History and Philosophy of Atomic Theory
Cristobal Carambo: Spring 2018

ABSTRACT:
Since the early 1980's science teachers have been encouraged to include Nature of Science (NOS) themes in their curricula. The principle reasons given are that such a study will humanize the science content and make it more relevant and accessible to various populations that we teach. While the themes cited in the literature are important, many fail to account for the complex philosophical, historical and cultural issues that contextualize science. This unit is meant to address the limitations in current NOS curricula by exploring the historical and philosophical contexts in which modern science has developed. The unit focuses on the historical factors that have influenced the development of the quantum mechanical model of the atom. The unit focuses on the history of science from the early Greek philosophers through to the 20th century and the development of the quantum mechanical model of the atom.

Keywords:
Nature of Science, Philosophy of Science, History of Science, Scientific Revolution, Quantum Mechanical Model.

RATIONALE

The Nature of Science

Since the early 1980's the national science educations standards have encouraged science teachers to make the study of the Nature of Science (NOS) a central component of their curriculum (Lederman, 1992). Each of these reform documents beginning with the 1989 report "Science for All Americans" (Rutherford & Ahlgren, 1990), through the 1996 National Research Council standards to the current Next Generation Standards (cite) has highlighted the need to include NOS in the teaching of science. While there is no universal consensus on a precise definition of the NOS the following themes from (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) are considered by most educators as essential components of a nature of science curriculum:

Science is an empirical activity that uses a variety of techniques to make observations of the natural world. Inferences made from these observations serve as the basis of our scientific knowledge

Laws are descriptive statements of the relationship among observations, while theories are inferred explanations of these relationships

Although science is based on empirical observations, imagination and creativity, are part of the scientific process. Science is not an exclusively rational activity.

Scientists theoretical perspectives, personal beliefs, prior knowledge and experiences influence their labors

Science is practiced within a larger culture and is subject to the social and cultural influences of the society in which the science is carried out.

I have used these themes as guiding concepts in my chemistry curriculum because they have helped students understand that

> "…generating scientific knowledge involves human imagination and creativity. Science, contrary to common belief, is not a lifeless, entirely rational, and orderly activity. Science involves the invention of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists…" (Lederman et al., 2002 p, 500).

The inclusion of the NOS themes is of particular importance when I teach my unit on the history of the development of modern atomic theory. During the unit, the class spends time exploring the biographies of the major theorists (from Democritus through Schrodinger) and the historical eras in which they lived. The discussions provide a historical and social context to the relatively abstract chemistry of atomic structure. Discussing the lives of these famous scientists, the challenges they faced, and the culture of their time, humanizes the science content and makes it more accessible and relevant to my students. Although I have considered the structure of this unit as a successful inclusion of NOS into my chemistry curriculum, I have recently discovered that my approach is incomplete as it fails to address critical philosophical perspectives that influenced the development of quantum mechanics and our current model of atomic structure. By focusing exclusively on the socio-historical aspects I failed to address how changing epistemological and ontological perspectives affected the theorists, their experimental procedures, and their conceptualization of science. These themes drawn from the literature on the philosophy of science are necessary for a more complete understanding of the nature of science (Matthews, 2012).
I also realize that my teaching suggested that the evolution of atomic theory occurred as a result of the continuous, logical progression of atomic models. I taught my students that each theorist (from Dalton through Schrodinger) used their newly discovered theory to address (and correct) errors in their predecessor's model. The resulting theoretical model then became the basis of a new more "accurate" depiction of sub atomic reality. This notion is an oversimplification of the evolution of atomic theory as there is no such continuous development between models that are so radically different. This notion of a smooth continuous evolution of theory is incorrect as (Kuhn, 1962) notes that the change between radically different conceptual models is not commensurate. This is especially true in the development of our current quantum mechanical model of the as there are several major paradigm shifts occurring during this period: thus, the progress between the models is necessarily incommensurate.

During the course of my research for this paper, I have learned of a subsequent error in my own conception of quantum mechanics. In teaching about the nature of quantum phenomena I have always implied that the microscopic world of quantum objects was the basis of the macroscopic properties of matter we observe. I have always taught my students that "the microscopic informs the macroscopic". Although I knew that the scientists who developed the quantum mechanical model of the atom; (Bohr, Dirac, Pauli, Schrodinger, Heisenberg, Einstein, and others), had serious theoretical debates about their models, I had always assumed that they were all realists who believed in the reality of the quantum world. While their mathematical models may have differed, there was an objectively existing quantum reality that underlay their models. The work of each theorist was therefore bringing man ever closer to an understanding of the objective reality of quantum particles. This notion I now realize is incorrect. In fact as Neil's Bohr (a chief architect of our quantum theories) often stated; "the quantum world does not exist" quoted in (Becker, 2018). The debates arose because many central tenets of classical physics and our observations of macroscopic phenomena could not be reconciled with the physical properties of matter at the quantum level. This debate over the "reality of the quantum world" continues to this day. Erwin Schrodinger one of the principal theorist of quantum physics is quoted as saying:

> The idea of an objective real world whose smallest particles exist objectively in the same sense as stones and trees exist, independently of whether or not we observe them, is impossible (Becker, 2018, p. 14)

The issue of the existence of a quantum reality is however, moot for many physicists because the theories derived from quantum physics have provided us the dizzying array of technologies that make modern life possible. Our cell phones, computers, GPS satellites, MRI scans, flat screen TV's: (the list is endless) are the results of our understanding of quantum mechanics (the nature articles). This is the "evidence" of the underlying reality of nature and proof of the efficacy of our scientific knowledge. But is it?

Keller (1985) notes that although modern scientific theories can stand the test of experimental replication and logical coherence, the findings are

> prescribed to meet particular interests and described in accordance with a certain agreed upon criteria both of reliability and utility. The decisions about which phenomena are worth studying and which data are significant and useful "depend critically on the social, linguistic and scientific practices of those making judgements in question" (Keller, 1985, p. 11).

The statement suggests that scientific theories are influenced by a variety of social, political, and cultural forces. If science is a truth-seeking enterprise, then we need to determine what "truth" is and how that truth is validated. We also need to know who determines these truths, and how; who controls scientific truth? How have societies used science? To what ends?

To answer these questions and to fully understand the nature of science one needs to interrogate both the history and the philosophy of science for as Lakatos notes: "Philosophy of science without history of science is empty; history of science without philosophy of science is blind" (Lakatos, 1978, p102)

Towards a Philosophy of Science

Philosophy of science seeks to identify the epistemological, ontological, and metaphysical perspectives that inform and guide the practice of science. (*more needed here)*

> Philosophy of science, like philosophy in general is a discipline that tries to expose the underlying presuppositions that structure important practices and institutions of life. It subjects the structures of life and thought to critical examination. In short, it makes us think about what we are doing and why (Machamer, 1998 p.1)

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Unit Rationale
I plan to use themes from the history and philosophy of science to infuse a more critical perspective into my unit on the development of atomic theory. Students will examine the historical contexts and philosophical perspectives that influenced the work of theorist from the early Greek philosophers; (Democritus, Aristotle, Ptolemy) to the physicists (Bohr, Schrodinger Heisenberg, and others) who developed the quantum mechanical model of the atom.
This unit plan will begin with a brief narrative of the history of science. *(More explanation of the Unit here).*
Note on the Scope of the Historical Narrative
Given the time that science has developed and the number of scientist, this will necessarily focus on the scientists and philosophical themes relevant to the development of the quantum physics.
The philosophical perspectives of the philosophers mentioned in the history of science narrative **are the basis** of historical debates on the nature of reality(ontology), how we gather scientific evidence (epistemology) and how we use that evidence to formulate scientific knowledge (. A discussion of the merits of the differing methods of inquiry (induction vs. deduction) is relevant to my science class and will be explored in the section that follows and in the curriculum unit. However, given the scope of this paper, I cannot fully engage in the ontological debate that questions the existence of an external reality. While this is an important (and unresolved) issue in the history of philosophy, I feel that I cannot adequately address the issue in my high school chemistry curriculum. I will however need to discuss the question during the analysis of quantum mechanics as the debate of an objective reality that exists independently is at the heart of the ongoing (and unresolved) debate between as to the nature of the quantum world.

BACKGROUND
Science, History and the Philosophy of Science
Science is a distinctly human social activity that seeks to understand how nature functions. It is at once a method of inquiry, our stored collection of knowledge about the natural world, and our use of that knowledge to facilitate our survival. Given this definition, one can say that science has existed since the beginning of civilized life on earth as mankind has always asked questions of the natural world. The word science comes from the Latin term "Scientia*"* which means knowledge (Harper, 2001); and it is this knowledge of the natural world that has helped man survive and thrive on this planet.
Early man's survival depended on his ability to understand and predict nature's rhythms and use that knowledge to his benefit. He initially used mythology, religious and spiritual beliefs to make sense of the natural phenomena. However, as he sought answers to more complex questions his reliance on theology and mythology lessened as he needed a more intellectually rigorous method of inquiry to address his need to go beyond myths and religious dogma.
The transition to our modern conception of science began as Greek philosophers discarded mythological explanations and began to use reason to investigate the nature of matter, the causes

of material change, and the cosmos. They were the first to theorize that fundamental elements combined in a variety of ways to create all matter on earth and in the heavens. Greek philosophy explored issues of **ethics, moral responsibility, religious beliefs, metaphysics, mathematics of and the nature and interactions of matter.**

Thales (considered the "first philosopher (c.624 - c.545 B.C.E.) proposed water as the fundamental components of all matter; Anaximander (c.610 - c.545 B.C.E.) suggested the Boundless - Aperion as the source of everything), Anaximenes (c.546 - c.528 B.C.E) proposed Air as fundamental matter, while Heraclitus (c.540-c.480 B.C.E0 saw Fire as the prime element. The two theorists of importance to the development of modern atomic theory were the atomists Leucippus (c.490 - c.430 B.C.E) and Democritus (c.460 - c.370 B.C.E) hypothesized that all matter is composed of small indivisible and invisible particles which they called "Atomos". Aristotle (c.384 - c.322 B.C.E.) proposed that four substances (Air -Fire, Water-Earth) combined to form all matter on earth while the heavens were composed of a combination of fire and air (quintessence or Aether (Graham, n.d.). The atomist theory was discredited by Aristotle whose metaphysics would dominate man's conception of matter until John Dalton supplanted it in the 17th century. It is interesting to note that Dalton would use the atomist model as the basis of his atomic theory. The "existence" of atoms and subatomic particles would be verified in the 19th and early years of 20th centuries through the combined experiments of J.J. Thompson, Ernst Rutherford, Eugene Goldstein, and Neils Bohr. The nature of the "reality" of those particles however became the focus of intense debates between the realist, instrumentalist, and positivist perspectives of the many physicist who helped create the quantum mechanical model of the atom. The debate is ongoing as there is no consensus as to the "reality" of quantum particles (Becker, 2018).

While many of the Greek philosophers have influenced modern thought, this narrative will focus on the works of Plato (c. 427 - c. 347 B.C.E), Pythagoras (c. 570 – c. 395 B.C.E), and Aristotle as their differing views on the nature of reality (ontology) and how we gain knowledge of that reality (epistemology) have had a profound and lasting impact on the history and philosophy of science.

Plato (a skeptic) felt that the world (given that it was ever changing and impermanent) could not be the source of true reality. He envisioned the existence of a permanent, perfect world of Forms behind the world we perceive. The Forms in this abstract world embodied the true nature of reality, however man could not gain true knowledge of reality with our senses. According to Plato, that which we perceive are but the shadows of this underlying reality. Only through reason and philosophical discourse can we gain true knowledge of the reality.

Aristotle's philosophical perspectives differed substantially from Plato as he believed that the world was real, and that man could use his senses to gain knowledge of that world. He proposed that man's understanding of the world begins with empirical observations of natural phenomena.

Through the process of induction, those initial observations are used to formulate a set of explanatory principles that would be used through a process of deductive reasoning to (predict and explain) other instances of the phenomena in question: thus, verifying the general principle. It is through this manner of inductive - deductive reasoning that we create a body of scientific knowledge. It is interesting to note that Aristotle did not propose experimentation (the altering of natural conditions) as part of his scientific methodology. He felt that any such alteration would not produce Explain and cite….: thus, he did not propose experimentation as a means of gaining "true" knowledge of the physical world.

Pythagoras (a mathematician) also believed in the existence of an underlying reality that man could not directly perceive. To his followers, this "true" reality was described by the mathematical harmonies found in nature: To fully apprehend the nature of the world one needed to use numbers: for everything was made up of numbers. These models were of an almost mystical nature for the Pythagorean philosophers who had a profound belief that they reflected the true "reality" of the world. Pythagoras and Plato's ontological perspectives were similar to each other as they each prioritized an abstract hidden reality (Numbers or Forms) over human perceptions of the world. Pythagoras's belief that mathematics is the language through which we can understand reality has remained as an essential aspect of scientific inquiry. In the words of Galileo:

> I mean the universe…. cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it (Drake & O'Malley, 1960 p. 184).

Galileo's sentiment has permeated every branch of science as virtually every scientific law or theory is at some point explained through the use of a mathematical model. Mathematics for many is the language of science.

Philosophical problems arise however, when differing mathematical models can explain the same natural phenomenon, or when they contradict a fundamental belief. This was the case for the Pythagorean philosophers who posited a world consisting of only rational numbers (the ratio of two whole numbers) but were dismayed when they discovered the "existence" of irrational numbers that did not fit their paradigm. Pythagoras is known to have called the existence of these numbers as "unspeakable" (Losee, 2001).

Mathematical modeling proved especially disorienting for early astronomers when attempting to explain planetary motion. Ptolemy (c. 100 - c.178 B.C.E.) discovered that several different mathematical models could be used to explain the retrograde motion of planets orbiting each other in circular orbits. [1] Given his lack of instrumentation he could not differentiate between the competing models: (each of his geocentric models were wrong: but he did not know this!), so he chose to propose the model that best represented what was observed (whether or not it was true). In subsequent years other astronomers facing similar situations presented models that explained what was observable to the public, whether or not it reflected the "reality" of planetary motion. This practice by astronomers to present convenient models to avoid having to explain contradictory explanations became known as "saving the appearance" (O'Connor,J.J. & Robertson, 2003).

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[1] for more information on the issues of mathematical modeling and "reality" see: (O'Connor,J.J. & Robertson, 2003)

Ptolemy's decision to **choose** a model that did not necessarily correspond to the "reality" of planetary motion is of importance in the development of the philosophy of science as it suggests that there is often a disagreement between an observation and the proposed explanation (a theory) for that observation. A scientist who believes in a pre-existing objective reality (a realist ontology) will propose that a given explanation (or theory) represents that underlying reality. Astronomers such as Ptolemy could be considered as (instrumentalist or anti realist ontology) as they had no commitment (or belief) in an objective reality as long as their theory was able to explain observed phenomena. This tension between these differing ontological perspectives will remain throughout history of science (Matthew, 2012). It remains as the backdrop of our current debate as to the "objective reality" of the quantum world (Becker, 2012).
As stated earlier, this research will not explore this ontological question as it is not the real issue:

> The issue arises then is not one of ontology (we are accepting the existence of an external reality: but the serious debate among philosophers is not the reality of the world, but the reality of explanatory entities proposed in scientific theories. This debate between realist on the one hand, and empiricists, constructivists, and instrumentalists on the other hand has gone on since Aristotle's time (Matthews, 2012, p. 12)

Astronomers from Ptolemy until the time of the scientific revolution chose to present models that did not accord with "reality" because they had no evidence that would help them decide which among competing models was "correct". Their models were accepted because they accorded well with observations and had explanatory (and predictive) power (cite).
Such was not the case with the medieval astronomers (Copernicus, Galileo, and Kepler) who were forced to refute their theories of a heliocentric model and endorse the flawed beliefs in a geocentric cosmos. Although the models were simpler and able to address the many flaws in the geocentric model, the Church exerted its authority and suppressed the radical new theories. In time however the combined effects of improved instrumentation, more rigorous scientific methodology, and new mathematics, provided the evidence needed to supplant religious dogma and usher in new paradigms. These changes during these years would eventually lead to our modern perspectives of natural phenomena and the role of science in society. Although the major theoretical shifts occurred during the era known as the scientific revolution (approximately 1543 -1642), the gradual changes in epistemology and ontology were the result of the rediscovery of many ancient Greek texts that became available to natural philosophers during the middle ages. This would not have occurred without the contributions of Islamic scholars and the translations of the works of ancient Greek philosophers that they passed on to European cultures.

Islamic Empire and Medieval Natural Philosophy: Beginnings of Modern Scientific Method

The predominance of Greek philosophy waned as their civilization declined and other world powers surfaced. Although Greek culture influenced the Roman and later Byzantine Empires Greek thought would not reemerge until the 9th century when Islamic scholars began to translate Greek texts on ethics, natural philosophy, mathematics, medicine, and astronomy into Arabic. As the Islamic culture expanded Greek thought became a central part of its intellectual and scholastic life. When the Christians conquests began to reclaim European lands, the body of Greek thought became available to West. Beginning in the 11th century, scholars (mainly Christian monks) began to translate the Arabic texts into Latin: the translations would continue through the 12th and 13th centuries and end during the 15th century (the late Renaissance). The vast body of Greek writings (approximately 131 texts) revitalized man's interest in himself and the world around him (Hasse, 2014).

> the introduction of Arabic philosophy into Latin Europe led to the transformation of almost all philosophical disciplines. The influence was particularly dominant in natural philosophy, psychology and metaphysics (Hasse, 2014, p. 1)

The reintroduction of Greek philosophical traditions had a pronounced impact on the practices of natural philosophers during the middle ages they were able to use Aristotle's metaphysics and method of scientific inquiry as the basis of a more experimentally based natural philosophy (Sylla, 1998).

Of the many philosophers of the time, four are known to have contributed to changes in epistemology and scientific methodology. Robert Grosseteste: (c.1170–1253) studied the propagation of light and rainbows using instruments of his own design (Lewis , 2013); Joseph Duns Scotus: (c. 1265–1308) (though not a scientist, was a strong critic Aristotelean metaphysics and proponent of new perspectives on matter and ………….. , and William of Ockham (c. 1287–1347) who also proposed new modes of inductive reasoning and quality of theoretical explanations: he was the first proponent of simplicity as a necessary attribute of scientific theory that is still known as "Ockham's Razor, and Roger Bacon (dates: citation) (considered by many as the first modern scientist) who proposed a new method of inductive reasoning based on experimentation. Each of these philosophers were guided by new translations of ancient Greek texts and each contributed to changes in epistemology and methods of scientific inquiry.

Of these and many other medieval philosophers, Roger Bacon is especially relevant to this historical narrative as he proposed a shift away from Aristotelean induction and emphasized experimentation (*scientia experimentum)* as a necessary component of scientific investigations. It was his belief that experimentation should serve to confirm (or refute) existing knowledge claims, provide new observations and create new investigatory techniques and instruments. In his writings on experimental method, he notes that "nothing can be sufficiently known without experimentation" (Sidebottom, 2013). Bacon also believed in the practical applications of science to improve human life and foster prosperity (Antolic-Piper, n.d.).

Although the authority of the church in all religious and philosophical matters remained absolute, many natural philosophers of the time felt that man (through the use of his faculties, new scientific methods, instruments, and experiments) could understand nature and use her to his benefit. As a result, the latter years of the Middle Ages would be a time of innovation and great technological advances as man used his new understanding of the natural world to create great technological innovations in architecture (Gothic cathedrals), energy production, mechanical devices most notably clocks and the printing press). The combined effects of these many changes in man's conceptions of himself, the world around him, and his evolving scientific perspectives would set the stage for the profound epistemological and ontological changes that were about to overtake the world.

Towards a Scientific Revolution

Although the work of many Greek philosophers had been translated from the Arabic into Latin the pace of translations slowed during the late middle ages and ended during the late 15th century as humanism (not natural philosophy) became the focus of most Renaissance scholars. As a result, many Greek texts (the works of Ptolemy for example) remained unavailable to natural philosophers of the West. Humanist scholars however, (many of which were teachers) introduced ancient Greek into the curriculum of many universities which provided students in many disciplines access to the writings of Greek philosophers. This direct access to Greek thought provided many astronomers of the West, access to Ptolemy's writings: they soon discovered that his explanations chosen "to save appearances" did not accord with their observations. Islamic astronomers during the 12th and 13th century had also found it difficult to reconcile their observations with the Ptolemy and Aristotle's views of planetary motion.

Now with their own access to the writings, many Western astronomers began to criticize the geocentric model. It is important to note that the criticisms were not overt as the Church remained in firm control over man's place in the cosmos. Thus no one until Copernicus published his manuscript (*On the Revolutions)* in 1543 openly critiqued the geocentric model.

In 1496 Nicolas Copernicus began to study Greek and astronomy as part of his medical studies at the University of Bologna: here he would study with an early critic of the geocentric world view. He would continue to study medicine at the University of Padua where he also studied medical astrology: astrology was included as part of the medical curriculum during this time, as the stars were thought to influence life on Earth (Rabin, 2015). It is believed that the combination of his early studies helped establish his lifelong study of astronomy. Copernicus did not become a physician: he did earn a doctorate in canon law, but his interest in astronomy remained with him as he continued to study planetary motion (he would build his own observatory) for the rest of his life. Over time, he (like many other astronomers) found it impossible to reconcile his observations with existing dogma. Sometime around 1510 Copernicus circulated (but did not publish) an early critique of the geocentric model as the Church's authority was not to be taken lightly. He would continue with his studies and observations, and calculations which convinced him that his model was correct.

Historians do not know why Copernicus rejected the geocentric model. Suffice it to say that the heliocentric model was able to explain a host of errors in Ptolemy's and Aristotle's assumptions. It also explained (correctly) that the apparent retrograde motion of the planets is not "real" as we observe it because the Earth is in motion. Copernicus's manuscript "*On the Revolutions* was published the year of his death. It was not immediately accepted as there were some anomalies in his calculations. Observations by Kepler added necessary corrections to the model which would become the model we use to this day.

Scientific Revolution (s)

Thomas Kuhn refers to a scientific revolution as a period of intense intellectual turmoil, as once firmly held world views (paradigms) are overturned and replaced with new perspectives: after such shifts everyone sees the world differently (Kuhn, 1962). The historical era known as the scientific revolution (approximately (1453 -1642) was a time when changes in man's view of his place in the cosmos, and the fundamental laws that govern motion on Earth and throughout the universe were radically altered.

> …the revolution overturned the authority in science not only of the middle ages but of the ancient world since it ended not only in the eclipse of medieval scholastic philosophy but in the destruction of Aristotelean physics…
> Since it changed the character of men's habitual mental operations even in the conduct of the non-material sciences while transforming the whole diagram of the physical universe and the very texture of human life itself. It looms so large as the real origin both of the modern world and our modern mentality (Butterfield, 1959, p. vii)

In addition to changes in the fields of astronomy and mechanics, the age also produced our modern conception of the role of science in our lives. The scientist that had the greater influence on our conception of the science in society and how the practice of science unfolds was Francis Bacon**.** He was such an important figure in English society that he was knighted by James I in 1603. Bacon was a strong critic of traditional scholarship and scientific methods which he thought had become outmoded and obsolete. He proposed what has become the foundation of our modern "scientific method" through the introduction of new method of inductive – deductive reasoning based on systematic experimentation and empirical observations. This new epistemology differed from Aristotle's inductive - deductive method which used observations to induce general principles which would be used to analyze natural phenomena. Bacon argued that this initial process was flawed as one needed a large body of experimental evidence before formulating general principles. He proposed that before one could use induction to propose a generalized principle one needed to use one's empirical observations to produce a hierarchy of intermediary axioms (generalizations) that would be verified through experimentation. Each intermediary axiom would be used to formulate a subsequent generalization which would also be experimentally verified before continuing with the inquiry. The increasing body of evidence would then be used inductively to formulate the generalized principle (a theory) which could be used deductively to predict, analyze, or explain natural phenomena. In the event that an intermediary axiom proved false, then the scientist would have the opportunity to use his body of verified intermediary axioms as the basis of a new line of inquiry (Klein J. , 2016). Bacon also suggested that science is a collective social activity that occurs in communities of practice guided by established norms and procedures. Such a community would openly share experimental results, critique knowledge claims and propose new avenues of research. This belief in an international community of science remains to this day as there are countless scientific societies that meet at regular intervals to collaborate on important research efforts.

Bacon is also credited with defining the role of science in modern society for he was the first to suggest that scientific knowledge is a form of power that provides the technological and mechanical discoveries that drive historical change (Simpson, n.d.). Closely allied to this is the belief that man is meant to control and dominate (and manipulate) nature for his benefit. This is a problematic perspective as it suggested (to many) that man's necessities outweigh his responsibility for the sustainability of the ecosphere. Bacon's emphasis on the collection of vast amounts of experimental data had long lasting effects on the scientists of the time. It was especially dominant in the works of scientists working on chemical analyses of matter. Although chemistry had yet to become an official discipline many chemists were at work on the nature of chemical compounds, the energetics of chemical reactions, the nature of elements, and the nature of gases. Antoine Lavoisier (considered as the father of chemistry) was the first scientist to posit a list of elements as fundamental components of matter. Thus, he was able to fully supplant Aristotle's theory on the composition of matter. Using precise gravimetric analyses, he was also able to discredit the existing paradigm (the phlogiston theory) of combustion and prove that process is a chemical reaction involving oxygen. This by many accounts would be the beginnings of the scientific revolution in chemistry. Lavoisier's work on elements would provide the experimental evidence that accelerated the discover of many chemical elements during this time. In 1869 Dimitri Mendeleyev and Lothar Meyer both published periodic tables of the known elements. John Dalton (1766 -1844) a British schoolteacher / chemist proposed that the fundamental components of all of elements were small indivisible particles. He called them atoms in accordance with the name given by the early Greek atomists. Dalton postulate a list of attributes of atoms which became the foundation of our modern atomic theory. It is important to note that several errors existed in his early theory: as he believe atoms are indivisible and that all atoms of an element are identical. It is also important to note that not all scientist of his time believed in the existence of particles that could not be observed. Objections from various philosophical perspectives existed until early in the 20th century when the work of theoretical physicists finally proved the "existence" of atoms (Weisberg, Needham, & Hendry, 2016).

In the 1897, J.J. Thomson experimented with cathode ray emissions and discovered the first subatomic particle: the electron. In 1911, Ernst Rutherford working with alpha particle emissions discovered that atoms had a dense central region composed of positive particles: in 1917 he would name these positive particles protons. Later in 1932 a student in his lab (James Chadwick) would name the final neutral subatomic particle: the neutron.

Does it Exist?

The concept of the atom as consisting of negative electrons surrounding a nucleus composed of neutrons and protons was accepted by most of the scientists of the early 20th century. Serious problems arose when the attempting to explain the arrangement of the subatomic particles. Thomson originally proposed a plum pudding model in which the electrons were studded inside a positively charged "pudding". Rutherford posited that the electrons orbited the positive nucleus but was unable to explain why the moving negative charges did not slow down and crash into the positive nucleus. Neils Bohr was able to solve the problem by using a quantum mechanics to explain the movement of electrons about the atom. His theory was also incomplete as he was basing his assumptions on classical theories of mechanical motion. In order to fully comprehend the nature of quantum reality a new physics based on a differing set of assumptions for the nature of reality would be needed. The combined theories of a wide array of theorists: (Paul Dirac, Erwin Schrödinger, Werner Heisenberg, Albert Einstein, and others) would create what is known as the quantum mechanical model of the atom.

Quantum mechanics is (along with Einstein's Theory of General Relativity) one of the major paradigm shifts of our modern world. The problem that contemporary physicists face is that the microscopic "reality" of the quantum world does not follow the physical rules that govern our macroscopic reality. In this sense the appropriate question is whether the quantum world really exists independent of us: at the present time the answer seems to be no (Becker, 2018).

UNIT STRUCTURE

The unit is divided into two major sections separated by a series of chemistry lessons on atomic structure. The first section focuses on general philosophical themes that are relevant to the development the quantum mechanical model. Given the scope of this paper, I have needed to limit the range of topics covered in this unit as the study of philosophy is quite extensive. However, teachers using this unit may wish to explore additional themes with their students. These additional Resources for Teachers" are located in the appendix. The lessons in between the section are from my general chemistry curriculum and they will not be as fully articulated as the other lessons in this unit. This will offer chemistry teachers the freedom to teach the content in their own style.

STANDARDS:

Next Generation Standards

HS-PS4-3 Waves and their Applications in Technologies for Information Transfer
Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-5 Waves and their Applications in Technologies for Information Transfer
Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

HS-PS3-2 Energy
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Common Core Standards

CCSS.ELA-Literacy.RI.9-10.7
Analyze various accounts of a subject told in different mediums (e.g., a person's life story in both print and multimedia), determining which details are emphasized in each account.

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CCSS.ELA-Literacy.RST.11-12.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations
CCSS.ELA-Literacy.RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
CCSS.ELA-Literacy.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

PA. State Standards:

3.2. A10. A5. MODELS
Describe the historical development of models of the atom and how they contributed to modern atomic theory.
3.2.C. A5. MODELS
Recognize discoveries from Dalton (atomic theory), Thomson (the electron), Rutherford (the nucleus), and Bohr (planetary model of atom), and understand how each discovery leads to modern theory
3.2.C. A6. MODELS
Describe Rutherford's gold foil" experiment that led to the discovery of the nuclear atom. Identify the major components (protons, neutrons, and electrons) of the nuclear atom and explain how they interact

UNIT LESSON PLANS

Day 1 **Topic: Introduction to Philosophy**
Essential Question: What is Philosophy: What Does It Study
Objective: To evaluate the claims and premises of an argument: To differentiate philosophical inquiry from scientific inquiry.
Narrative: This is the first class of the unit in which we will establish the meaning of philosophy, the components of reasoned argumentation, and compare the various branches of philosophy to other disciplines. **Direct Instruction:** Philosophy defined as a process of reasoned inquiry: forming arguments. Students will learn the components of arguments: (claims and premises) and as well as how to evaluate an argument. Students will differentiate philosophical inquiry scientific inquiry. **Strategies:** Direct Instruction and whole class discussion **Classroom Activity**: A provocative (T-F) question is written on the board. Students are asked to answer the question and provide three reasons that support their answer. The

class will determine which reasons provide evidence to support a given claim. The class should arrive at an understanding of how logical reasoning from evidence can support an argument. Students will then examine the hypothesis, procedures and conclusions of a laboratory experiment. Students will be asked to compare the two modes of inquiry: How is philosophical inquiry different / the same as scientific inquiry. To close students will be asked to reflect on a series of questions as to the nature of philosophy: Questions adapted from: Center for Philosophy for Children To close students will be given a set of four index cards and asked to write down a something they believe people ought to do: (a normative claim) and a negative claim. Students should write down three reasons that support their claim. The exercise will be completed the following day.
Materials: What is philosophy questions Note cards.

Activity modified from Squire Family Foundation: squirefoundation.org/ curricula

Day 2 **Topic: Supporting Arguments:**
Essential Question: What are the qualities of reasoned argument?
Objective: To evaluate the reasons supporting a claim
Narrative: The class will begin with a discussion of the norms that guide philosophical arguments. Norms are necessary to help arbitrate possible disagreements. Once completed the class will engage in an activity that evaluates reasons used to support normative claims. **Strategies:** Whole class activity and group discussion **Direct Instruction:** Teacher will lead class discussion of in discussion of handout on norms for discussion. Relevant classroom norms will be included. Teacher will list discussion norms in the class. **Classroom Activity**: After discussion the class will divide into two groups (Group A and Group B). Teacher will collect cards assigned as homework. Once all cards are collected teacher will select a card from Group A: He will read a reason from the back of the card and challenge a member of Group B to guess the Claim. If successful, the team gets 3 pts. If not a second reason is read: if successful, the team gets 2 points: If still unsuccessful a third reason is read: if successful the team gets 1pt: If still unsuccessful Group A is given a chance: if successful they get 1 pt.: Note at each challenge the quality of the reasons in support of a claim are discussed. At the end of the activity the class is asked to list the of how reasons are used to support claims.
Materials: Note cards from previous night’s homework: Normative questions for class discussion.

Activity modified from Squire Family Foundation: squirefoundation.org/ curricula

Day 3 **Topic: Components of a Reasoned Argument**
Essential Question: What are the parts of a well-reasoned argument?
Objective: To analyze and evaluate the components of an argument
Narrative: Class will begin with a brief video: Monty Python's "The Argument". Once done the class will discuss the difference between the two types of arguments in the video. Following the discussion teacher will teach the components of an argument: proposition, premise and conclusion. **Strategies:** Whole class discussion; video viewing; direct instruction **Direct Instruction:** Teacher will define the following: argument, premise, propositions and conclusion. Teacher will use the terms proposition, premise and conclusion to define analyze the structure of an argument. Teacher will show students the arrangement of premises and conclusion of an argument in standard form. **Classroom Activity**: Students will view the Argument video and evaluate the difference between a contradictory discussion and an argument. After teacher has defined the terms, students will be given a set of propositions and asked to determine which are premises which are conclusions and how they can tell the difference. Once completed students will be asked to write an argument in standard form using the several premises, and a conclusion. For homework students will be asked to identify an argument (from any source and in any form) and determine its propositions, premises, and conclusion.
Materials: Argument video available at: https://www.youtube.com/watch?v=Lvcnx6-0GhA

Activity modified from Squire Family Foundation: squirefoundation.org/ curricula

Day 4 **Topic: Epistemology**
Essential Question: How do know?
Objective: To analyze the nature of our knowledge and evaluate the certainty of knowledge claims.
Narrative: Today students will explore the concept of epistemology. **Strategies:** Whole class group activity; direct instruction and discussion **Direct Instruction:** Teacher will define epistemology. **Classroom Activity**: Students will work in pairs to answer the "test for truth questions". Students will use their answers to develop a test of truth for knowledge claims. Once finished the class will engage in an activity that examines how knowledge claims change over time.
Materials: Test for Truth Questions and Epistemic Adventure Questions

Lesson adapted from: https://depts.washington.edu/nwcenter/lessonplans/epistemic-adventure-are-you-sure-that-you-know/

Day 5 **Topic: Observation and Inference**
Essential Question: How do we interpret observations?
Objective: To analyze how direct and indirect observations are interpreted.
Narrative: This activity will introduce students how inductive reasoning can be used to make inferences based on observations. Students will use indirect observation (mystery boxes) and direct observations (the check activity) to make their inferences. **Strategies:** Group activity and class discussion. **Direct Instruction:** Teacher will introduce the lab and define relevant vocabulary to be used in the post activity discussion: observation, inference, inductive reasoning, hypothesis and theory, **Classroom Activity**: Pairs of students are given a black mystery box and asked to use the given materials to determine the contents of the box. Students are also given a list of additional tools they might use to determine the contents. They will be asked to note each of their observations and asked to use them to infer the contents of the box. Checks Inquiry: Each group of students (4 per group) will also be given a series of checks (16 checks) written over a period of time for a series of purchases. Students are asked to use the checks to infer who the person was and to create a historical time line and narrative based on the history of the checks. Students will have to use the checks as evidence in support of their hypothesis.
Materials: Mystery boxes: assembly details Resources. Sample checks are in Teacher Resources. Lessons adapted from http://www.indiana.edu/~ensiweb/lessons/unt.n.s.html

Day 6 - Day 7 **Topic: Scientific Methodology**
Essential Question: What is scientific inquiry? Is there a scientific method?
Objective: To evaluate the use of the scientific method.
Narrative: It is important to note at the outset that there is no set scientific method. There are however an accepted set of practices that scientists have traditionally used in their investigations / experiments. This lesson is meant to introduce students to those practices and connect them to the prior lessons on inference, observation, and collaboration. The "steps" of the method are as follows: observation, forming a hypothesis, experimentation, reaching a conclusion, and publishing findings. The introductory lesson is a reading activity on the discovery of penicillin by Alexander Fleming. Students will analyze his experimental procedure and relate it to the "scientific method. The second activity will be a pendulum lab where students will have to determine which variables (length of string, or mass) affect the period of the pendulum. This is especially pertinent as it is a seminal experiment in the history of science. **Strategies:** Text analysis, whole class discussion and laboratory **Direct Instruction:** Teacher will review steps of the scientific method, defining each term. Teacher will give a brief synopsis of Fleming's life and work prior to the activity. Teacher will then instruct students on the pendulum lab. He will give a brief review of the history of the experiment and Galileo's life. Teacher will explain the variables in the experiment, the materials used, how to collect and tabulate the data.

Classroom Activity: Students will be given a brief historical narrative of the discovery of penicillin. Students will be asked to write a brief summary that relates the experiment to the "scientific method". Once complete students will begin the pendulum lab: they will be asked to determine which variable affects the period of the pendulum, however they should be given the freedom to design the experiment as they want. The goal is to explore how an experiment is carried out: rather than recreating a known conclusion.
Materials: Narrative of Fleming's experiment. Materials for pendulum lab: String, Ring stands, clamps, tape, various masses, (any other equipment students request).

Day 9 Topic: Summary Discussion on the philosophy of science.
Essential Question: How does scientific inquiry differ from philosophical inquiry
Objective: To differentiate philosophical and scientific inquiry
Narrative: This lesson will end the first section of the unit's focus on philosophy. It is important to review the structure of reasoned arguments, how they are used in philosophical and scientific inquiry and the role / importance of each type of inquiry. **Strategies:** Whole class discussion and review of unit lessons. Students will use their experiences to write a concluding summary that compares and contrasts scientific and philosophical inquiry. **Classroom Activity**: Students will be given a series of arguments and asked to determine which field they relate to. They will need to provide reasons to support their claims. Once complete they will be given a set of questions (or scenarios) and asked to determine which type of inquiry should be used. Students will write a summary that explains how the structure of the arguments, modes of inquiry, and conclusions differ in each discipline.
Materials: Guiding questions and scenarios.

UNIT BREAK:

Before continuing with this unit, students will need to have a rudimentary understanding of atomic structure. This will help them place the work of the scientists in context. I will list the topics to be covered, but I will not expand them as each chemistry teacher will have their own method for teaching these concepts. They are as follows

- Electron, Proton, Neutron
- Atomic Number and Atomic Mass
- Anion / Cation
- Octet Rule
- Electron Configuration
- Rutherford atomic model
- Bohr atomic model
- Quantum mechanical model

Day 10 **Topic: Historical Change**
Essential Question: How do theories change over time? Are they always accepted?
Objective: To analyze the process of theory change in science.
Narrative: This class begins with a review of questions from the lesson on epistemology that ask how we hold on to our beliefs and how they change over time. Teacher will give a brief lecture on the scientific revolution and the difficulties with promoting the heliocentric model. Students will discuss how / why the model was resisted. Class will then read a short narrative of Galileo's difficulties. This lesson will begin the exploration of how social, cultural, and political contexts affect science. Class will use today's discussion to explore these issues. In subsequent days, they will be asked to use the same kind of analysis to explore the lives of atomic theorists from Democritus to Schrödinger. **Strategies:** Lecture, Whole Class discussion, Reflective writing. **Direct Instruction:** Teacher will explain the historical events leading up to the scientific revolution, focusing on the changes in epistemology, scientific methods, and the role of authority in science. Teacher will discuss the lives of Copernicus, Kepler, and Galileo and the religious pressures each scientist faced **Classroom Activity**: Students will read Galileo's story and answer reflective questions on the relationship between history, authority, and world views affect scientific knowledge.
Materials: Epistemic Challenge Questions (Day 4): Galileo's Story and Reflection Questions.

Day 11 **Topic: History of Atomic Models**
Essential Question: How has the atomic model changed over time?
Objective: To differentiate the five types of atomic models
Narrative: Students will first draw their own model of the atom: they will discuss the merits of their model based on their knowledge of atomic structure. They will then be shown drawings of the five types of atomic models from Democritus through the quantum mechanical model. Students will rank them and determine which model accords with their understanding: (students will determine their own criteria). Students will then redraw their mode of the atom. Once complete the class will read a short playlet that places each atomic model into a historical context. The playlet will be the beginning of the summary activity on the lives of the atomic theorists. **Strategies:** Whole class discussion: reading activity **Classroom Activity**: Drawing models of the atom; Reading playlet
Materials: Diagrams of atomic models: Playlet of atomic theorists.

Day 12 **Topic: Historical Context of Atomic Models**
Essential Question: How have atomic models changed over time?
Objective: To analyze the social, cultural, and philosophical forces that have affected the development of atomic models.

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Narrative: Students will begin their final activity of the unit with an exploration of the lives and histories of the atomic theorists. The class will separate in groups of four and each group will research the life and work of a particular theorist. Each group will be given a rubric of necessary information that their report must contain. Teacher will provide supplementary information in the form of a webquest that students may use, however each group must also include textual information in their report. Each report will be submitted in written form and formatted in APA format. **Strategies:** Group collaborative activity: **Classroom Activity**: Students will break up into random groups: groups will select a theorist to research.
Materials: Research outline, WebQuest,

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APPENDIX: Resource Materials to Accompany Lesson Plans.

Questions for First Day Reflection:

Test for Truth Questions: Adapted from https://depts.washington.edu/nwcenter/lessonplans/what-is-philosophy/

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EPISTEMIC ADVENTURE QUESTIONS:
https://depts.washington.edu/nwcenter/lessonplans/epistemic-adventure-are-you-sure-that-you-know/

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Mystery Boxes

Each "Mystery Box" is a rigid, permanently sealed, opaque, rectangular box with one or two glued-in objects and a rolling sphere (e.g. a marble or steel ball). Students are asked to move the sphere around as means of "observing" the object in the box.

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PDF of Checks is located at: http://www.indiana.edu/~ensiweb/lessons/chec.lab.html

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Constructed Response II
SCIENTIFIC EXPERIMENTATION
The Discovery of Penicillin

In 1928 the Scottish scientist Alexander Fleming returned to his lab after a long vacation. His lab assistant had not cleaned the lab very well, thus many of his petri dishes had become contaminated with a strange mold. Fleming had been growing a bacterium called *Staphylococcus aureus* in the petri dishes. Scientists of the time were trying to find a substance that would kill bacteria, but not harm human beings. Fleming was upset because many of his bacteria samples were now useless: his experiment seemed ruined. But what caught his attention was the fact that no bacteria were growing in the area around the mold. He called the area where there were no bacteria a "zone of inhibition". But instead of throwing the ruined plates away, Fleming decided to investigate the mold. He then spent several weeks growing more mold. The mold was from the family called Penicillium. Fleming continued his experiment by growing the Penicillium mold and mixing it with many types of bacteria. After many experiments Fleming concluded that bacteria could not grow wherever the mold was growing. Fleming could not find the exact chemical in the mold, but he did publish his results. In 1940 two chemists in England began to work with Fleming's findings. They were able to extract the chemicals in the mold and make a brown powder. They proved that the brown powder killed bacteria. They called the new anti-biotic chemical Penicillin.

IDENTIFY THE STEPS OF THE SCIENTIFIC METHOD IN FLEMING'S EXPERIMENT

1. What did Fleming observe that was unusual?
2. What questions do you think he asked when he saw the mold growing?
3. What was his hypothesis? (A hypothesis is a possible explanation for our observations.)
4. Why didn't Fleming throw the contaminated dishes away?
5. Why did he mix the mold and the bacteria together? What was he trying to discover?
6. Why did he conclude that the mold was killing the bacteria?
7. What does this passage tell you about how scientists discover new things? Do experiments always turn out as planned? Or do scientists make "mistakes"
8. Do you think that scientists use only their science knowledge, or do they use their imagination and creativity in their experiments?

STEPS OF THE SCIENTIFIC METHOD:

1. Observe the natural world and ask questions: determine what you want to discover / explore / investigate
2. Research: (study the work of fellow scientists): study your question, or use your imagination / creativity
3. Formulate a hypothesis: (a possible explanation for your observations, research, or imagination)
4. Experiment to test your hypothesis-
5. Analyze your results: if not successful then start again
6. Make your conclusion:
7. Publish communicate your results

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SCIENCE CHANGE QUESTIONS ADAPTED FROM SCIENCE ON LINE TKE
http://scienceonline.tki.org.nz/

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Galileo's story: Retrieved From http://scienceonline.tki.org.nz/

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From Democritus to Rutherford: Developing our understanding of atomic structure:
A Classroom Playlet: Retrieved From http://scienceonline.tki.org.nz/