

L=D²C,

RATIONALE AND PROVISIONAL LESSON PLANS FOR LEARNING HIGH SCHOOL
SCIENCE THROUGH DISCOVERING DIALECTICALLY AND CREATIVELY

A Synthesis Project Presented

By

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Critical and Creative Thinking Program

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ABSTRACT

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RATIONALE AND PROVISIONAL LESSON PLANS FOR LEARNING HIGH SCHOOL SCIENCE THROUGH DISCOVERING DIALECTICALLY AND CREATIVELY

May 2007

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A host of studies on students' understanding of science has revealed that persistent topic-specific misconceptions loom over wide groups of learners. However, in the literature, scant consideration is given to high school students' over-arching misconceptions. Those are erroneous conceptions about the nature of science that tend to be resistant even after traditional instruction. Those large-scale misconceptions lay at the frontier of philosophical standpoints and are likely to inhibit students' ability to construct conceptions aligned with accepted scientific views. This synthesis contends that educators can better address high school students' large scale misconceptions at the conjunction of interconnected scientific notions and philosophical praxis anchored in Socrates' dialectics and dialectical materialism.

From Socrates' approach, I borrow and apply adaptively the critical probing and pondering tool that I termed strategic questioning and reflexive thinking. Those categories inform the design of open-ended questions aiming at eliciting learners' reasoning on

natural phenomena. From dialectical materialism, I inherit a philosophy of continually developing and interacting processes punctuated by sudden leaps in nature. This dialectical outlook calls for the exploration of interconnections between contradictory elements of any systems, as one inquires about its wholeness, including its orderly structural patterns and its unforeseen disorderly chaotic behavior. Both dialectical approaches coalesce with pertinent theories of creativity to form an alternative pedagogical framework that I coin “Learning high school science through discovering dialectically and creatively, (L=D²C)”.

The pedagogical model aims at helping high school learners discover scientific notions through authentic experiments undertaken on the basis of critical and creative thinking, and to challenge students’ overarching misconceptions through strategic questioning in the context of epistemological discussions. A methodology and a set of lesson plans integrating physics, biology and chemistry are elaborated to assess the L=D²C effectiveness in the context of a high school science class and to further help in its eventual refinement.

For Marie-Andrée and Joseph-Emmanuel Rene

To Karl and Alex

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CHAPTER 1

INTRODUCTION

In most contemporary societies, science has evolved as the main cognitive factor, shaping human understanding of natural phenomena (Mshvenieradze 1986, 36). Science has also defined the essential features of forces of production upon which sophisticated modes of production have been built, and it has permeated most decision-making processes, epitomizing the very notion of human progress, if any (Noble 1986, 42, Weisskopf 1972, 335, Bernal 1967, 411).

In particular, as humans investigate the fabric of nature and construct bodies of knowledge systematically and rationally, science has defined the standards, the language, and the discursive forms for formulating natural laws and principles. Science has also shaped the elaboration of procedural heuristics and algorithms that further rationalize problem-solving activities. In this process, science has emerged as the main benchmark for thinking schemes in almost all domains of human inquiry (Ganovski 1981, 124-125). Moreover, science, along with technologies, mediates all citizens' interactions with nature and increasingly serves as interface in social relations (Fedoseyev 1981, Weisskopf 1972, 336). But as powerful and meaningful science seems to be, it is in reciprocal interactions with all aspects of social realities, preventing any scientific determinism (Fedoseyev 1981, Givishiani 1981, Cohen 1981, Hanecker 1974, Bernal 1967).

In school systems' frameworks and curricula, the presence of science has been equally pervasive. And, the ongoing debate around issues related to science education, along with incessant pleas for enhanced science curricula, foresees an even greater role

for science in the near future. As science educators attempt to keep abreast with scientific developments, making meaning of various theories and discoveries, they are called upon to reproduce in their classrooms favorable conditions leading to the formation of great minds doing and thinking science (National Research Council 1996, American Association for the Advancement of Science 1993). Consequently, school systems devote a substantial amount of time to science in a bid to convey its fundamental tenets to learners and to formally expose them to inquisitive approaches, as established by standards and frameworks (California State Board of Education 1998; Massachusetts Department of Education 2001). Yet, if dedicated teachers have been successful at helping the few highly performing students chart brilliantly their scientific journey, nevertheless, the nature of science and the meaning of scientific knowledge remain foreign to the majority (Mendelsohn 1981, 6-7, Peters 1982). And students' academic performance along with their level of interest in high school science remains low. Perhaps, a conjunction of different factors -- including students' nonchalance, curriculum choices, educational management styles, shallow educational materials, and teachers' competency -- may account for those alarmingly poor high school results in sciences and mathematics that all concerned educators seem to allude to.

In any case, most stakeholders in the educational system are frustrated in regard to high school science learning. The drawback has been that this alienating experience has further fed the observed trend of students' apathy in science classes (Gilbert 2004, 115) and partly fueled an overwhelming number of misconceptions in science. Many researchers confirm that the phenomenon of scientific misconceptions looms over very large groups of students and deserve significant attention (Peters 1981, Gunstone 1987,

Galili & Bar 1992, Griffiths & Preston 1992, Johnstone, MacDonald, & Webb 1977).

Researchers have particularly addressed a wide range of topic-specific misconceptions in high school and college science with some degree of success. Nevertheless, the growing number of research initiatives to curb the number of students affected by those misconceptions is symptomatic of the increasing significance of this problem.

Obviously, a comprehensive overhaul of the educational system is long overdue. Nevertheless, it is not the aim of this work to undertake such a daunting task. Instead, this work limits itself to the study of the nature of a category of students' misconceptions -- namely students' large-scale misconception -- and the elaboration of a pedagogical framework to tackle them.

As a science and mathematics teacher observing students on a daily basis, I have often noticed that many of the enduring alternative conceptions go beyond the widely studied topic-specific misconceptions that are associated with particular areas of scientific disciplines. Students' thinking patterns exhibit as well large-scale misconceptions in regards to the nature of science. Those large-scale misconceptions could be coined "overarching misconceptions". They are large-scale naïve conceptions that are at odds with mainstream thinking in the scientific community including scientists and philosophers of science but that students use to make sense of scientific approaches, models, and concepts and to construct their own theories.

McComas (1996), a professor of Science Education at the University of Southern California, lists ten "of the most widespread and enduring [large-scale] misconceptions held by students regarding the enterprise of science" that fits well this category of overarching misconceptions. The list includes the following: 1) Hypothesis becomes theories

which becomes laws, 2) A hypothesis is an educated guess, 3) A general and universal scientific method exists, 4) Evidence accumulated carefully will result in sure knowledge, 5) Science and its methods provide absolute proof, 6) Science is procedural more than creative, 7) Science and its method can answer all questions, 8) Scientists are particularly objective, 9) Experiments are the principle route to scientific knowledge, and 10) All work in science is revised to keep the process honest (McComas 1996).

McComas further explains that “misconceptions about sciences are most likely due to the lack of philosophy of science content in teacher education programs, the failure of such programs to provide and require authentic science experiences for preservice teachers and the generally shallow treatment of the nature of science in the precollege textbooks to which teachers might turn for guidance” (McComas 1996). One might postulate that on this basis students’ large-scale misconceptions, which hinder their understanding of sciences, equally stem from those same causes. The problem is compounded by the fact that some science textbooks inculcate many misconceptions and inaccuracies to students, as S. J. Gould, who was a professor of biology at Harvard University, argues (Gould 1988).

From my empirical classroom observation as a teacher, one persistent overarching misconception that students tend to harbor is the one related to accuracy in natural sciences. Conceiving natural sciences as “exact sciences”, they tend to equate scientific knowledge with absolute truth. In their mind, legitimized scientific knowledge is not only correct but also was meant to be definitive. And, as such, scientific knowledge needs not be questioned, particularly in high school. Assertive textbooks that leave no room for doubts and that seem to prohibit any re-thinking and/or revisiting of

accepted notions further deepen the belief in the definiteness and absoluteness of scientific knowledge (Cho & al. 1985). In effect, many students tend to value established scientific knowledge dogmatically.

If anything, of course, the process of science development negates this sense of certainty and infallibility, leaving plenty of room instead for scrutiny of established knowledge, flexibility in thinking, and creative endeavors. Einstein's questioning of Classical Physics and subsequent elaboration of the "Special Theory of Relativity" as a revolution in the structure of physics is one case in point (Knight 2004, 1151, Kuhn 1970). Another convincing example calling for flexibility is the Heisenberg's "Uncertainty Principle". It affirms that, from a quantum physics perspective, our knowledge about a particle is inherently uncertain given the impossibility of knowing well both the position and the momentum of the particle.

If they were to be exposed to the philosophical outlook of dialectical materialism that prioritizes change in nature and in theories about the outside world, students could have cultivated a more dynamic view of science as it interprets nature. Moreover, the influence of the probing aspect of the Socratic Model could have also stimulated students' will to always question theories -- scientific ones or others -- avoiding any dogmatism (or large-scale misconception) about the exactness of science, for example.

When over-arching misconceptions prevent learners from experiencing scientific flexibility, their creativity and critical thinking skills stifle. Conversely, the lack of creative and critical expressions leaves large-scale misconceptions untouched. It is unfortunate that science curricula make no mention of where, how and when students' large-scale misconceptions must be challenged in high schools. Equally unfortunate is

the fact that in the literature, only scant considerations are given to those large-scale misconceptions. Science educators seem to feel pressured to devote much of their class time enticing students to ingurgitate a vast array of established notions from the content area in compliance with their often dictated and detailed scopes and sequences. And, more and more, when additional time is available, teachers feel compelled to make use of it by helping students identify and practice what seems to matter for the successful completion of various high stake tests. In this context, pedagogical pragmatism seems to indicate that issues related to creativity, critical thinking, and philosophy of science must be sidelined in science education.

Little wonder that, from my empirical observation as a public school teacher, I scarcely note practical instructional initiatives conducive to creative endeavors in science classrooms. The teaching and learning have revolved primarily around rigidly predefined experiments and textbook-defined problems that students have to solve according to prescribed schemas and scripts. The apparent justification of such approach would be that the implementation of a curriculum that privileges creative activities could limit the scope of covered materials.

Concentrating on descriptions and demonstrations of established bodies of scientific knowledge, high schools allot no time for the probing of students' large-scale misconceptions and for the blossoming of their creative abilities. Students are expected to master countless notions within rigidly structured class settings that subject them to faithful accounts of established knowledge and that left no room for discussions pertaining to philosophical implications of science. Under such conditions, students can hardly foster critical thinking activities. And they have little interest in investigating

epistemological topics that could help them justify and/or falsify knowledge claims in science, uncover their large-scale misconceptions, and challenge them.

Yet, guideline documents for educators such as Benchmark for Science Literacy (American Association for the Advancement of Science 1993) and the National Science Education Standards (National Academy of Sciences 1995) advocate the integration of meaningful discussions of topics related to the nature of science, inviting students to delve in critical and creative thinking. However, they have not yet bear fruit. For instance, when, in keeping with recommendations of the National Research Council (1996), curriculum based on the inquiry method is introduced in the classroom, the inquisitive nature of the proposed activities does not necessarily give way to enhanced students' creativity. Usually those inquiry methods are pre-constructed laboratory steps leading students to the identification of fundamental notions already established in particular scientific fields. They are then followed by projects that do not necessarily solicit the inventive structures of the brain, challenge misconceptions, and initiate discussions about knowing and the nature of science. These empirical observations have been somewhat corroborated by many researchers, including Eisenkraft (2003) and Davis, Metcalfe, & Williams (1999).

Examining students' large-scale misconceptions, I have come to hypothesize that they lay at the frontier of philosophical worldviews and sciences. Consequently, I aim at investigating ways in which pertinent theories on creativity can combine with dialectical methodologies such as the probing strategies of Socrates' philosophy, and the dialectical materialism. I think that these philosophical currents can advantageously inform

pedagogical strategies in the teaching of sciences because they exhibit strong critical thinking stances and they significantly promote the pursuit of knowledge rationally.

My intent is to construct a pedagogical framework to help students discover scientific notions through authentic experiments undertaken on the basis of critical and creative thinking, and to challenge students' large scale misconceptions through epistemological discussions. This alternative pedagogical approach is defined at the intersection of creativity, science content and philosophical methodologies, including Socrates' dialectics and dialectical materialism.

My motivation to devise such an alternative approach to science teaching takes on even greater significance (at least for me) as it originates as well from my own internal needs to transcend my own unsatisfactory experience with my high school sciences. Indeed, my high school science curricula had failed short of inciting me as a learner to be fully reflective about what I had been learning and provided me with no clear conduit for expressing my creativity and addressing my large-scale misconceptions. My formal training as an engineer/scientist, my Critical and Creative Journey at the University of Massachusetts, and my subsequent readings in philosophy of science have convinced me that science should be taught and learned in high school under conditions that are more in tune with the process of its authentic fabrication (Chalmers 1990) along with epistemological discussions.

This approach, I hope, will not only infuse students with suitable strategies to understand sciences, it will stimulate them to do sciences by discovering knowledge dialectically (critically) and creatively. I termed this pedagogical framework "Learning by Discovering dialectically and creatively, forming the relationship $L = D^2C$."

This synthesis is organized around six different chapters, starting with this introduction in which I lay out the significance of science in society along with its importance in schools' curricula, and pinpoint the issues of misconceptions that are prone to arise from the process of teaching and learning science. In Chapter 2, I review the literature on misconceptions, drawing attention particularly on the pervasiveness and the resilience of misconceptions once acquired. This facet of misconceptions indicates that their eradication requires deliberate pedagogical acts that challenge them. In Chapter 3, I examine Socrates' dialectical philosophy and the principles of dialectical materialism. In particular, I identify their cognitive values and determine their suitability as frameworks of scientific interpretation, their cognitive features and the extent to which they may illuminate teaching and learning of sciences in high school in ways that undermine students' large-scale misconceptions and elicit creativity. This Chapter serves two functions. It primarily conveys the main characteristics of both the Socratic dialectics and the dialectical materialism in relation to teaching and learning of sciences, as I perceived them from the literature review. On the other hand, as an outgrowth of my loving relationship with philosophy, this chapter feeds back into my personal quest for better understanding of the ontological and epistemological aspects of philosophy of science.

Chapter 4 of this work fosters the examination of theories of creativity that relates to the teaching and learning of sciences. It investigates the relation between creativity and knowledge and lays the conditions conducive to creative expressions in high school. It also establishes the foundations to address large-scale misconceptions through creativity as students learn science.

From the fundamental notions that grow out of the literature review, I tentatively construct, in chapter 5, a pedagogical framework for discovering notions in sciences dialectically and creatively. This pedagogical framework purports to convey a pedagogical philosophy and to present a molding device for the crafting of high school science lesson plans. The conjugation of the inquisitive strategies from dialectics and the topics on creativity yields conceptual and methodological tools with which I frame my pedagogical framework, namely $L = D^2C$.

In Chapter 6, I develop a science unit to teach in an integrated fashion specific notions in the content areas of Physics, Biology and Chemistry. The unit investigates the interconnectedness between electricity and magnetism along with the larger connection between scientific fields such as Physics, Biology and Chemistry. The lesson plans are based on the $L = D^2C$, favoring learning and inquiry through dialectical praxis and creativity. Upon successful piloting and refinement, the unit may guide the development of other units and may form the core modules of a proposed one semester elective high school science class patterned on the $L = D^2C$ framework. The proposed class would survey, in an interconnected fashion, scientific fields such as Physics, Biology and Chemistry while challenging various students' large-scale misconceptions and eliciting students' creativity. The ultimate hope is that students who learn sciences within such a framework will be problem solvers, creators and reflexive practitioners.

CHAPTER 2

THE PERVASIVENESS OF STUDENTS' MISCONCEPTIONS

A wealth of studies has demonstrated that a large number of high school students approach science with a lot of mistaken preconceptions about natural phenomena and many do not free themselves from those misconceptions even upon attending university (Henriques 2000, Dermott & Redish 1999, Novack 1987). In this section, I examine the literature on students' misconceptions in sciences from a cognitive perspective.

Students' misconceptions result from non-scientific beliefs and conceptual misunderstandings that learners have acquired over time. Such unfortunate acquisitions, according to Joseph Stepan, professor of Science Education, stem from "innate feelings and perceptions people glean from textbooks, stories, media, and personal experiences" (1996). These alternative preconceptions are seen as misconceptions because they form naïve theories that mismatch with scientifically accepted knowledge (Heller and Finley 1992, Clement 1982). It is particularly in relation to their incompatibility with official trends in science and engineering that, here, those preconceived ideas are termed interchangeably misconceptions, alternative preconceptions, or naïve theories (Clement 1982).

Obviously, such a stance is, epistemologically, science-centered and purports to foster the mechanisms of acquisitions and uses of knowledge from a scientific perspective. Yet it does not intend to undermine the process of deriving "knowledge" from any other human traditions. Indeed, one ought to acknowledge the fact that the quest for knowledge in many other human traditions is as important as in scientific endeavors. The use of the term misconception in reference to ideas and thought processes

that differ markedly with official sciences is only pertinent insofar it stresses my acknowledgement of the privileged status that science enjoys in formal educational contexts and my will to enhance this status through more genuine scientific praxis in our school systems. Such a goal entails a clear understanding of scientific misconceptions' mode of operation and the crafting of suitable frameworks of scientific interpretations.

2.1. The Resilience of Students' Misconceptions

Researchers have observed that, generally, learners remain strongly anchored on the acquired misconceptions even when evidence points to their erroneous stances (Champagne, Gunstone & Klopfer 1985, McDermot 1984). Over time, the misconceptions get woven into new knowledge and build into bigger flawed representations (Heller & Finley 1992). To the extent that most learners cultivate their misconceptions unwittingly, their disinclination toward a scientifically recognized theory is far from being easy to overcome using traditional instructional practices (Gunstone & White 1981, Gunstone, White & Fensham 1988). Heller and Finley (1992: 259) argue that intuitive conceptions are generally rooted on logically consistent reasoning, though they remain at odds with accepted scientific thinking. Similarly, Sneider and Ohadi (1998), citing a series of studies on students' ideas about the earth's shape and gravity (Samarpongavan, Vosniadou & Brewer 1996, Vosniadou 1992, Vosniadou & Brewer 1987, 1992, 1993, 1994), suggest that students' misconceptions are not "simply loosely organized fragmentary ideas, but deeply seated personal theories of the world. However, Engelhardt and Beichner (2003) who also observe the presence of multiple misconceptions following instruction are less categorical. They reason that the pattern of

multiple misconceptions might be due to a “coherent naïve theory of some physical phenomena or a more fragmented and primitive response produced on the spot as a result of the questions posed”.

Either way, misconceptions wrongly provide students with a sense of confidence in their faulty opinions and hamper legitimate scientific learning opportunities as learners stubbornly hold on to their erroneous view, even after instruction (Goldberg & McDermott 1986). Obviously, misconceptions are very likely to give rise to inhibiting consequences in relation to learning. For instance, they tend to interfere negatively with the actual scientific notions that instructors attempt to convey to learners (Sneider & Ohadi 1998). Nevertheless, science educators need not be always doubtful of students’ conceptions. Indeed, as Clement, Brown and Zeitsman (1989) state, “not all preconceptions are misconceptions”. Some students’ interpretations are correct; some are incorrect (Wittmann, Steinberg, & Redish 1999). Obviously, students’ appropriate interpretations of scientific notions are solid foundations with which they should be urged to make meaning out of new ideas and upon which they should be encouraged to construct new and more advanced scientific knowledge. However, students’ erroneous conceptions need to be dealt with. And this does not mean that they should only be seen as negative elements that should be eradicated at any cost. Clement, Brown and Zeitsman (1989) point to the fact that some students’ faulty conceptions can play the role of “anchoring conceptions” upon which successful teaching strategies can be erected. It seems to me that strategic questioning grounded in Socrates’ probing approach (which I investigate in the next chapter) can help identify students’ misconceptions, confront them in regards to their inappropriateness and thereby assist one in engendering a mindset

conducive to one's scrutinizing of one's own knowledge claim and in developing a thrust to further investigate deep-seated views.

Students who harbor misunderstanding in any subject matter are cognizant of both the central aspects of their intuitive conceptions and the peripheral facets of their thinking. (Linn, 1986) The central or hard-core ideas are those ideas that learners persist in believing in, even when evidence contradicting these ideas is available. By contrast, learners express flexibility in their appropriation and use of the peripheral ideas. The research strongly suggests that science learners make use of their peripheral or protective belt of ideas in an adaptive fashion. They might readily change their peripheral ideas, according to Heller and Finley (1992), only in a bid to better defend their hardcore misconceptions. In this context, they provide imprecise and inconsistent notions about natural phenomenon and experiments.

Many studies have inquired about ways to probe and understand students' misconceptions along with their sustained autonomous frameworks informing their natural experience and shaping their conceptualization of the physical world (Sneider & Ohadi 1998, Stepan 1994, Driver, Guesne & Tiberghien 1985). They have investigated specific students' misconceptions in relation to particular areas of Physics, Biology, Earth Science, Chemistry, etc. Examples of particular areas where misconceptions are common include concepts related to mechanics, electricity and magnetism, properties of matter, light and optics, waves and sounds, genetics, evolution, and topics in modern physics. The research has offered insights into cognitive strategies suitable for establishing proper meaning in various instances where intuitive preconceptions have beclouded students' appropriate understanding of scientific notions in those specific areas of physics, biology,

and chemistry, to name a few (Treagust 1996, Chi, Slotta, & Leuw 1994, Mayer 1992). The subsequent pedagogical approaches amount to the production of distinct thinking procedures that might be taught in an attempt to correct targeted misconceptions that had been previously unearthed (Larkin & Reif 1979, Eylon & Reif 1984).

2.2. Exposing Overarching Misconceptions

The line of research targeting specific and localized misconceptions in particular sections of distinct sciences has been crucial in unraveling some of the mechanisms by which misconceptions operate with respect to cognition and their subsequent pitfalls against students' cognitive abilities. The research has also been instrumental in informing curriculum designs and class activities that are of great interest. However, it did little, if any, to address the larger issue of overarching trends of thinking that are at odds with scientific reasoning in general and the framework into which natural phenomena seem to be wrapped (Prosser, Walker, & Millar 1996, Hammer 1994, Reif & Larkin 1991). Among common large scale misconceptions figure ideas such as sciences include the following: the various fields of science are distinctly independent, scientific laws are absolute, scientific results are precise, science make accurate predictions, science is objective and well scrutinized, and science can solve all problems. This list of students' over-arching misconceptions can easily be lengthened, including McComas' (1996) subset of ten typical ones that I log in the introduction of this work.

To a large extent, many of these overarching misconceptions stem from a tendency to comprehend reality on the basis of its appearances, privileging the superficial evidences that strike directly (McCormas 1996). Yet those misleading mindsets are not

largely addressed in the literature. The failure to inquire about wide scope erroneous thinking runs counter to the achievements that have occurred in the fields of science as well as in the realm of thinking process, including critical and creative thinking.

As for our schooling process, it barely pays attention to such issues. Indeed, serving indirectly as breeding ground for overarching misconceptions, science teaching in high school largely disregards reflections about the nature of scientific processes it unfolds, the way of knowing it charts, and the essence of the knowledge it breeds. In addition, the fragmented instructional strategies valued in the praxis of high school sciences neither illuminate the larger issues of meaning making of scientific achievements along with its inherent limitations, nor shed light on scientific methods, nor elucidate the process of creativity. They fail as well to dispel prejudices espoused by students in attempting to grasp natural phenomenon. Owing to “simplistic” worldview, which favors conceptions that interpret things as being static and independent of one another over their dynamic behaviors and systemic connections, those prejudices hamper the formation of sound integrated view of nature (Cornforth 1968). Furthermore, the fragmented instructional techniques of sciences do not suggest any strategy that learners could use to rid themselves of metaphysical ways of thinking.

For one thing, the teaching of sciences in high school ought to be more than simple juxtaposition of known scientific facts along with some demonstrations and/or reproductions of some landmark scientific experiments without serious discussions regarding the limits of such processes of knowing and others. In effect, the limits are as important to ponder as the obvious observations and relevant findings. The importance of the limitative facets of the learning process stems from the fact that they are reflections

of the various levels of imperfections that scientists knowingly or unwittingly generate in any investigative enterprise. Those limits branch off on premises that are necessarily approximate, models that are inexorably reductionist, tools and instruments that are bias by design, and communicative outlets that are intrinsically constrained (particularly symbolic languages, diagrams, and logic rules).

Traditional methods of teaching sciences in high schools ought to be revisited and revised, if we are to form creative scientists and critical consumers of sciences devoid of overarching misconceptions. At the outset, overarching misconceptions need to be addressed right where they manifest themselves, i.e. at the intersection between science and philosophy of science using dialectical approaches and creativity.

2.3. Tackling Overarching Misconceptions Creatively at the Conjunction of Science and Dialectics

By their very nature, the overarching misconceptions appear to reside, as problems, at the frontier of sciences and philosophy of science. These naïve conceptions are scientific problems to the extent that they make erroneous claims in the fields that sciences investigate and they persist even after instructions in sciences have challenged them. They are philosophical issues as well because they arise from particular world outlooks. Consequently, they should be attacked through instructional strategies that allow students to be inquisitive and creative in their study of sciences. Undoubtedly, these assertions beg important questions. Would an approach, rooted in theories of creativity and philosophy of science, address those issues? Even more to the point, could a philosophical outlook, grounded in science and leaving ample room for creativity,

provide us with fitting guiding principles and significant insight to undermine large-scale scientific misconceptions?

Nowadays, as science makes great headways, counting breakthroughs exponentially, science students seem to distance themselves from philosophy. Graham (1972: 431) remarks that “the fashion is to maintain that philosophy has nothing to do with science”. In general, modern scientists tend to express unease with philosophy when practicing their trade. Still, despite this reluctance, during the last centuries a handful of great scientists, extending their thinking to topics and processes that go beyond the daily practice of their sciences, have contributed substantial answers to major questions pertaining to the area of philosophy of science. Among those philosophically inclined scientists we count Boltzman, Mach, Plank, Lorentz, Eistein, and Bohr (Cline 1965). In addition, many philosophical currents appear to model many of their features on scientific methods.

The scientist-philosophers seem to suggest that deep meaning making of scientific notions lay at the intersection of those two domains of human knowledge, namely doing science creatively and reflecting on science in search of greater insight into nature. The famous debate between Neils Bohr and Albert Einstein in relation to the “indeterminacy law”, with high philosophical overtone, in quantum physics illustrates this point (Cline 1965). Also, Levin’s and Lewontin’s book entitled “The Dialectical Biology” (1985) is another case in point. Two self-proclaimed dialectical biologists at Harvard, Levin and Lewontin have attempted to establish a direct connection between their scientific work and their philosophical outlook that is rooted in the dialectical materialism. A great deal of philosophical issues appears to be of interest to many other great scientists.

Discussions among those scientist-philosophers revolve, among other topics, around the role of science, the reality of externality, the problem of causality, the nature of science, etc. one can hence easily make a case for not only the compatibility between science and philosophy of science but also for the imperative necessity to associate the learning of science with such philosophical outlooks for greater insight.

Recently, at the dawn of the twenty first century, Roger G. Newton, a university Physics professor, made a call in favor of “thinking about physics rather than simply doing it” (2000). Obviously, we are still very far from the times when certain philosophical approaches had co-existed almost naturally with sciences. In those days, sciences had had some impact on philosophical outlook, and philosophy, in turn, had informed scientific reasoning and underpinnings. However, the artificial rupture between science and philosophy, which tend to become endemic, should not preclude one from probing both fields of knowledge for possible beneficial liaison that, if made explicit, might lead to greater comprehension of realities, undermining most over arching misconceptions. In particular, if a scientifically grounded philosophy could rationally inform the processes of question posing, hypotheses formulation, and scientific orientation in general, it would certainly be appropriate and necessary for science teachers and curriculum developers to insert such a philosophical perspective at the core of their enterprises. It would equally be important to integrate in the teaching/learning process pedagogical strategies that unearth and enhance students’ creativity and explore issues related to the nature of science as suggested in national educational policy documents (AAAS 1993, National Science Education Standards 1995).

I think that, in educational settings, scientifically inspired philosophy along with activities eliciting creativity can very much shape the scientific mind, in ways that would limit the cultivation of a wide range of misconceptions. If so, then, how would one implement such an approach? And, to what larger effects would one want to undertake such an attempt? It is a quest that I would like to pursue as I endeavor to enhance my intellectual and professional development on one hand, and my science students' practice and thinking about natural sciences, on the other hand.

To the extent that the frames of reference from which we attempt to capture the essence of natural processes significantly influence our comprehension of them, educators ought to scrutinize and assess those frameworks in the context of instructive and learning practices. In light of numerous students' over-arching misconceptions that arise in the process of learning science in high school, educators and students should attempt to comprehend the degree to which their world outlooks and schemes of scientific interpretations correlate to the concrete features of natural phenomenon. More importantly, educators should wittingly choose and expose students to such suitable philosophical frameworks that enlighten learners' scientific comprehension, expose them to the epistemological issues underpinning the scientific enterprise, equip them with methodologies to efficiently probe natural realities, and fuel their creativity.

To the degree that Socrates' dialectics and dialectical materialism, two philosophical currents, exhibit strong critical thinking stances and rational methodologies, I hypothesize that they suit very well a pedagogical framework aiming at achieving the aforementioned goals. In the next section, I review and examine those two philosophies in order to determine elements embedded in them that are suitability for a

pedagogical framework of science and the extent to which they could illuminate teaching and learning of high school science in ways that undermine students' misconceptions and elicit creativity. I intend to investigate Socratic dialectics and dialectical materialism in relation to their ability to facilitate the formulation of questions of scientific interest, to interpret physical phenomenon and to provide a framework to do sciences creatively in high school.

CHAPTER 3

DIALECTICAL PHILOSOPHIES AS COGNITIVE TOOLS IN THE QUEST FOR SCIENTIFIC KNOWLEDGE

3.1. General Overview

The question of knowledge, in some way, underpins most philosophical currents. Sometimes, the philosophical pursuit of knowledge is rooted in approaches that conflict with constructed scientific models. Nevertheless, in a significant number of cases, science, in its diversity, provides the background upon which particular philosophical outlooks claim to be erected. Yet the relationship between a philosophical viewpoint and its scientific source of knowledge is never a one-to-one function, and is far from evolving in a unidirectional fashion. In the bi-directional relationship, philosophical outlooks also inform the process of development of their own scientific sources of knowledge and they investigate issues pertaining to methodologies, interpretations, and representations of natural phenomenon (Cornforth 1983). Sometimes a particular philosophical standpoint might go beyond its source of knowledge to inform this source's inquiry process itself. Among various philosophies of science, dialectical materialism has claimed to have attained this level of synergy interconnecting science and philosophy dynamically. In more general terms, dialectic approaches, such as the Socratic inquiry strategy and the dialectical materialist method, have laid strong claim to the search for truth. Underlying this epistemological aspect that permeates the Socratic discourse, in his introduction to Socrates' dialogues, Grube characterized Socrates' inquisitive conversations as an intellectual pursuit aimed "at discovering the truth, at acquiring that knowledge and understanding of life and its values ..." (Plato 2002, ix)

In this chapter, I review the literature on dialectics in a bid to capture the correlation that can be established between both the Socratic dialectical Method and the dialectical materialism approach, on one hand, and scientific methodologies and realities, on the other hand. Very sensitive to the question of creativity in sciences, I particularly probe the dialectical views in search of cognitive tools to stimulate and enhance students' creativity. From the Socratic dialectics standpoint, I investigate the probing strategy associated with the search for truth. From the dialectical materialist perspective, I explore the attempt to explain the working of internal mechanisms in material realities and the methodology of studying things in their motion and in their change through their autodynamism.

3.2. Defining Dialectics

The category dialectics originates from the Greek word “dialegein”, which means discourse (McKinney 1983:179). The term was coined by Aristotle who credited Zeno as the inventor of the initial method in philosophy. However, over the years, many brands of dialectics have gained credentials. Historically, “dialectics” has referred to two different traditions rooted in ancient Greece. One of those traditions relates to sophism which used rhetorical argumentations systematically to support or debunk discursive stances. The second methodological line of dialectical thinking broadly attempts to unveil truth by capturing the essence of discourses and/or concrete things in strict correspondence with their internal contradictory nature (Ball 1979:786). It is the later dialectical tradition, which entails methodical logical reasoning, which is of interest to us here. In this rational context, the scope of dialectics spans many philosophical variants.

However, the Socratic approach and the dialectical materialism's methodology are only of concern in this work. This limitative aspect does not prevent great insights into dialectics in relation to both epistemological contents and cognitive elements. The richness and thoughtfulness of these philosophical currents along with their ontological postures have made them iconic intellectual achievements. To a large degree they both feature critical elements and discourse that can profitably be adapted to a pedagogical setting aiming at targeting large scale misconceptions, and scaffolding the creative construction of sound scientific notions. Of course, for those philosophical methodologies to be of any value in its making of a pedagogical framework for science, they need to be assessed rigorously and gauged against established scientific knowledge and its shortcomings. One can hence set out to be selective in the methodological elements that one would elect to combine and flexible (i.e. dialectical) in facilitating interconnections and interactions of possibly heterogeneous factors. In this process, critical and creative thinking is the best intellectual compass.

3.3. The Socratic Approach

3.3.1. Question Posing as a Methodological Strategy

Socrates dialectical inquiry revolved essentially around the systematic search for precise definitions of things. Socrates strategically scrutinizes discourses and submits statements to the test of contradictions. The unraveling of any contradiction in the discourse leads to significant learning and further dialogical inquiry. It is thus in the context of thoughtful dialogues, that Socrates circumscribes his pursuit of the "truth" (Plato, 2002). Some may take aim at the nature of the so-called "Socratic Dialogues";

chief among them my CCT colleague Lyonel Prime who in the context of many of our reflective practices on philosophy questions the genuineness of the Socratic encounters. I concur that there is a point to be made about the degree or lack thereof of authenticity of the “Socrates’ Dialogues”, for Socrates’ interlocutors appear to be mostly acting in ways that give Socrates all the necessary latitude to flesh out his philosophical method. Such critics have particular merit when the questions of interest revolve around dialogical processes of the deepest kind one would experience in say Critical and Creative Thinking. Nevertheless, this critical stance should not overshadow the pedagogical methodology at work in those philosophical masterpieces. I intend to elucidate the importance of that teaching strategy in relation to science in the next section.

In its relation to wisdom, Socrates’ epistemology pursues its quest for knowledge from within the individual. Buried in the mind of knowledgeable subjects, there would be epistemological assets that proper questioning would potentially be able to excavate. As such, knowledge proceeds from intangible factors that questioning would set in motion within an interlocutor’s cognitive structures, in connection with his/her devotion to the “Gods” (Plato, 2002, [Euthyphro]). Obviously, his reference to the “Gods” in the search of understanding is of no value to us in our bid to devise a comprehensive pedagogy of science. It can even be counterproductive for it carries an alienating charge. Unequivocally, we reject that aspect of Socrates thinking, but we want to delineate it unambiguously from his strategic questioning strategy. This probing practice that characterizes his search for comprehension and meaning is definitely worth investigating.

Socrates’ search for knowledge progresses through stages of clever and thorough questioning of his interlocutor. In this rigorous logical process, one question leads to

another in expressions of wonder. Primarily, Socrates' questions engage his interlocutor in critical thinking activity as much as they engage him into reflective practices. While his questioning is challenging, the philosopher as a critical thinker does not project himself arrogantly as a master teacher, in spite of his sarcastic tone. On the contrary, Socrates professes to be an ignorant interlocutor, although in reality he probes his interlocutor cleverly. Despite his sarcastic overtone, underneath his discourse there is a foundational humility upon which wisdom and sagacity rest and grow.

Consequently, as much as the initial Socratic questioning claims to emerge out of ignorance, it points to specific answer that embeds some hypothetical propositions, even though Socrates would never offer a specific alternative solution in any situation. Following any interlocutor's answers, Socrates assesses them for consistency by confronting one answer against another, as if the consistency would be the key factor validating them. McKinney noticed that Socrates strategy consists at showing that every definition of a particular concept that an opponent offers contradicts beliefs that he/she expressed in the course of a conversation (McKinney 1983:179). Discoveries of contradictions between statements or propositions are causes for concerns and usually call for a change of discursive path from the interlocutor whom Socrates embarks with subtlety in a pursuit of knowledge. Socrates' strategic questioning compels his interlocutor to confront his flawed views and to pursue better suited understanding of the reality at hand. Not only this dialectical praxis exposes misconceptions it places the interlocutor in position to reassess his preconceptions and to formulate new conceptions on possibly sounder ground than before. The net effect is that the interlocutor's hypothesis is either refined or discarded; the latter giving way to the formulation of a

different one by the interlocutor. And, yet Socrates would further test any other formulation using examples and counterexamples in a bid to highlight inherent logical contradictions in his interlocutor's discourse. In this fashion, this method prioritizes "falsifiability"-- in a Popperian sense (Popper, 1980:23) -- as mechanism to assess propositional statements. A physicist turned philosopher of science, Popper argues that "falsifiability", as a procedure, characterizes the very core of scientific praxis.

Could science educators adapt the Socratic probing method to a comprehensive pedagogical framework of high school science? Precisely, how much would students benefit from strategic questioning that questions the very core conception they have developed in relation to particular domains of scientific knowledge? More importantly, would unveiling contradictions/inconsistencies in students' views compel them to also question their own prior conceptions or misconceptions?

Strategic thinking does not necessarily give rise to a clear-cut dialogic process involving peers. In his "dialogues", Socrates leads the debates. Although he gives the interlocutor the option to state his thesis along with his proof, he then orients the reasoning process toward the falsification of his interlocutors' thesis. The dialogic process seems to lose its momentum at that juncture for Socrates' interlocutor usually is unable "to posit any crucial distinction" and nullify Socrates' objections. Usually, Socrates' interlocutor would be out of arguments to sustain his original premise and would be compelled to modify it along Socrates' suggestions. In the process, the interlocutor's critical thinking skills and reflexive ability tend to sharpen.

In reality, the so-called "dialogues" put in pedagogical situation a facilitator/teacher, i.e. Socrates, in search of some truth and an interlocutor whose mind is

riddled with overarching misconceptions in relation to a particular subject matter. Some might want to take aim at this limitative relationship. However, the method has the merit of engaging interlocutors in guided conversations, whereby the facilitator helps the defender uncover his logically misconceived views and transcend them. Strategic questioning would derive its usefulness in regards to a pedagogical framework from the fact that it provides teachers with a tool to engage students in discussions that can unveil their largescale misconceptions by contradiction.

If sustained, those discussions should unravel the flaws that the misconceptions conceal and guide learners to a seemingly better stance, which in turn should be challenged iteratively until teachers and students reach some suitable degree of satisfaction. If successfully adapted in classrooms, this Socratic probing method -- that I alternatively name strategic questioning -- can incite science learners to be more rigorous and meticulous when constructing scientific meaning. More generally, exposing students to strategic questioning will enhance their critical thinking skills and provide them with the opportunity to be reflexive practitioners.

3.3.2. Ignoring Empirical Evidence

While contemplating the integration of the strategic questioning strategy in a comprehensive pedagogy of science, one ought to establish a clear demarcation between instructional techniques that may facilitate acquisition of knowledge along with challenge to overarching misconceptions and epistemology itself. This cautious stand is important for from a scientific standpoint the idealist nature of the Socratic enterprise is problematic.

In particular, Socrates' ontology makes no connections to the external world and its epistemology remains remote from empirical realities. The supporting premises in Socrates' reasoning being linked to knowledge gained from within the mind, the philosopher has no reference to empirical evidences and inferences based on experimentation (Plato, 2002, [Euthyphro]). So, how is knowledge derived from within, without experiencing or referencing the world out there as a material reality? Socrates does not raise that issue. However, the fact that his line of questioning constantly left him unsatisfied, in that he could never reach the sought knowledge or something deemed to be close to it, makes that issue that more relevant (Plato, 2002, [Apology]).

Even more problematic, at times, Socrates' search for knowledge appears to be a pure academic exercise in logic that can never give way to or unearth pure knowledge. And he seemed to have been cognizant of this fact. As a matter of fact, one can argue further that Socrates remained skeptical about the possibility of achieving truth at all as he seemed to devote his time to refute mistaken beliefs and never attempted to construct a particular body of knowledge. His line of questioning seems to be geared toward proving by contradiction such a view (Plato, 2002 [Euthyphro]).

3.3.3. The Socratic Method versus a Typical Scientific Method

Hence, how can the Socratic Method assist in challenging misconceptions and the learning of sciences, which are devoted to the exploration, understanding, and explanation of real material phenomenon? Comparing and contrasting the Socratic Method and a typical scientific method should unveil ways in which teaching and learning of sciences can benefit from the spirit of the Socratic Method.

At its very core the Socratic model seems to be flawed, in relation to sciences. Its faulty praxis stems precisely from its total lack of reference to empirical inquiries that after all shape scientific enterprises. Its idealistic stance inscribes the search for answers in exercises riveted exclusively in critical thinking considerations, very remote from the objective world. Content-wise, not only it is not equipped to contribute in any way to a comprehensive cognitive method but it might even be counterproductive.

Yet in its quest for knowledge, the Socratic methodology parallels to a certain extent the conceptual steps of the scientific method. In particular, the methodical probing of Socrates, despite its lack of materialist considerations and its scientific shortcomings, can considerably be mapped to some formal aspects of scientific methodologies. Similarly to Socrates' philosophy, science is rooted in wonder and is propelled by curiosity. Typically it proceeds flexibly through steps like question posing, hypothesis, data collection, data analysis, findings, confirmation or rejection and reformulation of the previous hypothesis, rigorous analysis of subjective data in search of contradictions, argumentative assessment, feedback, synthesis, refinement, and some temporary conclusion leading to reformulation of hypothesis. One should hastily point to the fact that those listed scientific tasks need not occur in any particular order during concrete instances of scientific investigations. This word of caution is important because we refute the erroneous view that presents sciences as developing through a unique method that encompasses sacred steps constantly ordered in a particular fashion.

Philosophical thinking rooted in Socrates' method clearly provides analogies to many of the scientific phases. Such model should serve great critical thinking purposes

in the context of a more comprehensive pedagogy of science which purports to address over arching misconceptions that high school learners come to experience. It is particularly suitable to tackle large scale misconception because just like sciences, Socrates' philosophy attempts to critically probe ideas, propositions, statements, and claims for the purpose of meaning making and/or identifying flaws in them.

Both Socrates dialectics and the sciences have consistently submitted propositions to the test of "falsifiability", as understood from a Popperian prism (Popper, 1980:23). For his part, Socrates embeds in his discourse argumentative elements that tend to falsify his interlocutors' assertions in an effort to induce greater critical thinking in the course of a meaningful conversation that he leads strategically.

It is remarkable that the two entities, namely science and Socratic approach, which diverge markedly content-wise, tend to abstractly converge, at the procedural level, towards this very significant point of "falsifiability". The scientific practice of "falsifying" previous propositions embarks scientists in critical thinking journeys that shatter not only views that could have been legitimate but also naively preconceived ones. With Socrates, falsification of preconceptions is a deliberate act that is conducted through strategic questioning in search of some elusive truth. The methodological probing that permeates the Socratic falsification process lends itself very well to pedagogical adaptations that could be aimed at addressing misconceptions in science.

Students who inherit the Socratic questioning strategy and apply it as they do and reflect on sciences should have better mental conditions to dispel large scale misconceptions and activate their creativity through material achievements. That is not

to say Socratic methodology completely matches the spirit of sciences. They are in effect at odds on many points. For instance, contrary to Socrates' philosophy, science scrutinizes the outer world and/or analyzes and validates thought experiments on the basis of past and new material inquiries. In that respect, sciences depart from Socrates' heavy reliance on subjectivity. Furthermore, despite some inherent skepticism that prompts constant revisiting of concepts, relative "scientific truth", even on a temporary basis, is achievable and treated as such, at least, within specific frames of reference, establishing sharp differences with the Socratic philosophical epistemology in which even relative truth seems unattainable.

Still, Socrates' philosophical strategy of raising questions systematically is of paramount importance to teaching and learning science. Perhaps, when transposed to the process of scientific inquiry, the Socratic tradition of questioning conventional knowledge and challenging knowing itself could compel science students to be more rigorous and less pretentious. The exercise in questioning the foundation of all knowledge is the first necessary step students ought to take in addressing their overarching misconceptions, for it helps them set their cognitive processes for reflective practices about knowledge and knowing. Persistent and deep questioning of the Socratic dialectical kind targeting overarching misconceptions compels learners to revisit their naïve representations of realities, exposes flaws contained in their preconceived ideas and invites them to reconsider their thinking. Such a critical thinking process in teaching science is very likely to negate learners' overarching misconceptions.

Socrates uphold three categories that science students should always be mindful of; namely, doubt, strategic questioning and falsification. Each one of those concepts had

at some point in time been central to the discourse of particular scientist-philosophers. Descartes embraced doubt and posited it as an essential methodological component for any inquisitive mind. Einstein assertively presents questioning as one of the core strategy in creative scientific work. The important thing to him is to keep questioning. For his part, Popper makes falsification the leitmotiv of scientific enterprise.

In my attempt to construct a pedagogical framework that helps students learn sciences by discovering dialectically and creatively, it is the methodological formalism of the Socrates' philosophy that is of interest to me. For it may provide critical thinking habits amenable to addressing over arching misconceptions. Nevertheless, the subjective flaws embedded in Socrates' philosophy require the filtering out of its idealistic components and the selection of its probing strategy.

As for the structural basis of my pedagogical framework, it ought to rest on a methodological format that features conceptual tools and theoretical tenets ingrained in the materiality of nature. Dialectical materialism presents those elements and can lend itself to some methodological association with the critical thinking attributes of the Socratic format that are of great interest. In the next section, I examine such perspective as I investigate dialectical materialism.

My option of aligning the particular probing aspect of the Socratic Method with the flexible analytical frames of dialectical materialism might be seen as a daring enterprise for it indicates possible liaison between two philosophical outlooks – idealism and materialism -- that had been at odds historically. In reality, my pedagogical and scientific statements here only pinpoint that -despite obvious disconnects with concrete reality - idealist practice of the Socratic kind may bear significant methodological tools

that can profitably inform materialist thinking process. This approach is not new in itself. For instance, at the very inception of their dialectical materialism, Marx and Engels borrowed the very principles of the Hegelian dialectics brand and aligned them with their materialist view following the debunking of Hegel's idealist premises.

3.4. The Dialectical Materialist Approach to Nature

Dialectical materialism commits itself to reflect on material realities conceived as object developing in complete independence of the mind of the thinking subject and that is knowable (Cornforth 1983:26-27). That is to say, in contrast to Plato's theory of the hidden ideal Form, we can cognitively grasp not only the appearance of things but also we can study their phenomenal manifestations and their internal reality. The thing in itself is investigable and knowable through practice and critical thinking. Hence dialectical materialists feel at ease to claim that dialectical materialism opts unequivocally for substantive inquiries that match the very premises of scientific investigations in general. Cognitively, dialectical materialism sets the stage for inquiry methods that put learners in direct contact with the material world from which they shall derive objective knowledge, undermining particular large-scale misconceptions.

Dialectical materialism urges learners to transcend superficial ideas that they entertain about nature. Dialectical materialism exhibits even greater optimism as it asserts that humans can submit their material world to transformative processes using their creativity.

3.4.1. Defining Dialectical Materialism

The term "Dialectical materialism" synthesizes two worldviews that have at times operated in isolation and at other times coalesced; namely, dialectics and materialism.

Dialectics endeavors to unearth general principles underpinning processes and relationships that define changes in things. On the other hand, materialists stress the existence of an external reality, outside of our thoughts, which they identify as matter. Engels construes matter at two different levels. At one level, Engels denotes an abstract matter, a pure creation of thought, and at another level he identifies concrete matters having respective “qualitative distinctiveness” (Engels 1940, 322). The senses are the inlets that collect and convey to one’s minds, images reflected from concrete matters. Superposing to and interacting with that transmission process, are critical thinking and human ingenuity, which transform the reflected entities into perceptions of particular things.

Our perceptions of objects or natural phenomena do not necessarily reflect their proper/true qualities when they are constructed upon incomplete and/or superficial ideas that are not informed by practice. Perceptions that arise from either pure speculations or defective reasoning are misconceptions that if let unbridled may combine with other superficial thoughts and hamper proper understanding of natural phenomena.

If we can affirm with certainty that erroneous conceptions may take hold in one’s mind, we do not easily know the specific conditions for the existence and sustainability of suitable conceptions. This issue can be a problematic one for it goes into the heart of the question of suitable methodology in knowledge making. And science had not had a unique consensual way to go at it.

With Aristotle, formal logic was deemed to be the art of thinking, which, when properly applied would mediate the acquisition of knowledge. With Bacon, knowledge search and knowledge claim could only be legitimized through experimental method (by

induction). The foundational tenets of knowledge, in this empiricist view, were only properly defined on the basis of experience, which alone could validate or falsify conceptions. With Descartes, methodological reasoning claimed primacy for knowledge search, construction and testing. Knowledge is then achieved by deduction. In the quest for knowledge, such rationalist view regards experience as secondary to reason. With Auguste Comte and his philosophical heirs -- Ernst Mach and Wittgenstein, particularly - sense perceptions became the only permissible ground to construct knowledge and precise thought. The observer, along with his consciousness, becomes the central element of any scientific ventures.

On more pragmatic terms, by the 18th and 19th centuries, most scientists found that the best course of action in the pursuit of truth in nature necessitated some mixture of empiricism and rationalism, without much epistemological thinking. For them our perceptions transform into genuine notions, unraveling features of the external world, when they are molded by experience and guided by methodological reasoning. In this context, at the intersection of experimental method and methodological reasoning, human understanding of natural phenomena achieves some validity. The success of the sciences of the 18th and 19th centuries appears to have confirmed the legitimacy of the tacit consensus among scientists to draw logical reasoning and experience together into the process of scientific inquiry.

Nonetheless, validity embedded in some blend of empiricism, rationalism, and/or positivism does not necessarily approximate to a high degree of accuracy some kind of absolute truth. In other words, the mastery of those practical and rational conceptual tools in the search of knowledge, though somewhat important, does not necessarily cover

the whole spectrum of meaningful variables that enter into play. For instance, by requiring only the fragmentation of phenomenon and discrete investigation of resulting parts, scientists could not say much about complex internal processes and interactions. A philosophical outlook acknowledging the importance of processes and internal interactions as well as external connections is of paramount importance for knowing the big and full picture, so to speak.

Still, interestingly enough, regardless of the era and the paradigm under which science was operating, it managed to formulate theories, to enunciate laws that had had various degrees of validity. And, to a certain extent, regardless of the level of contradictory debate that characterized any scientific epoch, all the great empowering outlooks survived in some fashion. Various groups of scientists still rely on formal or refined versions of logic in their trade; they still hold the view of the experimental method as a foundational element of their enterprise; they still exercise methodological reasoning; and they still exhibit positivist views which narrowly restrict scientific investigations to the observed facts.

In reality, in most cases, pragmatic scientists interconnect those methods and let them interact freely in practical terms, depending on the need of particular investigations at hand. They all seem to have historically been necessary views for scientific advances, but not sufficient ones. In that, they have all failed to account for all reachable aspects of natural phenomena. As a result, inquiries have been limited in nature and in scope; and outcomes have been restricted as well. Narrowness and one-sidedness have triumphed in investigations and in reasoning.

By proposing the investigation of processes, dynamic connections between processes, interactions between coexisting parts within a whole, dynamics associated with the identity formation of a changing whole, and natural transformations of a whole from quantitative categories to new qualitative nature, dialectical materialism offers an insightful multi-layered sophistication in thinking, besides empiricism, rationalism and positivism. In that regard, dialectical materialism parallels the fundamental outlook of the new science of chaos. Hence, with a dialectical materialist outlook one should have a predisposition to pose a wider range of questions in scientific pursuits, and a richer conceptual reference frame for analytical activities. The net outcome might then be better articulated students of nature and greater validity of human knowledge. The production of knowledge would then unfold through an integrated view of nature, one which attempts to grasp the realities at hand with all their complexities and with a method that “combines analysis with synthesis, induction and deduction (Woods and Grant 2002, 81)”.

Engels represents the entire world – natural, historical, intellectual –as processes evolving through internal connections and forming continuous wholes (Engels 1957, *Anti-Duhring*). From a materialist standpoint, Engels contends that understanding adequately the world and making meaning of it should be done in terms of the world itself (Seehan, p.13). Matter should therefore be taken as being anterior to idea and is the primary factor that induces thinking. Still the process of mental thinking features contradictory aspects. It gives way to formation of genuine ideas, whose correspondence with particular aspects of reality has been verified as well as to elaboration of illusory

ideas, which, on the basis of evidence, are at odds with the features of the external world (Cornforth 1983, 64-65).

Thinking that results in deep knowledge, from a dialectical materialist perspective, ought to be rooted in concrete examination of parts, identified processes and relevant interactions forming a whole. Knowledge thus arises and develops on the basis of ideas gathered through practical human association that verifiably reflect concrete qualities of the external world (Cornforth 1983:151). The materialist perspective has brought Engels' outlook, ontologically, close to scientific practices; while its dialectical mechanism has set the stage for more flexible and thoughtful approaches in the establishment of process-based theories.

Dialectical materialism attempts to encapsulate the essence of natural processes into a certain number of principles borrowed from Hegel. They could be interpreted as sound guidelines in shaping learners' mind through the chaotic maze of interconnections and interactions that characterizes the world out there as long as one does not inflexibly consider them as forming a methodological end for- and in-itself, or a close system inapt to any evolutionary processes dictated and powered by substantive analysis of concrete realities. Dialectical materialism needs to be and remain an open system with dynamic feedback mechanisms for self-assessment and further improvements; otherwise, it would become "un-dialectics" and "un-materialist", both epistemologically and ontologically.

3.4.2. Principles of Dialectical Materialism

Dialectical materialism presents a set of overarching principles that appear to be widely verified in nature and that explains natural phenomenon through conceptual terms and explanatory schemes derived directly from science itself. For instance, modern

physics, including relativity theories and quantum mechanics, appears to support the assumptions of objective reality and primacy of matter upon which dialectical materialism is erected. And, just like sciences, dialectical materialism has been able to readjust some of its prior stances.

As it stands presently, dialectical materialism revolves around four major principles, namely:

- 1) Active interdependence of parts of a given reality and predominance of the totality;
- 2) Interpenetration of polar opposites forming internal contradictions that trigger changes;
- 3) Negation of a negation; and
- 4) Transformation of quantitative change into qualitative change.

The three last principles are commonly referred to as dialectical laws of all motion. Engels asserts “the dialectical laws are efforts to describe the most general uniformities in the processes of change that occur in nature.” He adds, “The dialectical laws are the principles by which complex substances and concepts evolve from simple ones” (Engels cited in Graham:1972:52). In actuality, those principles are processes, which entail dynamic operations within matter.

3.4.2.1. Active Interdependence of Parts and Predominance of the Totality

Dialectical materialism asserts that nature and individual objects are not accidental imbrications of elements within isolated and independent phenomenon. An object, seen as a system, interacts with its component parts. In the course of this interactive process, they mutually affect each other. Moreover, apparently isolated

individual objects enter into particular relations with one another as parts of larger systems that equally interact with their parts. To this effect, nature forms an integrated and cohesive whole, whereby objects and phenomenon are organically linked, interdependent, and jointly conditioning each other at various degrees. In life science particularly, this natural interconnectedness prevails (O'Connor 1998). For instance, plants and animals depend considerably on the environment that transform them and that they condition and influence.

In this relational world, parts and whole condition each other's existence and define each other's properties. Self-described "Dialectical Biologists", Levins and Lewontin express the relationship between parts and whole as organic interpenetrations that entail reciprocal transformations. They suggest that parts "acquire properties by virtue of being parts of particular whole, properties they do not have in isolation or as parts of another whole" (Levins and Lewontin 1985:3).

Examples of interpenetrations extend beyond the biological realm to many areas of physical science. Fritoj Capra, an author and a physicist at Berkeley, states well the increasing importance of interactions for the new physics. "The universe is no longer seen as a machine, made up of a multitude of objects, but has to be pictured as one indivisible, dynamic whole whose parts are essentially interrelated and can be understood only as patterns of cosmic process (1982:78)". Newton's third law of action and reaction between bodies (i.e. reciprocal actions or interactions) is a clear illustration of this dialectical principle of interactions. Coulomb's law of interactions between charges illustrates this point as well (Knight 2004). Henry Stapp (1971), of the University of California, also notices ample evidences of interactions in the field of elementary particle

physics (cited in Capra 1982:81). In their book titled Reason in Revolt – and subtitled Dialectical Philosophy and Modern Science – Alan Woods and Ted Grant (2002) offer a host of scientific notions ranging from evolutionary biology to quantum physics and to chaos whose interpretations resonate well with the dialectical materialism paradigm.

Hence dialectical materialism seems to be methodologically justified in asserting that things and natural phenomenon should be studied in relation to their surrounding environment and with regard to their liaison. In this respect, dialectical materialism is in sync with the spirit of natural sciences for the ultimate focal point of every science is the identification and study of relations, especially relations that are embedded within the structural make up of realities.

Interpenetrations are not only observed within particular scientific fields, their scope span throughout nature. Engels, from a dialectician standpoint, construes that the ensuing consequence is that the world has to be studied in function of the correlation among natural phenomenon (Engels 1958). Capra, from a physicist's perspective, claims that nature has to be understood entirely through self-consistency, it “cannot be reduced to fundamental entities, like fundamental building blocks of matter” (1982:93). Just like Engels, Capra emphasizes that the study of natural objects and processes in isolation, apart from their connection with the vast whole is an idealization with only approximate validity. (Engels cited in Graham:52; Capra 1982:55). Validating dialectical materialism from a scientific standpoint, Capra, the physicist, as well as Levins and Lewontin, the dialectical biologists, independently concur that the universe should be interpreted and studied “as a dynamic web of interrelated events” (1982:85-86).

Although many scientific examples tend to corroborate the dialectical relationship between whole and parts in nature, science curriculum in general provides no ways and means to study such interpenetrations and reciprocal transformations, leaving room for misconceptions related to a perceived fragmentation of science to persist. Students scientific thinking will grow in quality and in clarity as they interpret the coming together of parts as inducing new attributes to those parts and imparting to the whole new properties, which are reflected in changes in the parts, and so on” (Levins and Lewontin:1985:3).

The dialectical approach about whole and parts is of utmost importance in addressing broad misconceptions related to fragmented view of the sciences, which divorces with natural interconnectedness that is so pervasive in nature. The dialectical outlook favoring interconnections and particular processes between whole and parts constitute a framework from which reflective activities as well as investigative activities can spring to assist learners in ridding their cognitive mechanisms with the flawed atomistic view. I intend to explore ways to incorporate this dialectical and scientific approach in my pedagogical framework, favoring integrative science curricula in at least one high school science class.

3.4.2.2. Transformation of Quantity into Quality

Dialectical materialism claims that changes condition realities. Initially, internal interactions associated with a process translate into quantitative modification (Ollman 2003, 16-17). However, as quantitative changes proceeds, the internal relations dynamically evolved, setting the stage for an alteration of the very essence of the whole reality. Eventually, if quantitative changes persist, the process reaches a point at which

the very nature of the object is altered causing a qualitative change, as it becomes something else. Generally, the progressive quantitative increase that changes the magnitudes of some parameters associated with the system under investigation does not in itself modify the essence of the thing. Qualitative changes result when a small increase in quantity exacerbates the unbalance (“contradictions”, according to Engels) internal to the object, triggering the rupture of a shaken structural equilibrium. Dialecticians term this process of fundamental transformation, a change of quantity into quality (Engels 1958).

Physics and Chemistry offer a wide variety of examples illustrating this quantitative-qualitative dialectical relationship. For instance, by increasing the temperature of a substance, one can achieve phase transitions among the solid, liquid and gaseous states, and eventually change the substance’s physical and chemical properties (Knight 2004, Davis, Metcalfe, & Williams 1999). Biology as well evidences this quantitative-qualitative dialectical relationship through phase transitions in the underlying physical structures. For example, “enzymes denature at some critical temperature, and the waxy’s molecules of an insect’s cuticle lose their orientation when the temperature exceeds some threshold value, at which point insect’s body rapidly loses water” (Levins and Lewontin 1985, 39). Woods and Grant indicate that continual shifting of magnetic poles and eventual sudden pole reversals are “characterized by a weakening of the magnetic field, [that] culminates in a sudden leap (Woods and Grant 2002, 67).” They interpret this phenomenon as an expression of the “unity and interpenetration of opposites” in nature that gives way to “change from quantity to quality”.

Although actual high school science curricula acknowledge and teach phase transitions in natural phenomena, they fail to engage students in exploring the dialectical significance of such natural mechanism in the working/operation of nature. By ignoring the fundamental generalization of quantitative transformations into qualitative realities, those curricula miss an opportunity to expose students to general properties that could serve as guiding principle in synthesizing and making meaning of natural phenomena. They also overlook a critical notion that could help students defy overarching misconceptions related to “fixedness in nature.

3.4.2.3. Interpenetration of polar opposites forming internal contradictions that trigger changes

The dialectical approach claims that a reality, as a changing entity, undergoes phases driven by internal contradictions inherent to its formation. Contradiction here refers to the incompatible development of different, but dependent, elements within the same relation. Those differences are dynamic because they act on each other and they are grounded on particular variable conditions that influence them accordingly (Ollman 2003, 17).

The law of contradiction is at the kernel of the dialectical method. It entails that the real world intrinsically encompasses opposite poles or even processes that internally shape its becoming. More specifically, it postulates that things change due to internal interactions between their opposite forces (Simon 1979, 474, Cornforth 1960). The interaction between those polar opposites is partly an integrative process. But such integration, resulting from the interplay of opposite forces within matter, is only temporary. The coexistence is far from being harmonious for each opposite element

tends to individually affirm its existence by negating others. The struggle between the opposites represents the internal content of the process of development and leads to changes (Engels 1958). Subsequent to any change, a new opposition of contradictory factors emerges and gives rise to a new integration (Cornforth 1960).

This process of coexisting contradictions evolving into instability repeats itself constantly, for no contradiction is irreducible. This principle of interpenetration of polar opposites can be illustrated with the perpetual struggle between cells dying and cells coming into existence within a living organism, if we interpret this biological fact as death within life and inversely death within life when we account for cells that persist even a living organism is declared dead. Comparing and contrasting electron and positron, Woods and Grant (2002, 64) illustrate the principle of oppositeness and interpenetration in modern physics. They further realize that the phenomenon of oppositeness is pervasive: every particle having its anti-particle, as evidenced by any modern physics textbooks. Indeed, electron contrasts with positron; proton with antiproton; up-quarks with down-quarks; charm-quarks with strange-quarks, etc. Those opposite particles do not have a static existence; on the contrary, they are dynamic entities within “contradictory processes at the subatomic level”; which changes constantly. Modern physics teaches us that contradictions are not only within objects and between particles; they appear also in behavior of natural entities. The unintuitive wave-particle duality illustrates that point. Light, electrons, protons and matter in general display characteristics of both particles and waves. For example, wave-like electron is found in many positions while moving in different directions simultaneously. The theory of wave-particle duality finds its application in quantum-well lasers.

For dialectical materialism, contradictions in natural phenomenon are important because they influence change. Change, in general, is thus, from the dialectical materialist viewpoint, the solution of internal conflict. Nonetheless, this point is perhaps one of the most contentious issues among dialecticians. Professor Gurvitch, a dialectical sociologist, thinks that confining processes within the boundaries of opposing factors amounts to inflating contradictions (“antinomies”) while undermining many other empirical possibilities (Buck-Morse 1977; Jay 1973, 51). On logical grounds, namely logical laws of non-contradiction and of excluded middle, Norman also refutes the idea that contradictions are inherent in things. This stance prompts a debate in which Sayers, in defense of dialectics, affirms that the formal logic laws of non-contradiction and the logical law of excluded middle need not be universal laws that would prohibit dialectical contradictions (Norman & Sayers 1980). Still, Marquit (1990), another self-defined materialist dialectician, continues to opt for the refutation of the concept of contradictions on formal logical grounds arguing for instance that motion does not imply identity of opposites.

However some philosophers think that logical contradiction and dialectical contradiction are essentially two different categories and they need not be opposed to each other, contrary to Hegel’s stance (Schaff 1960, 245). Engels, for instance, does not reject the laws of formal logic that, he claims, do help in the pursuit of the truth as they prohibit inconsistent statements (Crocker 1980, 561, Narskii). Schaff (1960, 241) and Crocker (1980, 560) contend that Engels and Marx differentiated formal logical contradiction from dialectical contradiction, for one does not restrict the other, and they (Marx and Engels) made use of both versions. Schaff further clarifies the issue with two

examples involving respectively opposite poles of a magnet and the motion of negatively charged electrons around a positively charged nucleus in an atom. In both cases, he claims, the coexistence of opposites within uniquely defined realities, illustrating the dialectical contradiction, does not infringe the logical principle of contradiction. Such would have been the case if one were to say that the magnet has and has not a north pole; or that there is and there is not positive electricity in the atoms (Schaff 1960, 244). And that would have been objectionable.

For Gurvitch, the theory of contradictions may have some explanatory power but he asserts that the explanation of complex movements might entail other operating processes of dialectics that are distinctly different from contradictions. In addition to contradictions, he includes, in his tentative list of processes that might explain changes, the processes of: complementarities, mutual implications, ambiguity, polarization, and reciprocity of perspectives. Gurvitch's extended list of dialectical processes, if confirmed by empirical scientific evidences, would open up the array of possibilities dialectical methods would claim to offer in analyzing realities. In the meantime, it seems to me that a model that upholds the coexistence of contradictory elements in nature is a construct that is validated by many objective realities.

3.4.2.4. Dialectical Materialism: Negation of the Negation

According to dialectical materialism, matter not only moves and transforms quantitatively, negating its former state, but it gives rise to the production of still further qualities, thus negating the negation (Somerville 1938, 235). Negation of the negation is intimately linked to the idea that everything changes; "each entity is eventually negated by another" (Graham 1987, 57). Negation gives way to synthesis in nature. The

negation of the negation's principle takes the dialectical thinker deeper into the fabric of nature at a higher level of abstraction. In an effort to limit the level of complexity of my prospective framework, primarily geared toward high school science students, I decide to give scant consideration to this more complex dialectical principle.

It is worth mentioning that the list of "dialectical laws" is hardly exhaustive. As an open philosophical system rooted in change, dialectical materialism ought to expect breakthrough even within its premises and its "laws". However, other than increasing its repertoire of examples justifying its existing laws, it is not clear how anxious proponents of dialectical materialism are to revamp it. It is even harder to identify catalysts that would be intrinsic to dialectical materialism, self-facilitating its regeneration and extending its set of laws. It is no less easy to identify how dialectical materialism can assimilate notions from other philosophy of science for its enhancement. Nevertheless, its close tie with sciences and the fact that it has been quiet successful historically at formulating/reformulating scientific explanations in conformity with its general outlook gives it the advantage of keeping a scientific posture and of aspiring to guide scientific enterprises as well.

Engels contends that the dialectical method offers a suitable model to guide scientific investigation. He argues that "... it is precisely dialectics that constitutes the most important form of thinking for present-day natural science, for it alone offers the analogues for, and thereby the method of explaining, the evolutionary process occurring in nature, inter-connections in general, and transitions from one field of investigation to another" (Cited in Riepe 1958, 241). Not everyone is necessarily convinced of this supposed powerful methodological nature of dialectics. Some even challenge the

dialectics claim to a certain scientific bearing. In the next section, I review the salient aspect of the debate between critiques of dialectics and the refuting arguments dialecticians oppose to them.

3.4.2.5. Challenges to Dialectical Materialism

i). Popper's Suspicion and Challenge to Dialectical Materialism

Perhaps one of the sharpest academic criticisms ever leveled against dialectics came from Karl Popper, a philosopher of science. Popper became suspicious of dialectics in relation to its apparent extraordinary explanatory power within any field it addresses. Popper particularly questions the “incessant stream of confirmations, of observations which ‘verified’ the theories of dialectics” (cited in Cornforth 1968). Although this could be interpreted as strength, Popper asserts, “it began to dawn on me that the apparent strength was in fact their weakness.” (cited in Cornforth 1968) Popper grounded his doubt about and his refutation of dialectics on the fact that its theories fail to satisfy his axiomatic criterion establishing scientific status. Popper's criterion essentially postulates that a theory is scientific only if it is falsifiable, refutable, or testable (Popper 1983, 23). Cornforth, a dialectical materialist philosopher, who acknowledges the importance of Popper's work in the field of philosophy of science, takes issue with the supposed universality of his claim. While he accepts the validity of such a theory in general, he affirms that some powerful and fundamental scientific laws remain “unfalsifiable” (Cornforth 1968, 19). Many laws of physics appear to substantiate Cornforth's claim. For instance, the law of conservation of energy and the law of conservation of momentum are laws that always verify (Knight 2004).

Cornforth, thus, refutes Popper's debunking of dialectics. However, even as he takes the defense of dialectical materialism, Cornforth acknowledges that, as a theory of science, it needs to grow. For example, he concedes that the question regarding the provability of the principles of dialectical materialist remains open, regardless of the satisfactory nature of the evidence favoring the dialectical materialist positions.

Nevertheless, one should point to the fact that the absence of rigorous proof of those principles in itself should not be a cause for discounting them as valid statements. In Mathematics and science, conjectures - i.e. unproven propositions but largely supported by evidence - do serve great purposes at specific points in time and, sometimes, at later time, get proven. Moreover, in science not all so-called "laws" enjoy the higher level of validity that rigorous proof confers. Right on point, Graham captures the fact that not all universally stated relationship in natural science is subject to absolute proof (Graham 1982, 32). Cornforth elaborates as well on this point along Graham's line of thought (Cornforth 1968).

ii). Riepe's Aim of Stripping Dialectical Materialism of its "Fundamentalism"

In contrast to Popper's severe criticism and rejection of dialectical materialism, many authors who are critical of it still depict some of its aspects as worthy of consideration. For instance, Riepe acknowledges the validity of the so-called law of transformation of quantity into quality. He further thinks that the other two laws – laws of contradictions and negation of negation - have had some heuristic value. Nevertheless, he portrays them as being loosely stated without, unfortunately, describing their alleged flaws. He claims that they need not be considered as valid descriptions of natural phenomena without considerable qualification (Riepe 1958, 242).

Still, Riepe seems to value the attempt of dialectical materialism to construct a unity of knowledge, just like he appreciates the fact that “the logical empiricist has tried to construct, if not to find, a unity of language about science” (1958, 242). He, however, thinks that for dialectical materialism to have heuristic value, it should rid itself of its fundamentalism, develop and alter itself “along lines suggested by complementary philosophies relevant to the scientific outlook” Riepe coined the term “flexible scientific naturalism” to name his ensuing reformulation of dialectical materialism (1958, 241). In his view, flexible scientific naturalism could embody facets of two contending outlooks, namely dialectical materialism and logical empiricism in a humanist context (Riepe 1958, 244).

If Riepe’s proposed model does not clearly lay out a mechanism for implementation, it has the merit of pointing out the road to flexibility. The flexibility of this approach would stem from the fundamental premise, which postulates that scientific naturalism is a model open to change dictated by objective reality and the advancement of other philosophies of science. In addition, it should legitimize any question. Such a system, Riepe thinks, should promote creativity for the material betterment of mankind within the constraints of the scientific method and historical materialism. (Riepe 1958, 246)

Riepe’s suggested model is refreshing for it runs counter to the “dialectical dogmatism” that prevailed in the application of dialectical materialism to various areas of sciences during the 1930’s and 1940’s in the Soviet Union during the so-called Lysenko affair (Graham 1992). It seems to me that many attempts at guiding scientific practices in the 30s by dialectical materialism shed considerable light on some difficult scientific

problems. However, the dogmatism that permeated the Lysenko project grew to overshadow the initial creative venture. As in everything, while dogmatism ensured the strict interpretation of dialectical principles in approaching nature, it also inhibits to a large extent, the creative potential that could activate its growth (Graham 1972; Seehan 1985, 19).

While inflexibility is not ingrained in dialectical materialism as a philosophy, proponents must always be mindful of the fact that whenever openness to original and conflicting ideas is absent, dogmatism may prevail, inhibiting creativity. In the interest of its development dialectical materialism ought to affirm its flexibility. Such acquired flexibility generally opens methodologies to the necessary creative perspectives, but it does not uniquely defined creativity.

iii) Dialectical Materialism as an Instrument of Critical Thinking

The American geneticist, H.J. Muller, paraphrasing Lenin, strongly pointed to the fact that “all the facts of daily life, as well as those of science, together form an overwhelming body of evidence for the materialistic point of view. And he added, “therefore we are justified in our further scientific work, in taking this principle as our foundation for our higher constructions” (cited in Graham 1972, 46-47). Engels himself construed his “dialectical laws” as solid building blocks of his philosophy of science, for, he wrote, they are “derived from matter itself, not thought”. He argued, they are “not the starting-point of the investigation, but its final result; they are not applied to nature and human history, but abstracted from them; it is not nature and the realm of humanity which conform to these principles, but the principles are valid in so far as they are in conformity with nature and history” (Engels, *Anti-Duhring*, cited in Graham 1972, 34).

Indeed, one of the most salient aspects of dialectical materialism is its constant reference to scientific considerations and examples in attempting to validate its claim. Obviously, dialectical materialism needs science for its very existence but it also claims to provide an interpretative framework that can guide science itself. As a philosophy of science, dialectical materialism engages in an epistemological quest for a conceptual framework to understand, define, explain, and explore nature.

Dialectical materialism presents itself methodologically as an enhancing tool for science in general. But it has also swayed in the direction of science. In crafting most aspects of their philosophy, it is to natural sciences that dialectical materialists systematically turned to for testing materials and illustrative examples. This dependence on science does not prevent dialectical materialism to be critical of science at times. It is a relationship of adherence with and, simultaneously, a corrective attitude toward science that dialectical materialism sustains.

Yet in its relation with sciences, dialectical materialism has had also a critical overtone, questioning some of their interpretative approaches. It has also challenged, at least epistemologically, certain fundamental aspects of predominant scientific methods. For instance, in place of the fragmented view that science has embraced uncritically to comprehend nature, dialectical materialism has suggested an approach that systematically prioritizes interactions between the parts and the whole and interconnections between various aspects of a same reality.

Such a critical thinking conduit is amenable to thoughtful discussion about science that can pave the way toward unraveling and debunking of commonly held overarching misconceptions about sciences. In conjunction with strategic questioning,

the critical thinking aspects inherent to the dialectical materialism can efficiently address students' large-scale misconceptions and helps the rigorous learning of sciences.

It is precisely because it provides a systematic interpretation of nature using scientific notions, a critic of science itself, and because it aims at de-alienating social subjects from any alienating aspects of scientific applications, that dialectical materialism can evolve as the methodological thread of a pedagogical framework to interpret and teach sciences in ways that would rid students of overarching misconceptions about science.

One could be tempted to ask whether another philosophy of science could equally or better serve this purpose. This question would be legitimate for important aspects of philosophies of science during the nineteenth and twentieth centuries have been developed by highly praised thinkers such as Mach, Carnap, Popper, Kuhn, Lakatos, Wittgenstein, and Feyerabend whom are not part of the dialectical materialist current. However, Sheehan notices that none of those mainstream thinkers have developed a system of thinking about science as comprehensive as dialectical materialism. (Sheehan 1985) Moreover, she asserts that many of the themes that those thinkers have dealt with have received some deeper treatment within the dialectical materialism framework (Sheehan 1985).

For instance, looking at Wittgenstein's work, Sheehan argues that long before him, earlier dialectical materialist thinkers along with James and Dewey "understood that experience came already clothed in language; that meaning could only be understood in context; that no logical formalism could substitute for the real flow of actual experience." Assessing Kuhn's achievements, Sheehan claims that long before him, dialectical

materialist philosophers “knew that science was a complex, social, human activity; that it was a process characterized by both evolutionary development and revolutionary upheavals.” Examining Popper’s achievement, Sheehan noticed also that long before him, dialectical materialist practitioners, “spoke of the role of guessing in science; they criticized the view that science was a matter of straightforward induction and saw the part played by hypothesis and deduction”. Sheehan further points to the fact that the dialectical materialist tradition, among others, “understood far better the relationship of the history of science to the history of everything else”. And they, she adds, have positioned “science within a much wider socio-historical context than did Kuhn and his successors” (Sheehan 1985, 4-5).

Graham, who is far from being a dialectical materialist, further noticed that given its universality and degree of development “the dialectical materialist explanation of nature has no competitors among modern systems of thought.” He adds “one would have to jump centuries, to the Aristotelian scheme of a natural order or to Cartesian mechanical philosophy, to find a system based on nature that could rival dialectical materialism in the refinement of its development and the wholeness of its fabric” (Graham 1972, 430).

Yet dialectical materialists still have to develop and demonstrate particular instructional strategies to implement cognitive activities dialectically. Then it will be important to evaluate and revise them for further improvement in educational praxis.

Dialectical materialism presents itself as a meta-science aiming at unraveling and explaining general processes, inner relations, and general dynamical behavior of matter under any condition in a bid to enlighten individuals and undermine the sources of

erroneous interpretations of nature. Despite its limits, this comprehensive critical thinking system, which has evolved out of modern materialism endowed with dialectical principles, has gained great intellectual clout and is seen by some as having “an important educational or heuristic value” (Graham 1972, 430). Its main principles potentially represent guiding compasses for a high school science class that purports to address learners overarching misconceptions and broaden their horizon about relationships between processes in nature.

Yet, despite its wholeness, dialectical materialism can beneficially be complemented by other academic contributions. Particularly, theories of creativity can easily be incorporated in dialectics and strengthen the dialectical outlook on science. As it stands presently, dialectical materialism provides no discussion on creativity, let alone a cognitive strategy to explain creativity in general and to induce creative activities in a classroom in particular. The importance of creativity in science classrooms stems from the fact that science is ontologically a creative enterprise. Hence, its teaching can only be complete when the pedagogy scaffolds the learning experience toward the attainment or enhancement of learners’ creative potential in science. For science teaching to be successful, it ought to be done in ways that tap on students’ creativity and that engage them into producing creative work.

iv) A Theory of Creativity: The Missing Link between Dialectical Materialism and the Praxis of Science

Graham notices that more than any other philosophy of science, Engels’ dialectical materialism emerges as a comprehensive reflection on science and it evolves as well as a tentative guide for science. Still, however insightful this guide might be, it is

far from being complete and definitive. Perhaps, the absence of a theory of creativity in science within dialectical materialism's large body of knowledge is the greatest sign of its incompleteness. Proponents of natural dialectics have failed to characterize the features of dialectical creativity, its relations with sciences in general, and its mode of operation.

However, outside of the dialectical tradition, there exists an impressive literature on creativity. Some of these theories may very well complement dialectical materialism advantageously upon examination. To this effect, in the next chapter, I review the theories on creativity. Eventually, I hope to integrate suitable aspects of the findings on creativity within the dialectical methods in Chapter 4.

Insofar as creativity is an invitation to reformulate conceptions, to discover new relationships, and to initiate new practices, it – creativity - might very well be, in conjunction with dialectics, an empowering tool for the eradication of scientific misconceptions. That creativity is at the kernel of scientific enterprises in the real world, it is a fact that certainly supports such contention. Hence as I endeavor to develop a science curriculum that can tackle existing large-scale misconceptions and prevent the formation and burgeoning of others, I will devote considerable attention to creativity and leave enough space for it in my lesson plans.

Those two dialectical approaches are neither perceptibly synchronized nor do they operate under the same premises. However, as dialectical approaches, intersecting at the level of critical thinking, they share cognitive interests and develop cognitive mechanisms that probe contradictory factors immanent in/to real situations/realities and they share epistemic factors to understand those realities. In that respect, they seem to exhibit characteristics worth examining in a quest for an efficient science curriculum for

high school. Furthermore, to the extent that real science strongly correlates with creativity, any pursuit of a suitable framework of scientific interpretation has to investigate the research on creativity and ways in which it can blossom in science students. My overall plan is thus to shape an educational outlet inviting learners to learn sciences the way scientists do sciences and to reflect on sciences the way philosophers of sciences do.

CHAPTER 4

ON CREATIVITY

There exists a large body of research on creativity outside the dialectical tradition, but not necessarily at odds with dialectics' premises. As a matter of fact, dialectics can incorporate in its core many of these notions on creativity and it can in turn inform our quest for a greater understanding of creativity. To this effect, I review the research on creativity and discuss ways in which particular instructional strategies aligned with the research can be brought together with the combination of the two dialectical approaches that I prioritize in Chapter 3. It is my hope that such an attempt will facilitate the cognitive process in high school environment and enlightened students' creativity when it shapes science curriculum and lesson plans.

4.1. Cognitive Approaches to the study of Creativity

It is a rather difficult task for cognitive psychologists and other brain scientists to explain the exact building blocks and specific combinations of factors that generate creative processes. Indeed, no real dominant paradigm on creativity has emerged from the literature. Nevertheless, researchers have investigated many characteristics of creative cognitive processes and the impact that certain influential factors - such as knowledge, environment, and motivation - have on creativity. Although contradictory statements largely characterize the literature, it is instructive to review it for it offers significant insight that can beneficially shape pedagogical approaches for high school science. This review of the literature on creativity specifically explores creativity in relation to novelty and past, the impact of knowledge on creativity, the impact of the

cultural environment on creativity, and the effects of personal traits and motivation on creativity.

4.2. Creativity: Novelty and Past

In the western tradition, researchers generally define creativity as the ability to generate a product or a solution characterized by novelty, usefulness, and appropriateness (Mayer 1999; Boden 1999; Lubart 1999). Lubart depicts it as a product-oriented and originality-based phenomenon. Most creative achievements in sciences like chemistry and biology reflect this view. Examples in artistic activities like painting illustrate this view as well. Nevertheless, creativity can also be the utterance of a new idea, which may be far from actual implementation. Notions that Einstein enunciated in relation to general theory of relativity years before scientists could devise plans to implement them come to mind. In any case, whether it manifests itself in the realm of concrete products or rests within pure ideas, creativity is primarily anchored in newness.

However, researchers are at odds insofar as creative expressions and practices are concerned. Some researchers claim that creativity can be expressed by nearly anyone while others argue that, in any specific field of knowledge, only an elite group of people can detect creatively connections that are not apparent to most indifferent individuals.

Newness portrays a rupture with certain aspects of a past pattern, or with a whole paradigm, and yet it contains some elements of this past. This somewhat dialectic embodiment of the past within the new suggests that the new conceptualization rests as much on new insight as on certain aspects of prior knowledge and past achievements. In some way, the appropriateness of an original idea or product stems from the fact that it

prolongs ingeniously some aspects of past knowledge or accomplishments, as it departs from other aspects of that past, and incorporates new features into the emerging reality. However, how much prior knowledge is necessary to stimulate creativity? Answers to this important question differ and fuel considerable debates.

4.3. The Effect of Knowledge on Creativity

Many researchers contend that prior knowledge informs and shapes creative enterprises. However, some researchers discover a tension between knowledge and creativity (Campbell 1960). For instance, De Bono (1973) reasons that too much experience in a domain may undermine creativity, for old patterns, stereotyped views and scripts may inhibit the production of new and original ideas. Campbell sides with research that relates knowledge and creativity with a so-called U-shape model. In a given domain, this model pinpoints the attainment of creativity at a threshold level where previously acquired knowledge is significant but far from being complete.

Nevertheless, some researchers rebut the tension view and argue in favor of the foundation view, claiming a direct relation of proportionality between creativity and knowledge. They assert that creative work results from deep domain-specific knowledge that experts acquire as they immerse deeply into a field of endeavor over many years. This necessary but insufficient condition for notable creative contributions implies deliberate practices that translate into a process of thorough preparation, aiming at mastering complex skills and internalizing the established knowledge in the discipline. Deliberate practices involve learners' dedication to structured academic tasks and critical thinking under the clever guidance of a committed tutor providing timely feedback.

Within this theoretical framework, too much practice does not preclude one's accomplishment.

Research that underlies the strong correlation between expertise and creativity suggests that creativity can only be domain-specific (music, literature, science, etc). It affirms that rarely one would be able to reach the level of expertise that can bear creative thoughts in many unrelated domains. Moreover, researchers who link creativity with high level of expertise claim that it is attainable uniquely by very few exceptional people (Feldman et al. 1994; Simonton 1997, 1999). Great scientists who construct important paradigm shifts would for instance fit that distinctive category of creative minds. There is an elitist tone to this theory that views creativity as the reserved domain of an exclusive group of highly gifted individuals who possessed greater brain power and intelligence than most others, including all lay people and nearly all professionals.

However, other researchers relate creativity to ordinary thinking. As such, they spot the possibility for creativity throughout daily problem solving activities. In this context, creativity is broadly conceived as the agent causing some original changes in a reality or phenomenon. It does not necessarily imply great paradigm shifts. Yet it does involve cleverness and practical intelligence.

Researchers differ on many more aspects of creativity, "approach" being an important one. Matlin (2002, 388) reports two main contrasting approaches to creativity, namely Guilford's divergent production (1967) and Sternberg & Lubart's multiple necessary component of creativity (1995). Guilford's work characterizes creativity in terms of specific attributes associated with divergent thinking that can be measured. He

particularly points to fluency (total number of relevant responses), flexibility (number of different categories of relevant responses), originality (the statistical rarity of the responses), and elaboration (amount of detail in the responses). Essentially, he suggests that varied responses to specific test item should be evaluated rather than one single best answer. Many contemporary researchers still tend to investigate creativity within this framework (Barsalou & Prinz, 1997; Mayer, 1999).

However, Matlin notices that while the divergent model devises an “objectively scorable assessment device”, its selected measurable attributes fail to capture the concept of creativity (2002, 389). Particularly, Matlin stresses the fact that researchers identify]. Criticizing this theory, many researchers stress the following flaws: a) moderate correlation between people’s test scores and other aspects of their creativity (Guilford, 1967); b) little correlation between various measures of divergent production (Brown, 1989); and c) slight correlation between the measures and other ratings of creativity (Sternberg & O’Hara, 1999).

A competing approach to the divergent theory is the investment theory of creativity. Sternberg and his colleagues, who initiated this theory around the mid 1990s, argue that creative people “buy” or pursue ideas that have minimal appeal, sell them high in the aftermath of their creative venture and move on to another creative undertaking (Sternberg & Lubart 1995, 1996; Sternberg & O’Hara, 1999). This theory locates the emergence of creativity at the confluence of internal and environmental attributes. Creativity, it suggests, is a function of the interplay of intellectual resources -such as intelligence, knowledge, motivation- an encouraging environment, an appropriate

thinking style, and an appropriate personality. The investment theory of creativity alleges also that interactions between components may amplify creativity many fold.

The proponents of the investment theory of creativity assert that some components might have to be at least within some thresholds for creativity to blossom, regardless of the level of development of other components. Knowledge would be the most sensitive one. The theory seems to opt for a balanced view regarding knowledge. It suggests that too little as well as too much knowledge could be an inhibiting factor for creativity. Without sufficient knowledge one may not be able to pose a problem or understand its dimensions. However, under the influence of extensive knowledge, experts may over-stress top-down processing and may be unable to overcome mental fixedness in order to pose a problem from a different and original angle (Sternberg & O'Hara 1999, 389).

To be sure, no matter how innovative one can be, one stands on the attainments of others. Even greatest scientists of the caliber of Galileo, Newton, Darwin, and Einstein are no exception. No one can claim to have created something totally new or generated some fully unique idea from nothing. However, the issue regarding how much knowledge one should acquire before one can become creative remains contentious. Equally debatable is the question concerning whether or not creativity can be exercised as inexperienced learners search for knowledge. Still, regardless of the inconclusive nature of the research, from a teaching standpoint, one needs to define the contour of a practical educational space that would be conducive to the expression of creativity in science classrooms. I intend to delve into such venture upon examining the impact of cultural environment and motivation on creativity.

4.4. Personality Traits, Motivation and Creativity

Although creativity is, to a great extent, socially determined, it is, at its inception, an individual expression in a particular domain, stemming from individuation. This entails thinking processes, activities and behaviors that run contrary to a majority view (Maslach 1974; Sternberg & Lubart 1995). The creative individual features traits ranging from perseverance, tolerance of ambiguity, to risk taking (Lubart 1999).

Moreover, the research points to the fact that creativity usually rests on a supportive and nurturing network, encompassing parents and coaches, during years of immersion in a field (Weisberg). It is thus at the nexus of environment-defined factors and individual-hard wired or -cultured factors such as intelligence, cognitive styles, personality, and motivation that creativity manifests itself as acknowledged and accepted newness (Amabile 1983; Aneti, 1976).

In particular, researchers have extensively investigated motivation in its relation to creativity. Overall, researchers have praised motivation as a pivotal catalyst for creativity. Nevertheless, not all kind of motivation is as effective as some would think. Distinguishing between intrinsic and extrinsic motivations, cognitive psychologists have established the various ways in which motivations influence creativity.

Amabile and other researchers define intrinsic motivation as the internal urge to undertake a task deemed to be interesting, exciting, enjoyable, or challenging. They affirm that it has a great likelihood to strengthen creativity (Amabile 1990, 1996, 1997; Hennessey & Amabile 1984, 1988; Ruscio and al. 1998; Collins & Amabile 1999). On the contrary, researchers point to the fact that, extrinsic motivation - that is, the will to

implement a task in an effort to gain a material reward after evaluation - is most likely to stifle creativity (Amabile 1990, 1994, 1997). Examples of extrinsic motivation include doing a project for a reward under a contract; competing for a prize; and being evaluated during the implementation of a project. These examples and others are conditions that limit and control one's options. Their effects, according to some theorists, hamper both artistic and verbal creativity (Amabile 1983, 1990; Hennessey & Amabile, 1984, 1988, 1990, 1994; Einsberger & Selbst, 1994, 393). However, extrinsic motivation can be helpful when it leads to more efficiency in accomplishing task, and when it is conveyed with useful information (Amabile 1997; Collins & Amabile, 1999).

4.5. The Impact of the Cultural Environment on Creativity

A cultural environment that is highly conducive to creativity features tolerance of ambiguity, risk taking, openness to trial and error, and relativism in judging final products. On the contrary, a cultural environment that expects excellence from the inception of a project and throughout all its phases can easily stifle creativity. It sets unrealistic goals that only very exceptional individuals can achieve. A social environment that leaves room for mistakes and provides outlets for addressing them and transcending them can spur considerable growth in creativity.

On the other hand, creativity blossoms and takes meaning in contexts where it is socially valued. Creativity is hence "contextualized" and is partly function of particular cultural settings. The more supportive the cultural venue is, the higher the probability of social agents generating creative work. The cultural environment scaffolds creative expressions when it stimulates and supports motivated individuals' will to question, to

inquire, and to dare. It further frames and enhances creativity as it defines and evaluates it.

For science high school students, their science classrooms are the most important cultural environments that can either nurture their creative personality traits or stifle them. So far, more than anything else, our science classrooms have rather excelled in the latter. This effect results from their failure to prioritize inquiry methods that could lead to creative discoveries. This trend should be reversed.

To foster students' creativity, high school classrooms should emulate the attributes of supportive environments. To this effect, teachers need to be not only open and flexible to students' will to experiment on unmapped territories, but they also should provide lesson plans that invite students to explore sciences beyond textbooks and pacing guides. Teachers should engage students in activities that bring forth and activate aspects of students' creative personality traits. Although one may like to have high expectations of students, however, overachievements are unlikely to occur and aiming at them can be detrimental to the whole learning process.

Teachers and students ought to understand that in a classroom, creativity will most likely manifest itself in relatively small ways, in comparison to greater and more exciting accomplishments that might be occurring at professional and sophisticated laboratories. Hence, there need be particular considerations about reasonable expectations in any attempts at establishing creative classrooms in high school.

4.6. Defining a Playing Field for Creative Expressions in High School

4.6.1. Establishing the Need for Creative Classroom Environment

Two premises lay the ground for my belief that a creative classroom environment is necessary and feasible. Empirically, when exploring the unknown, people demonstrate significant uses of creativity; even more so, when scientists attempt to construct scientific theories and laws. Indeed, the very nature of any scientific fields is weaved with creativity. In addition, most creative thinkers assert that the enhancement of students' creativity is function of the practical activities requiring originality that they have undertaken.

It would thus seem appropriate to expect school systems to promote the learning of science through pedagogical strategies that elicit students' creativity for a genuine scientific experience in the classroom. One can hypothesize that high school teachers can help students experience established scientific knowledge in creative ways. Of course, this goal may rather be difficult to attain, owing partly to the low level of scientific knowledge that high school students are exposed to. However, it is necessary if students are to experience science authentically in school. Its feasibility depends on teachers' willingness and ability to establish creative perspectives in their pedagogical outlets.

4.6.2. Bringing Creative Perspectives in our Pedagogical Outlets.

The contradictory stances of various researchers have to a large extent prevented cognitive psychologists to conclusively affirm a definitive educational strategy to attain creativity.

Understandably, researchers have unearthed a great deal of factors that condition human cognition in the context of creative processes. Yet they appear to shy away from

specifically applying their findings to teaching and learning in high schools, for instance. Notwithstanding, insofar people of “normal intelligence” are concerned, many researchers seem to be assertive in answering the two central questions: Can we all be creative to some degree? Can creativity be enhanced? Raymond Nickerson, who thinks that nature and nurture are important determinants of creativity, claims, “few people realize anything close to their potential in this regard”.

To the extent that scientific undertakings must not only explain but also better inform practical activities of significant interest, a mature field of cognitive psychology would need to address such issues as teaching creativity in high school thoroughly. Teachers are anxiously awaiting a scientifically sound, meticulous and appropriate method. However, because in the meantime teachers should continue to teach and aspire to stimulate and enhance students’ creativity, they should shape their instructional strategies with essential notions that have surfaced from the research, despite the somewhat tenuous character of some evidence.

Given the inconclusive nature of the research, I cannot obviously pretend to be in a position to elaborate a blueprint strongly rooted in cognitive psychology to enhance high school students’ creativity. However, from a pragmatic standpoint, I purport to devise informed instructional strategies aiming at nurturing and developing high school students’ creative abilities in a bid to afford pedagogy of science more in tune with actual scientific praxis and to undermine high school students’ scientific misconceptions. Those pedagogical tools would be derived in such a way that they can be encompassed into the larger dialectical framework envisioned in the previous chapter.

For now though, following an assessment of the significance of the research on creativity for high school teaching and learning, I will point to a set of pertinent cognitive ideas that can efficiently assist in any effort to draft lesson plans aiming at enhancing students' creativity. However, prior to developing such lesson plans one needs to raise and answer the following fundamental question: What does it mean for students to be creative?

From a practical teaching standpoint, high school teachers need to define students' creativity with certain relativity. Specifically, gaining insight from the research and being realistic in relation to the high school context, one should adapt the conventional definition of creativity. One might want to consider as demonstrating creativity students who go beyond the notions taught in school or acquired in informal encounters. Students who express ideas and theories in new ways or develop practical items not customarily expected from people of their grade level can be viewed as expressing their creativity as well. Also, students who demonstrate great capacity to make connections between previously unconnected frames of reference, in relation to their curriculum, should be considered as being creative. This adapted view of creative individuals suggests that teachers should consider creativity as an ability that can be spotted at different levels and that can be expressed by all students with normal cognitive abilities.

For creativity to occur, high school teachers need to create, in the spirit of the research, an open-minded environment. That will help students combine cognitive and personality traits, so that they can freely connect ideas, describe patterns, identify similarities and differences, exercise flexibility, display aesthetic taste, be unorthodox,

express their motivation, be inquisitive, and question societal norms. Certain personality traits should be promoted for the enlightenment of creative students. The most salient ones are independence of judgment, self-confidence, risk taking, self-actualization, boldness, courage, freedom, spontaneity, self-acceptance and attraction to complexity. To nurture creative behavior, teachers should foster a creative classroom climate so as to forestall the main factors that tend to hinder creativity. Particularly, teachers should set an environment devoid of emotional reactions to insecure feelings, which are caused by fear of new or different ideas. By so doing, teachers would pave the way for risk taking in an open system that is student-centered and that favors flexibility and a climate of mutual respect and acceptance between students and teachers as Feldhusen and Treffinger argue (1985, 47).

In a high school science classroom geared toward creativity, teachers should expect students to create by simultaneously referencing past knowledge and conceptualizing new ideas. A modification of a past process, a change to a past experimental setting, or the re-discovering of a scientific notion could all be cataloged as creative products in a high school classroom. In attempting to elicit creative perspectives in high school science classrooms, teachers should therefore devise lesson plans that disseminate sufficient established scientific knowledge in order to inform and stimulate students' thinking, but yet leave ample room for students to exercise their cleverness and creative abilities.

Teachers would need to ensure that students acquire, in creative ways, significant amount of knowledge related to their curricula. A classroom environment conducive to creative work would need to ensure that students are not provided all the established

answers in a domain in order to avoid the inhibiting effect that too much information in a domain could have on creativity.

In general, students should not be expected to produce highly creative work. Students' creative outcomes do not need to be at the level where they would sustain the scrutiny of the professional scientific culture. It is at a lower level that their creative abilities can come into play as they attempt to solve cleverly daily problems or relatively challenging problems, requiring fluency, flexibility, originality, and elaboration. In any case, regardless of their level of proficiency in science, students ought to always be put in situation where they can be innovative.

The research puts particular emphasis on the cultural environment as possible scaffolding element, stimulating and supporting creative expression. The classroom can be such a supportive and nurturing network, encompassing teachers, administrators and students. The classroom can also be the instance of validation of creativity. That is novelty and usefulness would be judged and acknowledged within this restricted cultural setting the classroom has come to be. In this context, individuation, thinking processes that run contrary to a majority view, would be encouraged, just like perseverance, tolerance of ambiguity, and risk taking would be urged.

Teachers would need to be as flexible in timing students' work as they are in letting students experiment with considerable leeway. Indeed, teachers ought to be cognizant of the fact that sometimes, top-down factors, such as mental set and functional fixedness, interfere with one's creative process and prevent one's cognitive abilities to reason beyond the traditional strategies.

4.7. Complementing Dialectical Methodologies with Notions on Creativity

In the name of flexibility, I will complement the dialectical methodologies with the scattered notions on creativity that I have assembled here. In chapter 6, I attempt to synthesize into a pedagogical framework, the set of fundamental notions that I glean from dialectics and from theories on creativity, constructing in effect an alternative approach for teaching science, the $L = D^2C$. Subsequently, in chapter 7, I develop a tentative unit comprising 10 lesson plans grounded on this framework. Assessment of the effectiveness of the unit will eventually inform its refinement. First, in the next chapter, I present the methodology for an empirical study of students' learning after instruction based on the $L = D^2C$ unit.

Teachers should be able to explore strategies to teach -- to some satisfactory degree -- in ways that can train, stimulate, enhance, and assess creativity significantly, using insights provided by the research. Teachers can confidently hope that students in turn will eagerly undertake their creative journey and display great satisfaction from the act of creating as their intrinsic motivation gets incited. Indeed, the research reveals a very high correlation between intrinsic motivation and creative work. As intrinsic motivation stirs up, students tend to be very involved in their projects and produce more creative work. In keeping with this finding, the creative high school classroom would stimulate intrinsic motivation by encouraging students to undertake tasks that they enjoy. Cognitive investigations' emphasis on the joy that students exhibit when they genuinely work on insightful projects of their chosen, make creative lesson plans highly attractive and desirable.

But the creative option would require considerable transformation of the traditional classroom setting and conservative teaching methods.

CHAPTER 5

A MODEL CONDUCIVE TO CRITICAL AND CREATIVE THINKING: LEARNING THROUGH DISCOVERING DIALECTICALLY AND CREATIVELY, (L=D²C)

At the conjunction of dialectical materialist principles, strategic probing, and activities favoring creativity one can construct a rational pedagogical framework for the teaching and learning of science authentically. Such model can potentially help students do science through activities amenable to the reproduction of some concrete processes of its fabrication and significantly address many students' overarching misconceptions that negatively interfere with their learning.

In particular, the philosophical outlook of dialectical materialism can serve as a philosophy of science that informs students' scientific explorations and guides their view away from overarching misconceptions. As for the strategic probing approach, it can enhance students' critical thinking skills and sharpen their quest for deeper meaning of scientific notions. Overall, these pedagogical strategies anchored in exploration and inquiry activities will lead to discovery and function as outlet that facilitate the blossoming of creativity. The ensuing model is one conducive to dialectical and creative thinking. I coin it "Learning through discovering dialectically and creatively (L=D²C)".

In this chapter, I describe my initial conception of L=D²C. It is by no means a perfect framework. I fully expect the experience of teaching and evaluating the lessons based on the L=D²C, which I present in the next chapter, will allow me to refine my thinking, to revise my initial conception, and to enhance the model.

5.1. Re-Discovering Scientific Notions and Unveiling Dialectics in Nature

(Exploratory Nature of the $L=D^2C$)

The use of strategic questioning embedded in exploratory and inquiry practices is at the core of the model $L=D^2C$. Science units that this model shapes guide students through probing explorations that solicits their critical and creative thinking and facilitate the discovery of fundamental knowledge and the obliteration of perceived overarching misconceptions.

Typically, the first few lesson plans of a $L=D^2C$ science unit set the stage for students to discover or re-discover some basic scientific notions necessary to address a thematic project that encompasses subtopics pertaining to many fields of scientific inquiry. At the outset, students learn through strategic questioning of the Socratic kind and through experimental activities that they themselves devise, using at times some pointers provided by their teachers. The pedagogical practice orbits around teachers involving students into critical thinking and activities that urge them to develop strategies to set up experiments and to collect pertinent data, which, upon examination and class discussion yield rational theories. Following students' construction of knowledge, teachers expose them to the notions and laws officially recognized by the scientific community, in relation to the subtopics under consideration.

The most significant aspect here is the exploratory nature of the $L=D^2C$ model, which immerses students into a quest and a subsequent construction of knowledge. At the design stage of this knowledge construction, if need be, students can request teachers' scaffolding assistance. However, teachers, within the $L=D^2C$ framework, avoid taking

control of the investigative process. Instead, as much as possible, teachers urge students to maintain ownership of their investigative enterprise.

Students acquire content knowledge as they experiment and reason either directly on the factual evidence or indirectly by carrying out thought experiment. In additions, students develop reading skills and writing abilities specific to subject areas in overlapping scientific fields. Interacting in class discussion and cooperative learning activities, students negotiate and draw meaning from reading and experiments. However, consensus needs not always be reached in relation to individual knowledge formation. Eventually, they convey their constructed knowledge in class presentation while teachers challenge potential misconceptions through strategic questioning molded through dialectical materialism.

The model anticipates the possible existence of groups of students that either may lack essential notions necessary to pursue high level of knowledge or may experience the stifling of their creative process. Consequently, the unit supplies specific directives that teachers may use to assist those students to a certain degree. The tips provided for experimental settings aim at orienting students. They are part of a generative phase that should help students discover background knowledge necessary to elicit or feed their scientific creativity. They do not represent ready-made steps that students have to implement uncritically.

Whether students devise the experimental steps independently or with significant help from their teachers, those steps should direct students to make use of various abilities and to inquire about possible new notions. During their inquiry, students partake in critical thinking activities involving skills such as drawing, setting up experiments,

observing, collecting data, constructing tables, sketching graphs, and synthesizing ideas. To stimulate and sharpen creative thinking skills, the experiments should further involve students in drawing conclusion based on data analysis, reflecting on the significance of major findings and conclusions, and making inferences with an open mind.

Moreover, throughout the lessons of this first phase of the unit, teachers teach mini-lessons and question students in ways that help them identify patterns that point to a particular dialectical materialist principle and underline other known natural cases where such principle occurs. Teachers also engage students in discussion that leads them to confront the targeted overarching misconceptions.

Following this first phase of discovery of established scientific notions, of dialectical aspects of phenomenon, and of debunking of overarching misconceptions, the unit leads students to delve into a problem based learning introduced at the beginning in the first lesson. This second phase involves students in a thorough investigation of a concrete scientific problem.

5.2. Students' thorough investigation of a specific problem: PBL

The second phase of the **L=D²C** unit solicits students' higher order thinking and leads them to more authentic scientific work. It involves them in problem based learning activities that requires them to emulate professional scientists at work in their laboratories. During this phase, groups of students should decide on particular angles of a global problem that the class wishes to investigate. Students define the particular sub-problem they decide to explore through a thorough investigation designed to test a hypothesis that they formulate. Students thoroughly investigate the problem with

teachers' guidance in an attempt to identify connections across scientific disciplines, and the dialectical functioning of the various processes at work. This phase also allows students to revisit targeted overarching misconceptions and to debunk them.

5.2.1. Brainstorming

The first step in the process of formally defining a problem or sub-problem should be brainstorming activities. During that idea elicitation phase, teachers advise students to lower their level of self-criticism and to defer their judgment on peers thinking. They should be cognizant of the fact that one idea may provoke a new and better one. Due to that, everyone should be able to formulate or receive ideas in a relatively uninhibited fashion.

Following the first series of students' brainstorming, teachers should ask each group of students' divergent or open-ended questions that initiate thoughtful discussion. Divergent questioning should primarily activate students' prior knowledge and serve as launching activity that condition them to think dialectically about the subject under investigation. This process should overall prepare students to draft problem statements and hypotheses that the previous activities inform.

While at the inception of a unit brainstorming sets the tone for a great journey in cooperative learning, in general, brainstorming will weave, in the entire scientific experience. After all, teachers need to convey to students that, science is largely a cooperative endeavor in which interlocutors exchange ideas respectfully in their quest for knowledge.

5.2.2. Data Gathering

The second step concerns information gathering, usually through inquiry. This step includes reading scientific literature, questioning teachers and professionals, and trial-and-error activities. During this searching stage, teachers guide students toward the discovery of concepts and principles and play the role of a facilitator, ensuring a secure atmosphere where students are at ease to connect new ideas, to question, and to express their thoughts, feelings, and their progress or mental block. In addition, the teacher supplies information and materials as students indicate needs and inquire about task-relevant information.

Although during this phase students should enjoy substantial leeway, it is still important for teachers to be readily available to scaffold students' attempts at setting up experiments, and help students define and establish proper safety procedures. Particularly, for all activities that present an imminent danger as perceived by the teacher, he or she should assist students in the manipulations of instruments and/or dangerous components. In cases where class size is an issue, teachers should request teaching assistants. Interns and substitute teachers could be of significant help.

As the research progresses and ideas stir up, students may rewrite their hypothesis. Students should be able to backtrack at any stage to reconsider ideas, if deemed necessary. Indeed, as they progress, students need to be sensitive to the question of producing alternative solutions and of evaluating ideas. Frequently, group members should be encouraged to debrief on aspects of their research, and to brainstorm in order to break impasses and mental fixedness. Students should also be cognizant of insights gained after an incubation period. Then students should be prepared to put ideas into use

as they undertake knowledge construction and meaning making activities. Finally, using teachers and other professionals as facilitators and consultants, students should theorize, determine limitations of their work, and raise new questions that they or others could further investigate.

5.3. Creativity

The learner must be mindful of the fact that it is desirable that he/she exhibits creative attributes throughout the project. Those include fluency that generates relevant responses, flexibility that welcomes different categories of relevant responses, originality that encourages the search of uncommon responses, and elaboration that favors detailed responses. The learner should look for opportunities to express his/her creativity as he/she questions, makes hypotheses, combines known facts and principles to facilitate the construction of new knowledge and the development of suitable solutions.

Regardless of what subject matter students investigate, fostering a creative stance will always be of paramount significance. To be creative means to be daring and innovative. Hence, teachers should help students overcome timidity and fear of new or different ideas and undermine fear of failure, fear of displaying their weaknesses and fear of ridicule. Teachers would have also to prevent or deal emphatically with emotional reactions that those insecure feelings tend to provoke in students. It is thus of crucial importance that teachers attempt to soothe students' fear and set the tone by devising a classroom environment amenable to risk taking and open-mindedness in order to counter the powerful psychological deterrents to creative thinking.

Teachers along with students should create a flexible open system within a climate of mutual respect and acceptance. In such an atmosphere, students can be impelled by curiosity and pursue knowledge innovatively and in a meaning making fashion. It is only through such pathways that creativity can blossom in order to make the quest for knowledge and self-affirmation a thoughtful and pleasant journey.

5.4. Challenging Overarching Misconceptions

On the other hand, an **L=D²C** science unit exposes some perceived students' overarching misconceptions. It tackles them through strategic questioning and carefully suggested students' inquiry that leads to the unveiling of suitable and clarifying dialectical materialist principles. Teachers' assistance during that phase comes through mini-lessons that highlight the dialectical nature of the scientific notions that students discover and conferences that urge students to clarify their thinking and to use known principles to discard targeted overarching misconceptions. Hence, the **L=D²C** model challenges overarching misconceptions by confronting them primarily with legitimate prior knowledge. The model equally tackles overarching misconceptions through the process of knowledge construction that emerges as students conduct experiments and reflections in pursuit of greater understanding. Subsequent discussions, which underscore the discrepancies between perceived overarching misconceptions and analysis of class' collected data, further enlighten students and firmly establish the likely correct scientific view.

5.5. Assessment

In a pedagogical setting that is molded by dialectical materialism and creativity, assessment is desirable only if it empowers students to gauge their scientific thoughts through reflexive practices, and informs instructional strategies throughout the teaching and learning processes. In particular, assessment should enable students to pinpoint their achievements, or lack thereof, gauge the extent of their creativity in the subject under investigation, to highlight the knowledge they have constructed and to be cognizant of the misconceptions that may arise. The evaluation process should inform teachers about students' acquisition of possible scientific procedures, about the extent of students' application of their creativity, their scientific posture as they construct meaningful knowledge aligned with fundamental scientific notions, and argue dialectically against common misconceptions.

Given that the objective of the $L=D^2C$ is not to have students emerge from a scientific journey with top-notch theories, but rather to help them experience first hand some possible processes one may use in the dialectical construction of scientific knowledge. Actually, teachers should not assess students' work primarily because of their supposed correctness for in forming scientific minds the process of doing science is more fundamental than a particular answer and, in some cases, teachers may not even be aware of a particular correct answer. Instead, students work should be evaluated on the basis of how well they try to create experimental and analytical settings that help them collect significant data, identify patterns, uncover discrepancies, establish interconnectedness, specify coexistence of polar opposites, and identify or infer threshold point at which change in quantity will or might lead to change in quality. What matters

most in the context of the $L=D^2C$ is the initiation of students to processes of doing science and of fabricating knowledge rationally using the dialectical materialism mold.

As homework, students address specific questions that require creative thinking about the experiment. For instance, in an effort to stir up students' innovative capacities, teachers may ask them to identify some areas of possible improvements of the experimental set up and/or of the outcome of the experiment. In addition, the homework confronts students with questions that compel them to reflect on the unit's targeted misconceptions. For example, students address targeted misconceptions by comparing and contrasting them with their scientific findings and dialectical principles to which they have been exposed.

CHAPTER 6

SCIENCE UNIT

MAGNETISM AND INTERCONNECTION BETWEEN SCIENCES: UNCOVERING THE MAGNETIC LINK BETWEEN PHYSICS, CHEMISTRY, AND BIOLOGY

This chapter attempts to develop a set of lesson plans that purports to: 1) teach specific notions in the content areas of Physics, Biology and Chemistry and 2) incite students to devise and implement original experiments from which meaningful learning will occur and scientific knowledge might emerge. In particular, the unit investigates the multi-faceted connections between scientific fields of Physics, Biology and Chemistry through magnetism.

The unit, which is grounded on the $L = D^2C$ approach, revolves around a problem-based learning (PBL) involving magnetism and bird migration. It first provides an opportunity for students to discover established notions of magnetism, in a highly inquisitive fashion. During this phase, students will reflect on experimental settings they either develop autonomously or with the assistance of their teachers. As they explore magnetism, students uncover the threading of many scientific fields and discuss the significance of this interconnectedness in nature and science. Then the unit offers the opportunity for students to be deliberately explorative as they devise their own experiment and research strategies in search of new knowledge.

Throughout the unit students large scale misconceptions are exposed and confronted with scientific evidence in an effort to uproot them. In particular, as the unit focuses on interconnectedness in sciences, it aims at tackling two overarching

misconceptions that respectively depicts sciences as a collection of fragmented elements and promotes the view of a unique scientific method.

The lesson plans favor learning and inquiry through dialectical praxis and creativity. The hope is that students who learn science within such a framework will be great thinkers, problem solvers, and creators. These lesson plans are implemented in the context of block scheduling period of 80 minutes at 11th and 12th grade levels. They require students to have a science notebook, which serves as a log for physics reports and critical and creative thinking activities.

The unit is organized around the problem based learning (PBL) topic that follows. “Do chemical reactions in birds interact with earth magnetic field? Or else? Investigate the question in such a way that you explore associated fundamental notions and establish pertinent dialectical materialist links that might challenge overarching misconceptions related to fragmentation of realities and of scientific areas, about whole and parts.”

Following the presentation of this PBL topic, teachers engage students in a general discussion about bird migration and earth magnetic field, using Strategic probing in an effort to activate their prior knowledge on those aspects of the central question and to eventually identify particular areas that the class ought to investigate for a successful completion of the PBL. At the outset of the discussion, teachers ask each student, to fill in a KWL chart. Then teachers form groups of three to four students and ask them to brainstorm in order to chart a group common KWL. Later on teachers facilitate the drafting of a class based KWL on the board as a result of general class discussion. In discussing the class based KWL, teachers should weigh in to align areas of investigation that students perceived as necessary with fundamental areas of knowledge that the class

ought to investigate for a successful project. Those main areas include: dialectical coexistence of polar opposites, fundamental notions of magnetism and their interconnections with other aspects of sciences, quantitative change to qualitative change through the electromagnetic spectrum, and eventual influences of earth magnetism on bird migration.

Lesson Plan 1

Topics of Investigation: Whole and Parts

Lesson Overview: In this activity teachers engage students in discussion about whole and parts from a dialectical materialist standpoint. Teachers facilitate students' brief examination of the PBL topic from various angles. Teachers help students view the topic, seen as a reality, as a whole constituted of interconnected parts. Finally, students learn that reality as a whole is more than a simple juxtaposition of constitutive parts and challenge scientific misconceptions related to the belief that reality can be atomized.

Objectives

Students will be able to

- Identify whole and parts of a given reality
- Understand that the whole is more than the sum of the parts.

Activity I. Teachers form groups of three students. Teachers give to students a one page text describing an atomic model. Teachers ask groups of students to identify the parts of the model. Then teachers ask students to summarize the interactions of the parts that contribute to the functioning of the whole. Teachers ask students to share their work with the class. Teachers invite students to think about the relationship between whole and parts. Teachers dwell on the fact that the whole is more than the sum of the parts.

(Reference:

<http://galileo.phys.virginia.edu/outreach/8thGradeSOL/AtomicConstruct.htm>

http://www.britannica.com/nobel/micro/514_59.html

http://www.classzone.com/books/earth_science/terc/content/investigations/es0501/es0501page03.cfm?chapter_no=investigation).

Activity II. Discussing whole and parts from a dialectical materialist standpoint

- Teacher instructs students that realities present themselves as wholes that are messy and difficult to penetrate. As a result, we tend to identify their constitutive parts and to examine them from various perspectives as dictated by the various sciences and other cultural practices. We then hope that knowledge of constitutive parts will help us comprehend wholes. However, knowing fragmented parts from various isolated standpoints is a limitative knowledge that may flaw our understanding of the whole. Hence, multidisciplinary studies and understanding that the whole is more than the sum of the parts are necessary from a dialectical materialist view for in many instances wholes have been proven to be more than simple imbrications of the parts.
- Teachers invite students to write two to three paragraphs to reflect on: the complexity of an atom as a whole, ways in which its constitutive parts help understanding of the totality, and ways in which interactions between the parts make the whole more than just a static juxtaposition of those parts.

Activity III. Teachers present students with the following PBL topic. “Do chemical reactions in birds interact with earth magnetic field to provide sense of direction?”

- Teachers ask students to fill a KWL chart in order to underline what they know about bird migration and earth magnetic field and what they suspect they need to know about them in relation to the PBL topic.
- Teachers form groups of three to four students and ask them to brainstorm in order to form a common KWL.
- Teachers ask students to share ideas from their KWL and teachers facilitate the drafting of a class based KWL on the board.

- Teachers aligned students chosen areas of investigation with fundamental ones that the class ought to pursue for a successful project completion.
- Teachers should make sure that the following items figure in the list of main areas of investigation: fundamental notions of magnetism and its interconnections with other aspects of sciences, dialectical existence of polar opposites in magnetism, quantitative change to qualitative change in magnetism, and possible influences of Earth magnetic field on bird migration.

Activity IV. Class discussion:

- Teachers engage students in a general discussion about bird migration and earth magnetic field on the basis of their activated prior knowledge on those topics.
- Teachers list on the board, with students' assistance, some sub topics that are embedded in the PBL topic.

Homework: Teachers ask students to write a five paragraph essay about possible strategies that may help one develop the body of segmented knowledge related to each sub topic identified above, namely magnetic field, Earth magnetic field, and bird migration. Students should also extend their thinking about possible interconnections and integration of the atomized pieces of knowledge in ways that shed substantial light on the whole. Teachers ought to inform students that the critical thinking exercise at this stage is a tentative one, but an indispensable hypothetical view that gives the researcher a sense of direction.

Lesson Plan II

An Invitation to Explore Magnetism in Physics using Critical and Creative Thinking Skills

Activity Overview: In this lesson students explore magnetism and discuss some scientific skills in relation to the context of critical thinking. The skills include observation, prediction, data collection, and data organization using magnets and compasses. Students also identify the characteristics of creativity and discuss ways in which they can develop and exhibit their creativity.

Objectives: Students will be able to:

- Observe and think about magnetic phenomenon.
- Discuss strategic questions that teachers raise in a Socratic fashion.

Activity I - Warm Up: Experimenting with magnets.

1. Teachers ask students to use bar magnets to attract pieces of metal.
2. Teachers ask students to use bar magnets and iron fillings to form lines of force.
3. Students write and sketch their observation. Then, students share their work.
4. Teachers should stress the fact that two opposite poles coexist in the magnet.

Teachers also pinpoint that this observation reveals a dialectical principle.

Activity II. Strategic Probing: Teachers ask students the following questions and others in a bid to compel students to critically think about their findings.

- Can a magnet exist with only one pole? Explain
- Are the poles of a magnet always opposite to each other? Explain.
- Does the North pole react differently from the South pole in the presence of a metal? Explain.

- Do you know of any other cases where two opposite elements coexist within a whole? Explain.
- Sketch the pattern of the lines of force formed by the iron filings. Describe the sketch.
- How do the poles influence the shape of the lines of force?
- Compare and contrast the lines of force of the magnet with the Earth magnetic field.
- Teachers should ask follow up questions and more questions related to the shape and nature of the lines of force.

Activity II. Experimenting with compasses

Teachers ask students to observe a given compass and to record its main features.

Strategic Probing: Teachers ask students the following questions and others in a bid to compel students to critically think about their findings.

- Why does a compass needle move?
- How does a compass indicate the magnetic North?
- How do we know it?
- How accurate is this determination of North pole?
- Could there be another convention?
- Explain whether or not magnetism should play a role in establishing such a convention. What would you suggest?
- Teacher is urged to come up with follow up questions.

Activity III - Mini-Lesson: Teachers discuss the composition and mode of operation of a compass.

Strategic Probing on Creativity: Teachers ask students the following questions and others in a bid to compel students to think critically.

1. In which ways could the invention of the compass be seen as having been a creative solution?
2. What makes an enterprise a creative one? Teachers suggest students to dwell on: the degree of novelty the product displays, the level of originality that can be attributed to the product, and the usefulness of the product.
3. How can a science class be a place for creative expressions? Explain.
4. Can there be much creativity in a science class that functions under the assumption that there exists only a unique scientific method?

Activity IV: Inquiring about Earth Magnetic Field. Collaborative Learning:

Teachers form groups of three to four students and ask students to read a one page handout providing them with the basic facts about the Earth's magnetic field. A good reference for the handout is page 574 from the textbook titled "Conceptual Physics". Students discuss, in small groups, particular situations (natural phenomenon or applications) in which the Earth's magnetic field plays an important role. Students focus on Earth's magnetic field: its formation and its mode of operation; the Earth magnetic field reversal and its consequences. Teachers underline that functioning within dialectical contradictions, opposite poles coexist in the same Earth magnetic field.

Activity V. Critical Thinking:

- Teachers urge students to raise probing questions about the validity, and the accuracy of the notions presented on the handout.

- Teacher encourages students to introduce also possible extensions of the notions presented, possible consequences of such notions, and possible alternative views.
- Teachers help students formulate hypothesis for questions that cannot be answered on the spot and to discuss the logical reasoning justifying them.

Homework/Strategic Probing:

I. Teachers ask students to read the following two articles:

1. Earth's Magnetic Field by Wikipedia

(http://en.wikipedia.org/wiki/Earth%27s_magnetic_field).

2. The Earth's Magnetic Field

(http://liftoff.msfc.nasa.gov/academy/space/mag_field.html) Dec. 5, 1995.

II. Teachers ask students to answer the following questions.

- 1) Describe the process of magnetic field variations.
- 2) How does the Earth's magnetosphere function?
- 3) How do we know that magnetic reversals have taken place on Earth?
- 4) How might a new magnetic reversal affect human behaviors?

Lesson Plan III

Dialectical Coexistence of polar opposites

Activity I. Warm Up:

- Teachers hand out a text on the production of magnetic field. Teachers ask students to attempt to explain the production of magnetic field at the level of individual atoms in a crystal of iron and to dwell on the resulting effect of interactions among adjacent iron atoms.

Activity II. Practicing Strategic probing

- Teachers ask pairs of students to engage in mutual strategic probing in relation to their constructed theory of atoms' magnetic field. Teachers converse with groups to reinforce the probing session. If some students experience difficulties to formulate questions, the teacher helps them with the process.

Activity III. Mini-Lesson: Demonstration of the coexistence of polar opposites:

- Teacher breaks a magnet bar into many pieces.
- He/she approaches the pieces close by in ways that first make them attracting each other and then repelling each other.
- Teacher makes class understand that each piece is still a magnet standing on its own.
- Teacher stresses the fact that magnetic poles exist in pairs regardless of how small the pieces are.
- **Teaching:** Teachers instruct that this is an instance of coexistence of polar opposites whereby north and south poles are intimately linked. The breaking of the magnet at any point, including at any pole, gives rise to other bi-polar magnets. The

opposite poles interact in ways that create a new magnetic field. It is in that sense that one may want to talk of dialectical coexistence of polar opposites.

- **Probing Questions:**

1. What type of auto-dynamism does the unity of opposites entail?
2. Can we reverse the polarity of a magnet? Explain.
3. Can we de-magnetize a magnet bar? Explain.

Activity IV. Class Discussion: Teachers engage students in discussion about dialectical coexistence of polar opposites in magnets:

- Teachers emphasize the fact that magnets are comprised of two poles that always coexist even when the magnet broke down into pieces.
- Teachers help students interpret this fact as an instance of dialectical coexistence.
- Teachers extend the notion of dialectical coexistence of polar opposites to nature in general.

Activity V. Experiment and Discover: Teachers invite students to experiment about the effects of magnetism and urge them to theorize using their findings.

- Teachers divide the class into groups of three to four students.
- Teachers provide students with the following: sheets of paper, bar magnets, iron filings, and compasses.
- Teachers ask groups of students to devise an experimental plan that makes use of the given items in order to develop a theory about the effects of magnetism.
- Teachers conference with groups to inquire about their plans, identify scientific flaws in their thinking, and scaffold their investigative process by moderately helping them with their experimental plans.

The following points are directives that teachers might suggest, in a selective fashion, to students who seem to experience mental blocks:

2) Place sheets of paper over bar magnets and sprinkle iron filings on the paper. Focus on: magnetic poles, patterns of iron filings' curves; paths and areas of greater/less accumulation of iron filings; magnetic force and magnetic field. Make pictures and record observation.

3) Repeat the experiments by increasing the number of magnet bars and by placing them in parallel and/or in series at various distances. Make pictures and record observation.

4) Do similar steps as in (1) but using compasses instead of filing irons.

5) Repeat similar steps as before using both iron filings and compasses.

6) **Words of caution:** Teacher should always avoid taking control of the investigative process by directly assigning students particular experiments to conduct. At all times, students should maintain ownership of their investigative enterprise.

Activity VI. Presentations and Discussion.

a. **Reporting:** Each group reports its data, analysis, findings, and eventual questions.

b. **Constructing Theories:** Students form new groups in such a way that each new group is composed of members that have been previously in different groups. Each new group develops a theory about magnetism on the basis of experiments that the previous groups conducted and raises questions that remain to be answered.

c. **Students' reports:** Students report their theories and teachers challenge them in order to expose flaws, to highlight limitations and to clarify.

d. Teachers along with one representative from each group synthesize the findings, finalize the theory about the effects of magnetism, and present it.

Activity VII. Extension:

1. Teachers ask students to reflect on the coexistence of polar opposites in nature and its significance, if any.
2. Teacher presents the accepted scientific theories about magnetic fields produced by each electron based both on orbital motion and spinning motion, magnetic fields produced by bar magnets, and the notion of magnetic domains.
3. Teachers engage students in discussion about coexistence of polar opposites in the theory on magnetic domains.

Homework: 1. Explaining phenomenon. How can a magnet attract a piece of iron that is not magnetized? (Research at a library and/or on the internet might help students answer this question.)

2. Innovative use of natural phenomenon. How can the alignment or the non alignment of domains in a crystal iron be used as a code for information storage and information processing purposes? Explain whether or not the notion of coexistence of polar opposites informs your thinking process for this application. (Research at a library and/or on the internet might help students answer this question.)

Lesson Plan IV

Critical Thinking in Scientific Investigation as it relates to magnetism

Critical Thinking Objectives: Students will be able to:

- Discuss the following notions: observation, prediction, data collection, and data organization in relation to magnetism
- Probe the notion of scientific method in relation to magnetism

Activity I. Viewing of PBS Show on Magnetic Field at

(<http://www.pbs.org/wgbh/nova/magnetic/about.html>). The show is written and produced by David Sington. Nov. 18, 2003.

Activity II. Teachers divide the TV show transcript

(http://www.pbs.org/wgbh/nova/transcripts/3016_magnetic.html) into five sections and distribute them respectively to groups of three to four students. Teachers ask each group of students to read their assigned section and to discuss it together.

Activity III. Class Discussion. Each group presents its assigned section and answer questions from classmates and teachers.

Homework.

1. Earth's Magnetic Field is Fading. John Roach for National Geographic News, Sept. 27, 2004.

(http://news.nationalgeographic.com/news/2004/09/0927_040927_field_flip.html).

2. The Dynamo Effect. <http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html#c1>

3. Earth's Inconsistent Magnetic Field.

(http://science.nasa.gov/headlines/y2003/29dec_magneticfield.html).

Lesson Plan V

Connecting Magnetism and other aspects of science: Interconnectedness within sciences

Activity Overview: In this activity, students investigate the relationship between electricity and magnetism; and also they examine the connection between bird migration and magnetism. Students deflect compass with a wire carrying electric current demonstrating that the flow of electric charges produces a magnetic field. They observe also that moving a magnet relative to a coil produces a current in the coil, establishing the interconnections between electricity and magnetism. Then, students investigate the variables, which determine the strength of an electromagnet. Students, also examine the relationship between magnetism and biology by studying bird migration and magnetism in human body. Finally, students reflect on interconnectedness in nature as a dialectical principle. Teachers engage students in discussing how considering interconnectedness in analyzing realities make for more thoughtful and insightful understanding.

Objectives: Students will:

- Observe induced currents.
- Observe magnetism of a current-carrying wire.
- Examine the interconnection between electricity and magnetism.
- Investigate variables in an electromagnet which determine the strength of magnetic fields.

Activity I. Warm Up: Students write for five minutes about how they think Critical thinking might help them become better scientists. Pairs of students share their writing and dialogue about them.

Activity II. Connecting Electricity and Magnetism

1. **Be Creative and Experiment:** teachers urge groups of four students think of strategies they could use to investigate the effect of current-carrying conductors on compasses.

2. **Probing Questions:** Teachers stimulate students thinking with probing questions of the sort:

- What do we know about electrical current?
- What do we know about magnetism?
- How does compass operate within magnetic field?
- Are there interactions between electricity and magnetism?
- Can we produce one from the other? If yes, how?

3. **Experimental Setting:**

- Teachers expose students to basic electric circuit by analyzing with them the diagram of a simple circuit composed of a battery connected to a lamp holder with electric wire.

- Teachers demonstrate the implementation of the simple circuit for the class.
- Then, teachers ask groups to:
 1. Design a suitable electric circuit with a battery, a coil, and a lamp.
 2. Decide where they will place compasses,
 3. Implement their design after teachers' approbation.

4. Students record their observation in a format conducive to data analysis.

Help: Students ask for teachers' scaffolding during their design process if need be.

Words of caution: Teacher should always avoid taking control of the investigative process by directly giving to students particular experiments to conduct. At all times, students should maintain ownership of their investigative enterprise.

Activity III. Predict and Verify:

1. **Predict.** Students predict what would occur if iron filings were sprinkled on a piece of paper at the center of which they respectively placed:

- a) A current-carrying wire that is part of their simple circuit;
- b) A current-carrying loop that is part of their simple circuit; and
- c) A coil that they introduce in series in the circuit with teachers' help.

2. **Verify/Falsify.**

- Students devise three different experimental settings to verify/falsify their predictions.

Activity IV. Theorize.

- Students create theories on electromagnetic fields based on predictions, verifications/falsifications, and refinements.
- Students should comment on whether or not their theories can explain the existence of magnetic domains.
- **Be Creative:** Think of a strategy one could develop to create a code based on the concept of magnetic domains. Describe your designed code and its advantages.

Activity V. Class discussion: Interconnectedness within Physics and among scientific fields.

- Teacher invites students to reflect on connections between Electricity and magnetism, establishing interconnectedness within Physics.
- Teacher urges students to discuss the possible drawbacks an “isolation view” would cause if it were to insist on keeping magnetism separate from electricity.
- **Possible topics for class discussion:**
 - a. Explain how scientists would have missed the fundamental principles of electromagnetism that lead to the generation of electricity had they held to an “isolation view” in dealing with magnetism and electricity.
 - b. Consider the opportunities for electromagnetic applications in medical fields such as radiology that the “isolation view” would have totally disregarded.
 - c. Reflect on the richness of interconnectedness in science using the observations and results.
- Teacher points out the dialectical interconnection linking scientific fields and the greater completeness of scientific answers that incorporate such interconnectedness. Teacher fosters:
 - a. themes and notions that run across disciplines such as motion, force, energy, and change.
 - b. ways in which each scientific field’s approaches are parts of a whole; and
 - c. ways in which wholeness provides the larger picture and greater understanding.

Homework:

1. **Internet Research or Library Research or Interview: Coding:** How does a magnetic stripe on the back of a credit card work? Can you identify some interconnection in such application? Explain.

2. Internet Research: Nuclear Magnetic Resonance Spectroscopy: Download two short articles/items on nuclear magnetic resonance (NMR). After reading them, explain ways in which sciences interconnect in this application.

3. Interactions of whole and parts. Identify two areas where magnetism interacts with other natural phenomena to give way to a larger reality. For example, electricity and magnetism combine to form an important field named electromagnetism. The two parts (electricity and magnetism) become a whole, which, in turn, interacts with the parts.

Lesson Plan VI

Magnetism and Bird Migration: Exploring connections between some parts of nature.

Overview.

Objectives. Students will be able to:

- Hypothesize about animal migration
- Explore connections between some parts of nature
- Review some literature on bird migration.

Activity I. Warm Up:

1. Teachers ask students to read the article Birds, Eels and Turtles: Migration and Magnetism.
2. Then, teachers engage students in discussion around the following question. Can the fact that birds use magnetism to navigate be seen as a case of connection between parts in nature? Explain.

Activity II. Class Discussion – Strategic Questioning - Hypothesize:

- Do birds use magnetic field to plan migration routes? Explain.
- How do birds use the Earth magnetic field for migration?
- How do birds sense the Earth magnetic field?
- Where is the sensory organ located? Explain.
- What are the characteristics of geomagnetic sensory input? Explain.
- How do migration birds detect the strength of Earth magnetic field?
- How do migration birds detect the direction of the Earth magnetic field?

Activity III. Reviewing Literature. Teachers make available in as many copies as necessary the following articles that focus on animal navigation. Teachers ask group of three students to select six articles and to decide on a division of labor between teammates and a strategy for each learner to report the key ideas each article conveys. Then the group answers collectively the questions that were raised on the warm up activity. Groups can seek help from other groups as they attempt to answer the questions.

Activity IV. Class Discussion: Teachers facilitate an open debate between students by raising the questions one after another and by asking necessary follow up questions.

Homework.

1. Teachers ask students to choose two articles on animal migration for reading at home.
2. Teachers ask students to hypothesize on the PBL topic that was previously presented on Lesson I.
3. Teachers ask students to draft an experimental strategy to carry out the PBL.

Lesson Plan VII

Quantitative Change in Electromagnetism

Activity I. Electromagnetic field: Creating magnetism using electricity.

a. Mini-lesson: Teacher exposes students to electromagnetic theory:

Electromagnetic field is directly proportional to number of turns in a coil, the intensity of the current, and the voltage across the coil.

b. Students Probing Teacher: Teacher urges students to probe him on electromagnetism using the Strategic questioning approach.

Activity II. Electromagnetic field: Creating electricity using magnetism.

A) Mini-lesson: Teacher exposes students to the electromagnetic theory indicating that a movable coil in the vicinity of a magnetic field creates electricity and so does a varying field in a nearby fixed coil.

B) Experiment: Verify/Falsify.

- Teachers engage students in discussion about possible experimental settings that could be used to verify / falsify the theory. Teachers ask students to work in groups of three to devise a final version of an experimental setting and a list of pertinent type of data that they may want to collect.

- Teachers ask groups to present their work and to enhance it based on other students' design and comments.

- Students devise experimental settings and conduct experiments in order to verify/falsify the theory.

Help: Students ask for teachers' scaffolding during their design process, if need be.

Teacher helps with the thinking process moderately but does not provide full answer.

Words of caution: Teacher should always avoid taking control of the investigative process by directly giving to students particular experiments to conduct. At all times, students should maintain ownership of their investigative enterprise.

C) Possible experimental settings and directives.

Teachers present to students the following example of experimental setting that they can use if their attempted design had unaccepted flaws.

1) Experimental settings:

- Students form a coil by wrapping a 25 meter copper wire around a cardboard tube (similar to those that form the center of paper towels).
- Teachers provide to students a diagram in which the ends of the wire are connected to a galvanometer while the coil is maintained in fixed position.

2) Experimental Steps:

- i. Students introduce a bar magnet into the cardboard and pull it. In both cases they observe the galvanometer and record what occurs;
- ii. Slowly, students push and pull the magnets many times inside the cardboard tube and record observations;
- iii. Students repeat (ii) but they push and pull the magnet bar fast;
- iv. Holding the magnet bar in fix position, students move the coil back and forth, first slowly and then fast, and they record observations;
- v. Students analyze the data; vi) Students synthesize their findings;
- vi. Students ask probing questions relevant to the experiment;
- vii. Students relate predictions in (2) with their findings and synthesizing.

D) Further Investigation of Electromagnetic Strength:

3. The effect of number of turns on electromagnetic strength.

- Teachers give nails, copper wire (#22 AWG), and many batteries 1.5 volts to students
- Teachers ask groups of 3 students to brainstorm in order to figure out how to design a circuit with the components that will facilitate the investigations of various number of coil's turns on electromagnetic strength.
- Teachers ask groups of 3 students to devise actual plans for conducting their investigations. Plans should include, circuit diagrams, tables to organize data such as number of turns, intensity of current, and electromagnetic strength.
- Teachers ask students to describe in one paragraph their strategies to analyze data and to synthesize findings.
- Teachers ask students to present their work thus far.
- Teachers finalize with students a circuit diagram, and a set of directives to collect data and to analyze them.
- Students conduct the experiment and synthesize their findings about the effect of various number of coil's turns on electromagnetic strength.

4. The effect of voltage on electromagnetic strength.

- Teachers give nails, copper wire (#22 AWG), and many batteries 1.5 volts to students
- Teachers ask groups of 3 students to brainstorm in order to figure out how to design a circuit with the components that will facilitate the investigation variable voltage's impact on electromagnetic strength.

- Teachers ask groups of 3 students to devise actual plans for conducting their investigation. Plans should include, circuit diagrams, tables to organize data such as voltages, intensity of current, and electromagnetic strength.
- Teachers ask students to describe in one paragraph their strategies to analyze data and to synthesize findings.
- Teachers ask students to present their work thus far.
- Teachers finalize with students a circuit diagram, and a set of directives to collect data and to analyze them.
- Students conduct the experiment and synthesize their findings about the effect of various number of coil's turns on electromagnetic strength.

Activity III. Group Reflection / Class discussion:

- Groups reflect on the activity and jot down important aspects of their reflection on paper.
- Each group discusses its ideas with another group.

Teacher will want to make sure that students discuss / acknowledge the following facts:

- ◆ the investigation revealed a relationship between magnetism and electricity;
- ◆ a magnet affects a compass as does an electric current;
- ◆ one can create electricity by moving a magnet past a coil of wire or vice-versa;
- ◆ one makes an electromagnet by using current through a coil;
- ◆ electromagnetic strength is directly proportional to the number of coils' turns;
- ◆ electromagnetic strength is directly proportional to the voltage;

◆ Overall, quantitative changes, without qualitative changes, were observable through.

Homework.

1. Teachers ask students to choose two articles on animal migration for reading at home.
2. Teachers ask students to ameliorate the hypothesis they wrote for the PBL topic that was previously presented on Lesson I.
3. Teachers ask students to write a second draft of an experimental strategy to carry out the PBL.

Lesson Plan VIII

Metacognition: Thinking about one's own Thinking in Magnetism and Bird Migration

Activity Overview: In this activity students investigate the relationship between electricity and magnetism. After establishing that a compass is a magnet, students deflect the compass with a wire carrying electric current. Then they observe that moving a magnet relative to a coil produces a small current in the coil. Finally, students investigate the variable that determines the strength of an electromagnet.

Physics Objectives: Students will:

- Observe induced currents.
- Observe magnetism of a current-carrying wire.
- Infer the importance of relative motion
- Build an electromagnet.
- Investigate variables in an electromagnet.

Critical and Creative Thinking Objectives: Students will be able to:

- Understand the concept of metacognition
- Model metacognitive thinking under simple conditions.

Activity I. Warm Up: Students conduct a thought experiment about the scientific research program one could set up in order to eventually develop a system that makes use of electromagnetic field to serve as early warning for tsunami in his/her state. Students then answer the following questions:

- 1) What are some fields of science that should be connected for such a program to become successful? Why?
- 2) Anticipate the interactions between the whole that would be formed and the parts.

Investigating the effects of number of coil turns and of voltage on electromagnetic strength

Generate Hypothesis: Students form groups for collaborative investigations and learning.

Activity II. Mini-Lesson: Teach about metacognition, i.e. one's thinking about one's own thinking.

Activity III. Students' metacognition:

1. Have each students to think about his own thinking as it relates to what he/she has learned so far in this unit and in relation to what he thinks he may still need to learn in order to pursue the PBL.
2. Have students share, in small groups of three, their metacognitive thinking.
3. Have each student reports briefly the main ideas from one of his/her interlocutors' thinking.

Activity IV. Discussing the PBL topic.

1. Ask students to share the hypothesis they wrote for the PBL topic that was presented on Lesson I and the second draft of the experimental strategy they devised to carry out the PBL.
2. Ask students to identify and discuss similarities and differences in their hypothesis and experimental strategies.

Homework:

Each student improves further his/her experimental strategy for the PBL as he/she reflects on new ideas that emerge from the discussion with his/her classmates.

Lesson Plan IX

Magnetic Spectrum: From quantitative change to qualitative change

Activity I. Warm Up: teachers provide students with a chart that shows the electromagnetic spectrum. Students identify the fundamental parameters on the electromagnetic spectrum, including wavelengths and colors.

Activity II. Making Sense of Numbers: Students answer the following question: What is common to all the values of wavelength? How are those values related? Explain.

Identify patterns: Students examine each column of the chart separately. Students make statements synthesizing the pattern they notice. Students answer the following question: What does the analysis of the electromagnetic spectrum suggest electromagnetism in nature?

Activity III. Jigsaw: Investigating electromagnetic spectrum: Each group identifies 5 to 7 characteristics that are unique to its assigned portion of the electromagnetic spectrum. Each group presents its findings while other groups take notes in the appropriate area of the table given as handout.

Analyzing. Each group analyzes its table of characteristics.

Questioning. Could we talk about “quantitative to qualitative transformations”? Justify your answer using the data registered in the table.

Be Creative. Magnetism and Environment. The ozone layer is deemed instrumental in protecting humans against fatal effects of ultraviolet, X rays, cosmic rays, and gamma rays. Working as a member of a UN ad hoc committee on environmental issues, devise a comprehensive plan/chart in 5 points that is intended to raise youngsters’ consciousness about ways in which the ozone layer protects us against magnetic phenomenon.

Homework: 1. Complete your chart at home. 2. Develop a plan to teach those points to high school students. 3. Identify areas where your chart would need to improve. Develop a proposal for doing further research to enhance your chart. The proposal is to be addressed to the UN general secretary for approval.

Lesson X

More Interconnections: Linking Physics, Biology, and Chemistry

The Basics of Nuclear Magnetic Resonance Spectroscopy (NMR spectroscopy)

Mini-Lesson: Teacher asks three to four students to read their answers to the question on NMR spectroscopy that was assigned as homework for Lesson IV. As students read, teacher identifies the main features of NMR spectroscopy. Teacher complements students data, if need be.

Field trip. Teacher organizes a field trip to a microbiology or a chemistry lab at a research university. In the Boston area, Harvard outreach program is a good contact to arrange such field trip. Students visit laboratories that have NMR spectroscopy up and running. Students ask questions to the lab researchers and/or technicians about the machine particularly: its components, its mode of operation, its uses, and the way in which physics interact with biology and chemistry in this machine. Students observe and manipulate, if possible, the NMR spectroscopy under labs' researchers' and/or technicians' supervision.

Back to class. Jigsaw. Groups of students take notes from articles on NMR assigned respectively to each group. Reports: each group prepares a report synthesizing the main ideas of its article, incorporating lesson learned from the field trip, and indicating ways in which NMR spectroscopy is an example of a juncture at which physics, biology, and chemistry interact. Each group presents its report. Teacher engages students into discussion about the significance of interconnectedness in relation to NMR spectroscopy.

Brainstorming. Groups brainstorm about a research project they think they could conduct using NMR spectroscopy. They indicate the strategy/method they would use to

conduct the experiment. They formulate hypothesis. They write a cover letter along with their research proposal to the laboratory researchers they visited and ask them for advice to further their quest.

- **Homework:** Write a one page essay about ways in which magnetism might link many sciences.

Lesson Plan XI

The bigger Picture: Whole and Parts.

Class Discussion: Have students read their essay from previous homework. Pinpoint ideas from essays that allow discussion about whole and parts.

Problem Based Learning:

This lesson aims at engaging students in a Problem Based Learning (PBL) connecting bird migration and magnetic field. Students will devise an experiment to test hypothesis with very little help from teachers.

Magnetism: The Biological Connection. Do chemical reactions in birds interact with earth magnetic field to provide sense of direction? Or, else ...?

Students should be given appropriate time to set up and conduct experiment.

Activities for Problem Based Learning:

1. Students hypothesize in writing about birds' migration.
2. Class selects one problem related to birds' migration to investigate thoroughly
3. Form groups that would distinctly tackle particular aspects of the problem.
4. Students brainstorm and define sub-problems to investigate.
5. Question posing: groups formulate a set of research questions and choose one or two by consensus.
6. Review of literature, information gathering, usually through inquiry including reading, questioning (teachers and professionals), and trial-and-error activities. For all activities that present an imminent danger as perceived by the teacher, he or she should assist students in the manipulations of instruments and/or dangerous components.
7. Experiment settings,

8. Hypothesis
 9. Further data collection, Students should be urged to research books, magazines, and the Internet. In this context, the teacher guides students towards the discovery of concepts and principles and plays the role of a facilitator, ensuring a secure atmosphere
 10. Analysis of collected data,
 11. Conclusion and applications if possible.
 12. Teachers should ask each group of students a certain number of open-ended questions capable of initiating thoughtful discussion about whole and parts. Discussion might focus on nature and magnetism, birds and nature, birds' migration and survival.
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Lesson XII. Extension

Science and Society:

Electromagnetic field and Public Welfare

Warm Up. Students identify two cases in which electromagnetic field might endanger people in their opinion. Students explain the reasons motivating their suspicions.

Class discussion. Students present their cases and teacher tabulates them on the board. Teacher selects, with students' input, four recurring/important cases for class discussion. Teacher engages students into discussion about steps that should be taken to address their suspicions.

Teacher makes articles on electromagnetic field and society available to groups. Each group chooses an article. It identifies a potential problem associated with electromagnetic field that would be of some interest. It formulates research questions in relation to the potential problem. It formulates a hypothesis and develops a research strategy to investigate the issue. Each group hypothesizes on strategies to address the issue.

Presentation. Groups present: problem definition, research question, summary of investigation, recommendations, and methodologies to evaluate proposed solution and to refine it.

CHAPTER 7

CONCLUSION:

CONSIDERATIONS AND FUTURE DIRECTIONS

This synthesis evolves as a journey into the possibility of investigating science creatively in high school through the prism of a philosophy of science. In particular, this work underscores the prospect of blending dialectical materialist with Socratic probing and notions on creativity in a bid to scaffold the learning of science in authentic ways that can challenge and/or prevent overarching misconceptions. As it stands, the journey is far from reaching an end. However, at this stage, it warrants some considerations as a way to take stock of this rather unusual excursion, and some reflections on suitable future directions it might pursue.

Considerations

On writing, high schools standards and frameworks welcome students' creativity and inquisitive abilities, however, instructional practices in the classroom fail to reflect any kind of agenda that aims at stimulating or enhancing students' creativity and promoting dialectical understanding of natural phenomenon. Consequently, students tend to remain within the confines of simplistic interpretations that tend to flaw their reading of scientific notions and breed countless overarching misconceptions about science.

The teaching of science in high school has been based on models that exclusively present the sciences as distinct fields and in the forms of bits and pieces of information that students ought to learn in textbooks or to verify in pre-designed laboratories; without any other opportunities to neither study the underlying connections within a particular

scientific field nor the salient links between various sciences. In the process, the actual pedagogy of science limits the extent of students learning of science and overlooks the creative factors that underline the make up of science along with the potential educational strategies that could help students acquire science through their creativity. Yet students harbor in their cognitive processes various constitutive elements of creativity that could be enliven and incorporated in the teaching and learning of science. As a result, students appear to be withdrawn and distant from their classrooms.

Dialectical materialist provides critical vantage points from which one can investigate nature for significant understanding. Major dialectical materialist principles that can guide learners in their scientific exploration include: a) active interdependence of parts of a given reality and predominance of the totality; b) interpenetration of polar opposites forming internal contradictions that trigger changes; c) negation of a negation; and d) transformation of quantitative change into qualitative change. Coupled with the Socratic probing method and various strategies to elicit and boost creativity, those dialectical approaches coalesce into a comprehensive pedagogical model that can tackle students' large scale misconceptions and facilitate students' discovery of scientific notions with ingenuity. While the dialectical materialist principles can suitably shape science learning through its principles, it should also be opened to science for extensions of its own corpus and greater understanding of nature. Particularly, dialectical materialist ought to be searching through nature for other fundamental principles and further generate original reflections on the dynamics of science, which might in turn shed greater light on a genuine pedagogy of science in high school and other academic venues.

A science class that teachers structure around dialectical strategies while tapping in priority on students' creative attributes will bring not only more excitement to the learning experience but also greater understanding of nature's processes and operations. Such a project should help students be more responsive to classroom instructions in science and to use their cognitive processes more efficiently in processing academic notions. Equally important, dialectic approaches will help students espouse the habit of questioning their preconceptions, of opening their mind creatively to scientific ideas, and of implementing creative endeavors.

The model discussed in this work, Learning through Discovering Dialectically and Creatively ($L=D^2C$), tentatively provides an alternative pedagogical tool to achieve such goals. In a typical $L=D^2C$ unit, the preliminary lesson plans set the stage for students to capture and reconstruct established scientific knowledge in an exploratory fashion while they challenge their misconceptions. Those lessons aim at providing students with the appropriate background necessary to pose and research scientific questions in the context of problem base learning.

In this synthesis, I develop a unit that investigates the interconnectedness between electricity and magnetism, and interconnections between physics, biology and chemistry. The unit is designed for eleventh and twelfth graders. As the unit focuses on interconnectedness in sciences, it addresses two overarching misconceptions, namely naïve views that depict sciences as fragmented elements and that claim the existence of a unique and universal scientific method. The unit affords students the opportunity to be creative and reflective practitioner in doing science. In addition, students problem solve creatively by investigating the possible relationship linking magnetism and bird

migration. They create their own experimental settings, to reflect on their scientific methods as they inquire, and discuss about the nature of science. The instructional strategy involves teachers probing students with questions in the Socratic style while students research the literature, design experiments, and discuss on the nature of science in order to challenge particular over-arching misconceptions.

Future Directions

As a philosophy of science, dialectical materialism ought to be informed and molded by science as it attempts to make meaning of science and raise questions that transcend the scientific realm. Given the great affinity that links dialectical materialism with the new sciences of quantum mechanics, chaos and complexity; it has great potential to strengthen its explanatory power and to authoritatively raise and answer important philosophical questions related to the fabrications, applications, and consumption of sciences in society. Dialectical materialism's future relevance is thus tied to its capacity to confirm and revamp itself as the emergent sciences unfold conceptually and ontologically.

As for my own dialectical itinerary, it reaches a crossroad; just like an electron within its "electron cloud", which underscores its probabilistic occurrences in infinitely many spots, simultaneously, within a range. That is to say, I am tempted to go in many directions, wishing that I will grow wiser and uncover the "truth", the profound one. However, some opposing and perhaps more pragmatic internal factors are interacting with the bid for extremely optimistic pursuits, reminding me not to undertake more than I can handle realistically. This is not an easily reconcilable contradiction, for I do not even

have an accurate method to predict what is / would be really realistic. Can we ever know that before hand?

In any case, I have glimpsed at many new and higher degrees of complexity along my journey. I have come to appreciate their richness, precisely because of the rudiments of dialectical materialism's understanding that I have garnered along the way. It seems to me that it might be suitable to set a goal of investigating deeper complexity as a logical evolution of my dialectics journey. Perhaps, Peter Taylor's Unruly Complexity (2005) is a good place to re-start my new spiraling laps into the vast adventurous maze of contradictions and complexities that nature seems to jealously preserve for anyone who dares to seriously probe its hidden essence, be it simple or complex itself.

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