Poisonous metal so limited use; rechargeable batteries; electroplating; absorbs neutrons; used in paint
49	In	Indium	Used to coat the bearings of high speed motors; electrical; low melting alloys; electrodes
50	Sn	Tin	Resists corrosion & used as a protective coating on other metals; tin can; many alloys
51	Sb	Antimony	Sometimes found free, brittle, poor electrical conductor, used in flame-proofing
52	Te	Tellurium	Semiconductor; used to color glass and ceramics; alloying agent; forms many compounds; used to improve the properties of some metals or alloys
53	I	Iodine	Small amounts required by human body (thyroid); antiseptic nature; poisonous; radioactive iodine is used in treating the thyroid gland
54	Xe	Xenon	White light of strobe lights; used to kill bacteria; power ruby lasers; space probe
55	Cs	Cesium	2 nd lowest melting point of all metallic compounds; reacts violently with water; used as a radioactive element in medicine
56	Ba	Barium	Forms several useful compounds; used in radiology and an opaque liquid for contrast; getter of other gases; used in paint
57	La	Lanthanum	Rare earth element used to make carbon arc lights of motion picture industry; flints; part of the group of rare metal
58	Ce	Cerium	Most abundant of the rare earth elements; used to make carbon arc lights; catalyst to refine petroleum
59	Pr	Praseodymium	Primarily used as an alloying agent with magnesium to make high-strength metals for aircraft engines; forms the core of carbon arc lights in motion picture industry
60	Nd	Neodymium	Used to make flints for lighters; component of didymium glass in welders glasses; used to remove the green color of iron contaminants; added to glass to create violet, red or gray
61	Pm	Promethium	Does not occur naturally on earth; could be used to make a nuclear powered battery or portable X-ray source, provide electricity for space probes and satellites
62	Sm	Samarium	Rare earth element used in carbon arc lights; used in flints for lighters; combines with cobalt to form a powerful magnet with the highest resistance to demagnetization
			Most reactive of the rare earth elements; no commercial

63	Eu	Europium	applications; good absorber of neutrons so may be used in nuclear reactors in the future
64	Gd	Gadolinium	Greatest ability to capture thermal neutrons of all known elements; combines with yttrium to form garnets used in microwave industry; alloys with iron and chromium to make them resistant to high temperature and oxidation; color television industry
65	Tb	Terbium	Used to dope some types of solid-state devices; terbium oxide is a crystal stabilizer in high temperature fuel cells; compounds are used in television tubes and laser lights
66	Dy	Dysprosium	No commercial applications for dysprosium; easily absorbs neutrons and has a high melting point so could be used in nuclear reactors; compounds used in laser material
67	Ho	Holmium	No commercial applications; unusual magnetic properties
68	Er	Erbium	Alloyed with vanadium to make it softer and easier to shape; nuclear power industry
69	Tm	Thulium	Least abundant of the naturally occurring rare earth elements; no commercial application
70	Yb	Ytterbium	Few uses; alloyed with stainless steel to improve some of its mechanical properties
71	Lu	Lutetium	One of the most difficult elements to prepare; no practical uses; can be used as a catalyst in the cracking of petroleum
72	Hf	Hafnium	Good absorber of neutrons; used in control rods of nuclear reactors; HfC has the highest melting point of any two-element compound, alloying agent with other metals
73	Ta	Tantalum	Strong, ductile metal nearly immune to chemical attack at room temperature; drawn into a fine wire to evaporate metals, high melting point; substitute for platinum; does not irritate the body so used in surgical sutures, implants, artificial joints and cranial plates
74	W	Tungsten	Used to make filaments for incandescent light bulbs, fluorescent light bulbs and television tubes; metal and glass seals, target for x-ray production, heating elements in electric furnaces and for parts in spacecraft and missiles that must withstand high temperature
75	Re	Rhenium	Used in flash lamps for photography; filaments in mass spectrographs and ion gauges; most frequently alloyed with tungsten and molybdenum and as a catalyst for olefin; manufacture of lead-free gas
76	Os	Osmium	Primarily used to make very hard alloys; ball point and fountain pen tips; record player needles, electrical contacts and other devices where friction must be minimized; compound of osmium used to treat arthritis

77	Ir	Iridium	Thin world-wide layer in the layer of sediment from the Cretaceous period; proves theory of meteor or asteroid strike on earth resulting in extinction of dinosaurs; used in pacemakers and pen nib alloys
78	Pt	Platinum	Widely used as a catalyst; handwarmers; catalytic converter or exhaust systems
79	Au	Gold	Used in jewellery, dentistry and currency; usually alloyed with other metals; most malleable and ductile of all known metals; electrical and heat conductor; isotope 198 used in treating cancer
80	Hg	Mercury	Forms alloys with other metals called amalgams; poisonous; used to make thermometers, barometers and other scientific instruments; conducts electricity; streetlights, batteries
81	Tl	Thallium	Pure thallium combines instantly with oxygen so there are no uses for pure metallic thallium; used with S, Se or As to form low melting glass
82	Pb	Lead	Soft, malleable and corrosion resistant; shield for X-rays; lead-acid storage batteries; Several lead alloys; forms many useful compounds
83	Bi	Bismuth	Does not occur free in nature; by-product of mining and refining Pb, Cu, Sn, Ag and Au; Mixed with other metals for form low melting alloys
84	Po	Polonium	Discovered by Madame Curie; many radioactive isotopes; eliminate static electricity
85	At	Astatine	Small amounts exist in nature as a result of the uranium and thorium decay; no uses outside of basic research due to small amounts and short half-life
86	Rn	Radon	Radioactive gas found in mines and in the ground; can sometimes seep into homes
87	Fr	Francium	Little naturally occurring; no uses outside basic research
88	Ra	Radium	Discovered by Madame Curie; self-luminous paints for watches, aircraft instrument dials and other instrumentation; used to produce radon for cancer treatment
89	Ac	Actinium	Rare element present in uranium ores in small amounts; no significant applications
90	Th	Thorium	Used as an alloying agent to improve Mg strength at high temperature; used to coat tungsten filaments; has radioactive isotopes; Thorium oxide has many uses
91	Pa	Protactinium	Rare, poisonous and expensive element present in uranium ores in small amounts; due to scarcity, high radioactivity and toxicity no uses outside scientific

			research
92	U	Uranium	Uranium-235 used in nuclear power; fissionable material; dense metal used outside of the nuclear power industry; target for X-ray production; ammunition, radiation shields
93	Np	Neptunium	Extremely small amounts found in uranium ores; no applications
94	Pu	Plutonium	Pu-238 used in radioisotope thermoelectric generators in space probes; Pu-239 modern day nuclear weapons and in some nuclear reactors
95	Am	Americium	Used in smoke detectors and as a portable source of gamma rays.
96	Cm	Curium	Scientists have produced many compounds of curium but it the element has no use outside of basic scientific research
97	Bk	Berkelium	Only small amounts have ever been produced; no known uses outside basic research
98	Cf	Californium	Used as a neutron source to identify gold and silver ores by neutron activation; used in neutron moisture gauges to find water and oil bearing layers of oil wells
99	Es	Einsteinium	Only small amounts ever produced; no known uses outside basic scientific research
100	Fm	Fermium	Only small amounts ever produced; short half-life; no known uses outside research
101	Md	Mendelevium	Only small amounts ever produced; no known uses outside basic scientific research
102	No	Nobelium	Only small amounts ever produced; no known uses outside basic scientific research
103	Lr	Lawrencium	Only small amounts ever produced; no known uses outside basic scientific research
104	Rf	Rutherfordium	Only small amounts ever produced; short half-life; no known uses outside research
105	Db	Dubnium	Only small amounts ever produced; short half-life; no known uses outside research
106	Sg	Seaborgium	Only a few atoms ever made; no uses for seaborgium outside of basic research

107	Bh	Bohrium	Only a few atoms ever made; no uses for bohrium outside of basic research
108	Hs	Hassium	Only small amounts ever produced; no known uses outside basic scientific research
109	Mt	Meitnerium	Only small amounts ever produced; no known uses outside basic scientific research
110	Uun	Ununnilium	Only a few atoms ever made; no uses for ununnilium outside of basic research
111	Uuu	Unununium	Only a few atoms ever made; no uses for unununium outside of basic research
112	Uub	Ununbium	Only a few atoms ever made; no uses for ununbium outside of basic research
113	Uut	Ununtrium	Not yet produced
114	Uuq	Ununquadium	Only a few atoms ever made; no uses for ununquadium outside of basic research
115	Uup	Ununpentium	Not yet produced
116	Uuh	Ununhexium	Thought to be found but claim of discovery later retracted
117	?	?	No name and not yet produced
118	Uuo	Ununoctium	Thought to be found but claim of discovery later retracted