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Personal Beliefs as Key Drivers in Identifying and Solving Seminal Problems: Lessons from Faraday, Maxwell, Kepler and Newton

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ABSTRACT: The movement towards the use of the history of science and problem-based approaches in teaching serves as the impetus for this paper. This treatise aims to present and examine episodes in the lives of prominent scientists that can be used as resources by teachers in relation to enhancing students' interest in learning, fostering skills about problem solving and developing scientific habits of mind. The paper aims to describe the nature and basis of the personal beliefs, both religious and philosophical, of four prominent scientists—Faraday, Maxwell, Kepler and Newton. P atterns of how these scientists set the stage for a fruitful research endeavor within the context of an ill-structured problem situation are examined and how their personal beliefs directed their problem-solving trajectories was elaborated. The analysis of these key seminal works provide evidence that rationality and religion need not necessarily lie on opposite fences: both can serve as useful resources to facilitate the fruition of notable scientific discoveries.

KEY WORDS: history of science; science and religion; personal beliefs; problem solving; Faraday; Maxwell; Kepler; Newton

INTRODUCTION

Currently, there has been a movement towards the utilization of historical perspectives in science teaching (Irwin, 2000; Seker, 2012; Solbes & Traver, 2003). At the same time, contemporary science education reform efforts have suggested that teachers utilize problem-based instructional approaches (Faria, Freire, Galvão, Reis & Baptista, 2012; Sadeh & Zion, 2009; Wilson, Taylor, Kowalski, & Carlson, 2010). These separate orientations served as the impetus for this paper which aims to present and examine episodes in the lives of prominent scientists. Insights from this review can serve as a resource for teachers in enhancing students' interest

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in learning, fostering students' ideas about problem solving competencies and cultivating scientific habits of mind.

The literature is replete with descriptions and commentaries about how scientists solve problems to arrive at significant discoveries, but scant research has focused on how they choose the problem that they solve and how their beliefs serve as focusing mechanisms for this process. Personal beliefs may significantly influence the type of research problems that scientists may choose to work on (Berkson, 1974; Coll et al., 2009), the approach that they use in addressing the problem (Berkson, 1974), and the magnitude of effort and dedication that they invest in finding the solution to their chosen problem. Religious worldviews can be one such set of beliefs that affect one's research trajectory because such beliefs can interact with scientific thinking and influence the development of a scientist's "habits of mind," such as open-mindedness, skepticism and rationality (Coll et al., 2009, p. 211). These habits of the mind are important as they help scientists to come up with sound solutions to their chosen problems.

There are instances, however, when personal worldviews may hinder the progress of research and the growth of knowledge in science. For example, assumptions that are used in framing a problem may limit the possible solutions to be considered in solving the problem (Bransford et al., 1986). These assumptions can also reduce the margin of error that can be tolerated by a scientist before declaring a particular observation as acceptable in supporting a proposed theory (Kozhamthadam, 1994): too small a margin of error may lead to the dismissal of a potentially fruitful discovery, while a margin of error that is too wide may lead to the acceptance of false claims. In some cases, scientists may prioritize their religious beliefs over their scientific thinking when the two are in conflict (Coll et al., 2009). Religious convictions of certain groups may also delay the acceptance of revolutionary ideas that challenge current accepted views. A striking example is the strong resistance of the, then, leaders of the Catholic Church to the heliocentric view proposed by Galileo and Copernicus.

An extreme stance, floated in the 19th century, was that theological beliefs were grounded on irrational thinking (Stark et al., 1998) and needed to be set aside in scientific pursuits. Religion was usually associated with subjective and "non-communicable" knowledge, while science was associated with objective, universal and communicable form of knowledge (Tanzella-Nitti, 2009, p. *ix*). It might sound surprising, but several authors contended that the development of the idea of a scientific method started from philosophical and theological grounds (Tanzella-Nitti, 2009). Furthermore, many historic discoveries from the 16th and 18th century, dubbed as the period of scientific revolution, were crystallized by renowned scientists who were deeply religious. These golden years in the history of science saw how the great of works of Boyle, Gassendi, Descartes, Galileo, Oersted, Faraday, Maxwell, Kepler, and Newton slowly unfolded. These were examples of scientists who viewed their research as complementary, instead of threatening, to their faith. Their life and work served as a testimony to the possibility that personal beliefs, particularly religious beliefs, and science could have a harmonious interplay towards the generation of seminal ideas.

In this paper, we were particularly interested in exploring how prominent scientists -- such as Faraday, Maxwell, Kepler and Newton -- while wearing their religious and philosophical lenses, identified and dealt with problems that served as the foci of their scientific investigations and historic discoveries. We were fascinated by the coherence of their religious and philosophical beliefs and scientific pursuits that seemed to converge on the unity in nature. It was also interesting to note the fortuitous resemblance in social contexts of their scientific discoveries. Both Faraday and Kepler came from humble beginnings and the doors to scientific greatness were opened for them by their prominent employers who hired them as research assistants. Both struggled to make it on their own while living in the shadows of their eminent benefactors. Maxwell and Newton, both born into well-to-do families and regarded as gifted mathematicians, built upon and formalized the work of Faraday and Kepler respectively, to arrive at more comprehensive and impactful laws and principles that became the foundations of physics.

In this paper, we aim to:

1. extract patterns of how four creative minds set the stage for a fruitful research endeavor within the context of an ill-structured problem situation and how their beliefs directed their problem-solving trajectories;
2. build a case to show that rationality and religion need not lie on opposite fences, both can serve as useful resources for scientists, along with other problem solvers, to clear the barriers that stand in their way to notable scientific discoveries;
3. develop a resource that can be used by teachers in increasing students' interest in science learning, and
4. foster the realization that, just like scientists, students can undertake scientific endeavors without shelving their religious beliefs.

In addressing our objectives, we intend to show that science classroom contexts can be more accommodating to students' personal beliefs, which, in turn, can direct the students to fruitful scientific undertakings.

HISTORY OF SCIENCE FOR LEARNING

The use of a historical approach in science education has been introduced to enhance students' understanding of scientific knowledge (Irwin, 2000; Klopfer, 1969; Solomon, Duveen, Scot, & McCarthy, 1992). The history of science has asserted that the development of scientific knowledge is a dynamic process involving social, historical and other contextual elements, rather than being purely an abstract and a theoretical endeavor (Wang & Marsh, 2002). The historical approach of teaching science puts forth the following views.

1. A better understanding of the dynamic character of science can lead to more interest and motivation in science learning. The use of the history of science in teaching can result in the students' dynamic understanding of the discipline, because it exposes them to the conceptual, procedural and contextual dimensions of science (Wang & Marsh, 2002).
2. History of science enhances conceptual understanding, because it makes more interesting how scientific knowledge is presented, in addition to its predisposition to highlight the tentative character of scientific knowledge (Wang & Marsh, 2002). An enriched presentation of science knowledge does not merely recall concepts and theories, but explains how scientific ideas are constructed.
3. A historical perspective emphasizes the tentative nature of science, where it shows that theories can be in conflict with each other and that existing ones can be replaced by novel formulations, thus presenting a more nuanced understanding of how concepts are formulated.
4. The historical approach to science teaching can improve procedural understanding by providing descriptions and explanations about the processes involved in the design of the experiment and investigation, as well as the formulation of inference and conclusion (Wang & Marsh, 2002).
5. In terms of contextual understanding, history of science can provide explanations regarding psychological factors such as motivations, incentives and purposes that propelled scientists to address certain puzzles (Wang & Marsh, 2002).
6. Explaining the social and cultural dimensions that facilitate the scientists' interest in certain queries -- such as the influence of fellow scientists and social and political factors that affected their research thrusts -- likewise enriches contextual understanding of the theory-building endeavor (Wang & Marsh, 2002).

There has been a push to utilize the historical perspective in science teaching due to its benefits in advancing students' learning (Irwin, 2000; Mamlok-Naaman, 2011; Seker, 2012; Solbes & Traver, 2003). In the succeeding sections, the historical approach is applied to understand the conceptual, procedural and contextual aspects of the theory formulation and problem solving approaches of four eminent scientists. Given the focus of our paper on the scientists' personal beliefs and how such beliefs impelled their problem finding and theory building trajectories, we intend to contribute to enriching science teaching by deepening students' contextual understanding of scientific theories. Our contextual discussion specifically focuses on personal stories that can help in humanizing the scientists before the eyes of the students. The use of personal narratives as a teaching approach is found to stimulate students' interest in science learning (Hadzigeorgiou, 2006; Klopfer, 1969).

THE FOUR PERSONAL STORIES

1. Michael Faraday: Blending Sandemanian Faith and the Principle of the Economy of Nature in Investigating Electricity and Magnetism

Michael Faraday was hailed as one of the most influential scientists in the history of physics because of his discovery of electromagnetic induction, which was just one entry in the long list of his various pioneering accomplishments. His scientific efforts were guided and circumscribed by his religious beliefs, which were in line with the Sandamaian faith (Cantor, 1991). He believed that God created a well-designed natural world that embodies His perfection. He also subscribed to the principle of the "economy of nature." This indicated that all natural processes operated by following a certain divine order and obeyed a number of metaphysical principles which included, among others:

a. causality (i.e. every effect had a matching cause);
b. "simplicity" (i.e. laws tended to be simple);
c. "lawlikeness" (i.e. laws of nature governed the universe and represented a constant relation between cause and effect);
d. "invariability" (i.e. laws of nature were universal and unchangeable);
e. conservation (i.e. matter and force were conserved);
f. "unity and harmony" (i.e. laws of nature and matter were in harmony with each other; powers of nature were interrelated);
g. rationality (i.e., everything had a purpose and nothing was useless in nature); and,
h. "direct proportions" (i.e., simple proportionalities represented economical systems). (Cantor, 1991)

Faraday believed that his duty was to understand parts of God's design (Cantor, 1991). In line with this belief, he seemed to have identified a central problem that guided his scientific endeavor -- to find the connection between the “powers” of nature, particularly electricity, magnetism, light, heat and gravity (Cantor, 1991). Of all these powers of nature, electricity seemed to have received the greatest attention from Faraday.

Faraday’s fascination with electricity was seeded during the time he read books about electricity, while working as a bookbinder. His ticket to greatness was seemingly handed to him by Humphrey Davy, who hired him as a laboratory assistant. Working under the supervision of Davy, Faraday’s typical activities involved reviewing and repeating experiments conducted by other scientists. One seminal experiment that amazed Faraday and his eminent employer was that reported by Hans Christian Oersted in 1820--the generation of magnetic effects by electric current. Faraday’s interest in Oersted’s experiment could have sprung from the coherence of the findings with the principles of the economy of nature, especially in relation to unity in nature.

The repetition of Oersted’s experiment, according to Khlar and Simon (1999, p. 527), could have led Faraday to speculate a new hypothesis: if, as Oersted showed, electric currents could generate magnetism, then there should be circumstances under which magnetism would generate electric currents. However the fertile situation that encouraged the solution to this problem did not occur until almost a decade later. In 1824, Arago observed that a non-magnetic conductor, rotating below a freely suspended magnet, produced an attraction between the two; no attraction was detected when the disc was stationary (Cantor, 1991). Other physicists during that time were baffled by this problem: what made the moving non-magnetic material become attracted to a magnetic material? Aiming to address this problem, Charles Babagge and John Herschel conducted a similar experiment and conjectured that the attraction could be due to “magnetic induction” (Cantor, 1991, p. 235). This was the first time the term “induction”, which was typically associated with static electricity, was used in relation to a magnetic phenomenon. Faraday had seemingly thought about a new problem, on the basis of Arago, Babagge and Herschel’s findings: was it possible for electric induction to occur by means of a process similar to the generation of magnetic induction? On 28 November 1825, he indicated in his diary that he conducted three experiments using two circuits: the first circuit had a wire connected to a powerful battery and the second circuit had a similar wire connected to a galvanometer. He failed to detect current in the second circuit after varying the form of wires (straight or wound in a helix) in each experiment. After about six years, (29 August 1831) he modified his original set-up, this time winding copper wire around soft iron for each circuit to form two helices that could generate a stronger magnetic field. When he switched on the first circuit, so as to generate a strong magnetic effect from the current, the galvanometer showed a deflection signaling the presence of an induced current, albeit only momentarily. On that day, Faraday succeeded in solving one key problem that had troubled him for a long time — to show that magnetism could generate electricity.

After successfully generating electricity from magnetism, other problems still baffled Faraday. With similar passion as he did for linking electricity and magnetism, he attempted to address the problem of linking electricity and gravity, but he failed (Cantor, 1991). He also tried to understand the mechanisms that transmitted forces between magnetic poles or electric charges. To tackle this problem, he conceptualized lines of force linking opposite electric charges or magnetic poles; and introduced, intuitively, the concept of electric and magnetic fields acting throughout space (Tolstoy, 1982). Because of his limited mathematical skills, he was not able to formalize the laws involved to describe the interactions of lines of force.

Faraday's approach to problem identification and problem solving seemed to be anchored largely on his religious beliefs, which led him to focus on finding the relation between natural "powers", such as between electricity and magnetism on the one hand, and electricity and gravity on the other (Cantor, 1991). Guided by this key objective, he selected phenomena, or events that could be the springboard for identifying more specific problems.

Faraday also repeated and re-conceptualized the experiments of other scientists. Repetition of experiments, according to Gooding (1990), was a valuable way of enhancing the interpretation of a written account of the experiment and of acquiring procedural knowledge. He conducted exploratory experiments without a definite structure and clearly delineated goal, and was guided only by an ill-defined conjecture (Klahr and Simon, 1999). Ideas and questions that arose from his previous exploratory experiments served as the foundation for his subsequent exploratory experiments.

Overall, Faraday appeared to have played with ideas, tools and representations that were transient and flexible (Gooding, 1996). Although he emphasized the value of ideas based on actual observations, which was the hallmark of positivism, he also recognized the value of speculations in doing research. This approach served him well in his quest for uniting powers in nature, at least in the case of electricity and magnetism. This quest was later continued by Maxwell.

2. James Clerk Maxwell: Continuing the Quest for Unity in the Powers of Nature

James Clerk Maxwell (1831-1879) was a brilliant Scottish mathematician and theoretical physicist. He has been regarded as one of the pillars of physics owing to his formulation of the electromagnetic theory, which unified the three fundamental powers of nature: electricity, magnetism and light. In contrast to Faraday, who had limited formal education and mathematical competence, Maxwell had the finest education from the Edinburgh Academy and Cambridge University and embraced by the scientific community as an astute mathematician.

Campbell and Garnett opined that the “leading note of Maxwell’s character was a grand simplicity” (1882/1997, p. 204), which resonated with his propensity for the principle of simplicity. He considered the simplicity and conservation of the building blocks of matter as a reflection of the God of creation. In one of his public lectures on the *Discourse on Molecules,* he expressed the belief that the constituents of matter across the entire universe were identical in structure and behavior, and indicated that they were conserved over time:

> No theory of evolution can be formed to account for the similarity of molecules…None of the processes of Nature, since the time when Nature began, have produced the slightest difference in the properties of any molecule. … the molecules out of which these systems are built—the foundation-stones of the material universe—remain unbroken and unworn. They continue this day as they were created—perfect in number and measure and weight …they are essential constituents of the image of Him who in the beginning created, not only the heaven and the earth, but the materials of which heaven and earth consist. (Campbell and Garnett, 1882/1997, p. 176-177)

In harmony with his belief about the simplicity in nature’s design, Maxwell also found tremendous significance in a universe where the laws of nature were linked together. On many occasions, Maxwell expressed his profound belief that the unity in nature was part of God’s divine plan during creation. Stanley (2012), described Maxwell’s views as follows:

> [G]od communicated His existence, and it was the unity of laws that revealed this communication. An ‘arbitrary’ distribution of individual laws (like the articles of a magazine) would not suggest anything about a divine plan, but unification (like the chapters of a book) would be highly improbable and therefore was a kind of divine communication. God had a plan for the world, and part of that plan was designing natural laws to fit together like the pieces of a puzzle. (p. 61)

Maxwell believed that “hidden in the chaos of observable phenomena” was a fundamental principle, consideration of which led him to conceive the unification of fundamental powers in nature, such as light and electromagnetism (Stanley, 2012, p. 59). In line with this goal, he seemed to have found value in the works of:

(a) Faraday, who linked changes in magnetism to generation of electricity;

(b) Oersted, who linked changes in electrical currents to generation of magnetism;
(c) Ampere, who had shown that current-carrying wires exert mutual forces that are inversely proportional to the square of the distances (i.e., inverse-square law) between the wires, and
(d) Gauss, who linked the electric field -- to the distribution of electricity in an area.

All these significant discoveries linking the phenomena of electricity and magnetism were still fragmented during Maxwell's time; no grand theory was in place to provide an integrated perspective on the unification of the two phenomena. Cognizant of this gap in existing knowledge, and consistent with his predilection for simplicity, Maxwell wrote that "a process of simplification and reduction of previous results to a form in which the mind can grasp them would be the goal after studying the concepts and using highly mathematical tools" (Mahon, 2003, p. 56).

As history has it, Maxwell was successful in formulating mathematical expressions that succinctly presented the major laws of electricity and magnetism, which are known as Maxwell equations. These equations successfully forged the link between electricity, magnetism and light. Maxwell's formulation of his equations was hailed as momentous by the scientific community, but it was the addition of the last term in Ampere's law-- the displacement current-- that was regarded more as Maxwell's novel contribution to the field of electromagnetism. According to Chalmers (1975):

> Once the appropriate form of that current had been introduced, dramatic consequences, such as the propagation of electromagnetic effects in time through empty space and an electromagnetic theory of light, followed from it (p. 46).

Maxwell's inclusion of the displacement-current term in Ampere's law led to a dramatic consequence. It showed that an alternating electric field induced a magnetic field, and a changing magnetic field induced an electric field, which then produced a self-sustaining wave called an electromagnetic wave. Maxwell calculated the speed of this wave by determining the ratio of the electrostatic and electromagnetic constants in the modified Ampere's law. The result turned out to be equal to the speed of light! These developments resulted in the unification of electricity, magnetism and light and served as one of the most important theories in physics – the electromagnetic theory. Maxwell noted that "we can scarcely avoid the inference that light consisted in the transverse undulations of the same medium which was the cause of electric and magnetic phenomena" (Maxwell, 1965, p. 500).

Several authors gave varied explanations as to why Maxwell had conceptualized the addition of the displacement current in Ampere's law. Most of the reasons cited by the authors could be linked to Maxwell's philosophical beliefs. Using Bleaney and Bleaney's (1965) interpretation, Maxwell seemed to have realized that Ampere's law was incomplete, as it focused only on current from closed circuits. In the words of Maxwell (1873), in Volume 2 of his *Treaties*: "The currents used by Ampere, being produced by a voltaic battery was, of course, a closed circuit…no experiments on the mutual action of unclosed circuits had been made" (p. 151). Maxwell appeared to simplify or generalize Ampere's law by extending it to unclosed circuits which could have been inspired by his belief in simplicity. For Siegel (1975), Maxwell's motivation on adding a displacement current "was oriented toward the goal of theoretical completeness," showing compliance with the "methodological canon" that a theory must not only be comprehensive, but also complete (p. 364).

Modern textbooks usually note that Maxwell could have conceptualized the idea of the displacement current so as not to violate the principle of conservation of charge (Selvan, 2009), which was what clearly happened in an unclosed circuit (e.g., in the small space between capacitor plates). Maxwell's propensity for symmetry could have also predisposed him to extend Ampere's law. Tolstoy (1982) wrote that Maxwell might have adopted the following reasoning when he introduced the notion of displacement current in Ampere's law: "If electric currents generated magnetic forces, the converse, it seemed, should be true; on the grounds of symmetry" (Tolstoy, 1982, p. 113).

However, Chalmers (1975) believed that Maxwell thought about the idea of adding a displacement current, not because of his ideas on simplicity and symmetry, but for heuristic purposes: that is, in line with his problem-solving approach that followed progressive stages until the most appropriate solution to a problem was achieved. Chalmers highlighted that Maxwell progressively adjusted his initial heuristic model to come up with a final model that would produce a transverse electromagnetic wave travelling at a speed of light.

Maxwell's s philosophical beliefs that crystallized early in his career influenced and directed his scientific investigation. The fascinating unification (Salam, 1990) of electricity, magnetism and light through his elegant equations, was believed to be driven by the belief that the unification of the powers of nature was intended for discovery. Stanley (2012) wrote that:

> Maxwell's God wanted him to understand the world in deeper and deeper terms…He argued that God made the universe obey laws that were fundamentally unified and that He wanted humans to discover that unity. (p. 65)

Maxwell died at an early age of 48, but he was immortalized by his equations explaining the "never-ending wave that spread throughout all the dimensions of the physics of the 20th century and whose influence will continue to be felt for the centuries to come" (Rautio, 2006, p. 88). Boltzmann was in great awe when he read Maxwell's elegant mathematical equations – "a system of relationships between changing electric and magnetic fields—a whole universe of electromagnetic phenomena, miraculously contained in a few lines of elegant mathematics" (Tolstoy, 1982, p. 126).

Although some expressed reservations about linking Maxwell's scientific ideas to religious principles (Stanley, 2012), it was however apparent from his own writings and from the accounts of others who assiduously studied his work (Turner, 1996) that his discoveries were significantly inspired by his firm belief in the unification, symmetry, simplicity, conservation and order in the universe, authored by a God whom he believed in.

3. Johannes Kepler: Harmony in Religion, Reason and Observation in Investigating Harmony in the Universe

Johannes Kepler was an astronomer and mathematician who was credited with presenting the first truly sun-centered view of the universe and discovering the three laws of planetary motion. With humble beginnings that seemingly paralleled that of Faraday, Kepler worked as an assistant of a famed observational astronomer, Tycho Brahe. Just like Faraday, Kepler's religious beliefs, along with his philosophical convictions, influenced his scientific pursuits and other life decisions, even that of working under Tycho (Kozhamthadam, 1994; Baumgardt, 1952).

Kepler embraced key theological beliefs and views about nature that were also supported by Faraday (e.g., causality, unity and harmony, lawlikeness, rationality, simplicity and fixed proportions). However, he also espoused additional views which were regarded as non-traditional and, at times, bizarre by his contemporaries. For example, Kepler anchored his belief on unity in nature with the concept of the Trinity, which he linked to the existence of celestial spheres in the universe. He associated the *Father* with the center of the sphere, the *Son* with the surface of the sphere and the *Holy Spirit* with the space inside the sphere (Gingerich, 2011). Embedded in this belief on unity was the notion that elements in the world were linked to everything else (which paralleled Faraday's notion of the linking of "powers" in nature). Another non-traditional religious view that Kepler upheld was the notion of God working according to the principles of mathematics, particularly geometry, and harmony (Field, 2003). His view of harmony in nature was associated with quantifiable associations or definite proportions between quantities—which was inspired by ancient tradition (Field, 2003).

Kepler's philosophy was consistent with the principles of realism, part of which involved linking the material world to the spirit world and studying the universe by identifying real causes or forces responsible for events in the natural world (Kozhamthadam, 1994). Based on these foregoing beliefs, Kepler proclaimed that the core problems that he wanted to resolve were finding the real causes of celestial phenomena and identify laws (i.e., patterns or rules) describing the heavens parsimoniously (Barker & Goldstein, 2001). Kepler viewed God like a human architect who created the world in accordance with some order and rules (Baumgardt, 1952). A related key objective of Kepler was to study the existence of harmony in the universe (Field, 2003). In addressing these problems, he placed high value on precise observations and the concordance between observation and theory (Baumgardt, 1952).

In line with his core problems, Kepler formulated more specific problems, based on available information and his underlying religious and philosophical beliefs. First, he recognized that he needed to settle the problem of identifying the center of planetary motions before he could advance to identifying the laws that guide the motion of celestial bodies. At that time, the available alternative views were those proposed by Tycho, Copernicus and Ptolemy. Noting that the Sun was the source of light and life in the cosmos and thinking that the Sun was a reflection of God the Father who occupies the central point in the representation of Trinity, Kepler considered the Sun as the only celestial body that fitted the role of being at the center of planetary motions (Kozhamthadam, 1994; Gingerich and Voelkel, 2005) and rejected the geocentric view of Ptolemy. He also veered away from the Tychonian and Copernican systems that both considered planets as moving around a point with nothing in it, thereby violating the principles of causality and realism: He based this notion on the argument that an empty point could not be a cause, because "nothing" could be a cause of something (Kozthamthadam, 1994, p. 148).

In studying harmony in the universe, Kepler drew inspiration from Platonic and Pythagorean traditions. He implicitly aimed to answer this particular question: what aspects of the universe were constructed by God according to the model of musical harmonic ratios? He wanted to draw a connection between the universe and music, which meant consideration of mathematics (Field, 2003). During Kepler's time, a musical universe connoted a universe that was described in terms of mathematics; and the notion of harmony was linked to the musical harmonic ratios (Field, 2003). He claimed that heavenly bodies, just like people, had soul or awareness of cosmic harmonies (Baumgardt, 1952). Before dealing with this problem, Kepler realized that he must first find the theoretical basis of the musical ratios, along with the musical scale, by analyzing ratios between the string lengths of musical instruments (Gingerich, 1992). He was able to confirm that strings with lengths following consonance ratios (e.g., 1:2, 2:3, 3:4, 4:5

etc.) produced pleasing sounds. After doing this, he focused on planetary distances and motion around the sun. He tried multiple calculations but he found harmonic ratios only in relation to the speeds of planets (i.e., angular motion) when they were nearest and furthest from the Sun (Field, 2003). For example, Kepler's records showed that the minimum and maximum speeds of Jupiter were 430" and 530" per day, respectively (Gingerich, 1992); thus, its speed ratio was approximately 4:5, after disregarding the difference in seconds. The results were even more astonishing when he calculated ratios between extreme speeds of different pairs of planets: He was able to generate the intervals for musicals scales (Gingerich, 1992)! Quite amazing was the concordance between the small whole number ratios on planetary speeds that were found by Kepler and those found using modern instruments (Field, 2003).

Another investigation of Kepler that was apparently directed at unraveling cosmological harmony was essentially driven by this question: what is the relationship between the planetary distances from the Sun and planets' periods of revolution? Kepler was the first to pose this form of problem that presupposed a physical connection between the planets and the Sun. Kepler managed to rearrange Tycho's data on planetary distances from the Sun and the period of revolution of each planet to make this association more visible. After conducting multiple calculations, he was able to find a neat relationship between planetary distance and motion: the square of a planet's period was directly proportional to the cube of the planet's average distance from the Sun (Gingerich, 1992).

Kepler's idea of linking the Sun with the planets also turned out to be a part of addressing his goal of identifying the true cause of the motion of planets. He posited that the Sun exerted a magnetic force on magnetic planets that decreased with distance (Barker & Goldstein, 2001). He formulated this idea by drawing an analogy between the moving power of the Sun and those of light and magnet (Barker & Goldstein, 2001). Just like magnetic force and intensity of light, this power of the Sun decreased with distance and permeated space. He viewed the apparent connection of the Sun's force, magnetic force, and light as part of the divine plan of God (Barker & Goldstein, 2001).

Although the foundation of Kepler's quest to understand the harmony, beauty and mathematical nature of God's design was largely anchored on religious assumptions, this did not prevent him from adopting the philosophical view that theory should be consistent with, and should be supported by, experience. Kepler wrote, in a letter to Herwart: "For these speculations a priori must not be in conflict with experimental evidence: moreover, they must be in accordance with it" (Baumgardt, 1952, p. 6). Kepler kept an open mind as he conducted his investigation and was not afraid to abandon his initial hypotheses whenever available evidence pointed to the contrary and even if these initial hypotheses were aesthetically pleasing and markedly consistent with his notion of harmony. Examples in support of his open-mindedness and attribution of high value to observation included his abandonment of the notion of circular, in favor of elliptical, orbits of planets and rejection of the use of the famous Platonic solids to explain the distances between planets (Baumgardt, 1952). What seems to be fascinating in his work was the harmonious interplay between strong religious and philosophical beliefs, sound reasoning and meticulous observation.

4. Isaac Newton: Blending Faith and Natural Philosophy in Investigating Celestial Motion

Isaac Newton was a genius who "set a pattern for science for the next three hundred years" since the publication of his works on the laws of motion and the theory of gravitation (Hamilton, 1991, p. 15). Newton was the first who offered the most concise explanation of "how the universe worked from the smallest particles to the stars and galaxies" (Hamilton, 1991, p.15). Newton's book, *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) or, simply, the *Principia* (first published in 1687) was one of the most important works in the history of science and its "monumental significance was universally recognized" (Westfall, 1983, p. 21). It was also, in the *Principia*, particularly in the second edition published in 1713, where Newton appended the *Scholium Generale*, where he wrote about his theological beliefs about the role of God in nature.

The *Scholium*, among others, contained Newton's treatise against mechanical philosophy -- particularly the Cartesian variant which was dominant during the seventeenth century (Schöborn, 2007; Hall, 1992). Mechanical philosophy essentially treated "the creation as a 'universe machine' complete and self-sufficient in itself, perfectly stable and unchanging for all eternity" (Hall, 1992, p. 75). Such worldview, argued Newton, encouraged atheism because philosophers who subscribed to it confused God and matter. This notion was evident when Newton wrote: "[I]t is not surprising that Atheists arise ascribing that to corporeal substances which solely belongs to the divine" (Hall, 1992, p. 75). Newton's criticism of mechanical philosophy could also be traced in *De Gravitatione* (1668-70), which he wrote prior to the *Principia*. In this work, he particularly criticized Descartes for diminishing God's "guardianship of the creation" (Hall, 1992, p. 75).

In contrast to mechanical philosophy, Newton supported a *grand design* argument (Schöborn, 2007; Snobelen, 2001). Newton reiterated the hand of God in nature and His ubiquitous presence in it (Snobelen, 2001; Hall 1992). In the *Scholium*, Newton (1713/1999) insisted that the regularity of motions of bodies in space "did not have their origins in mechanical causes" and further asserted that the "most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being" (p. 940). Additionally, for Newton, God was constantly active and in control, directing His will over his creation (Snobelen, 2001, p. 202). However, unlike Kepler, Newton's God was unitarian rather than trinitarian in nature.

Although a known Newton biographer, Richard Westfall, expressed reservations about Newton's theology significantly influencing his natural philosophy; other scholars believed otherwise. Snobelen, for example, maintained that Newton's theological commitments crucially motivated him to "search out the wonders of creation" (2001, p. 197). A widely known letter, written by Newton to the Reverend Dr. Richard Bentley dated 10 December 1693, showed further proof of how Newton's theology had informed his natural philosophy. Stated in the first paragraph of this letter was the following:

> When I wrote my treatise about our system, I had an eye upon such principles as might work with considering men for the belief of a Deity; and nothing can rejoice me more than to find it useful for the purpose. But if I have done the public any service this way, it is due to nothing but industry and patient thought. (Thayer, 1974, p. 46)

Aside from religious beliefs, Newton shared many of Faraday's beliefs about nature and the process of scientific investigations. His belief in the unity of phenomena in nature and its use was included in his Rules of Reasoning, and his support for the principles of parsimony and simplicity can be traced in his scriptural writings (Snobelen, 2001). As an empiricist, he placed higher value on experimentation than on formulation of hypotheses to explain natural phenomena (Westfall, 1981). As a manifestation of his empiricist inclination, Newton wrote: "The proper Method for inquiring after the properties of things is to deduce it from Experiments" (Westfall, 1981, p. 342). As reflected in the *Principia*, Newton (1713/1999) introduced a method of natural philosophy that was empirico-deductive (in contrast to Descartes' hypothetico-deductive approach), whereby "propositions were deduced from the phenomena and were made general by induction" (p. 943).

With Newton's religious beliefs providing the impetus for him to study the grand design of the workings of the universe, he was drawn to the problem of explaining the motion of celestial bodies. His interest in this problem was shaped by reading the writings of Galileo and Kepler and correspondences with contemporaries, such as Hooke and Halley. In one paper, Newton substituted Kepler's third law into his formula for the centrifugal force (i.e., outward force from center of motion) of planets travelling in circular paths around the Sun and showed that this force was inversely proportional to the squares of the planet-sun distances (Westfall, 1983). Although he later abandoned the notion of centrifugal force, this mathematical approach led to the formulation of an inverse-square law that was applicable to planetary motion. In 1684, a thought-provoking question was posed by Halley to Newton: "what kind of curve would be described by the planets supposing the force of attraction towards the Sun to be reciprocal to the square of their distance from it?" (Christianson, 2005, p. 66). To this question, Newton replied that the shape would be an ellipse. When asked by Halley how he knew this, Newton answered that he had calculated it (Hall, 1992, p. 208). In an earlier manuscript, dated 1679, Newton acknowledged the role of Hooke's ideas in his linking of elliptical orbits of planets, which Kepler described as the inverse-square law for planetary motion (Cohen, as cited in Nauenberg, 2005). Prompted by Halley's request for the calculations that he had done, Newton made further improvements in the calculation; these efforts led him to the writing of the manuscript for *De Motu Corporum in Gyrum* (On the Motion of Revolving Bodies) and the longer treatise, *Principia*, which chronicled his three laws of motion.

Newton linked the inverse-square law for planetary motion with Galileo's writings on the motion of falling bodies. He used pendulums to test Galileo's conclusion that all bodies fell with the same acceleration. "When experiments were carefully made with gold, silver, lead, glass, salt, sand, common salt, water wood, and wheat," Newton noted that pendulums of identical length had identical periods (Westfall, 2007, p. 56). He concluded that "this is only possible if the Earth attracted all the particles in those various substances in exact proportion to their quantities of matter" (Westfall, 2007, p. 56)**.** After the consideration of pendular motion, Newton's belief in the unity of phenomena seemed to have led him to extend the application of the inverse-square law to the motion of the Moon around the Earth and then to the motion of all planets around the Sun (Snobelen, 2001). He eventually arrived at the conclusion that every particle of matter in the universe attracted every other with a "force directly proportional to the product of the masses and inversely proportional to the square of the distance between them" (Cohen, 2002, p. 58). This law of gravity was "sufficient to explain all the motions of the heavenly bodies and of our sea" (Newton 1713/1999, p. 943). It also elevated gravity as a universal relational property of objects with mass as an essential property of matter (Janiak, 2009). It could be inferred that Newton's efforts to universalize his law of gravitation, along with his three laws of motion, could have been inspired by his belief in a unitarian God, "the supreme God (who) necessarily existed, and by the same necessity he was *always* and *everywhere*" (Newton, 1713/1999, p. 942). Although other scholars (Weinstock, 1994; Kollerstrom, 1999) argued that Newton received more credit for the discovery of the universal law of gravitation than he rightfully deserved, it could not be denied that he was among the first few scientists to make a systematic formulation of unified view of forces causing motion by blending faith, reason, mathematics, and observation.

CONCLUSIONS AND IMPLICATIONS

Our analysis of the key scientific works of four great scientists-- Faraday, Maxwell, Kepler and Newton-- shows a human facet of scientific thinking, as well as illustrates how scientific minds draw connections between theory and evidence (Coll et al., 2009): that is, how scientists' personal beliefs, particularly religious beliefs, serve as an influential mechanism that direct their scientific works to monumental outcomes. Science students, like these scientists, enter the classrooms with their own personal beliefs. Often, teachers ask students to suspend their beliefs to foster objectivity in carrying out science activities and develop scientific understanding. Our review suggests that this need not be the case: Students, just like scientists, can meaningfully engage in science endeavor without setting aside their beliefs, as asserted by some science education researchers (for example, De Carvalho, 2013; Roth & Alexander, 1997).

In this paper, we also extract valuable information on the nature and basis of the personal beliefs of four great scientists, who are regarded as authority figures when it comes to the creation and evaluation of scientific knowledge, and how these beliefs bolster the efforts they devote to their scientific research that lead to astounding scientific discoveries. Their belief of an intelligent divine designer who is responsible for the order and unity in nature inspired them to find connections among natural phenomena, such as electricity, magnetism, and light, as well as search for forces and laws that govern the universe.

To pursue scientific quests in congruence with faith in grand design, Faraday carried out replication and exploratory experiments; Kepler performed meticulous calculations on large volumes of astronomical data; and Maxwell and Newton, capitalizing on their mathematical prowess, formulated elegant equations representing fundamental laws in nature. Contrary to the perceived antithetical relationship of religion and science, their religiousness did not bar them from utilizing empirical evidence as a key criterion in considering the paucity of proposed ideas. All of them maintained an open mind that had the readiness to adjust or change existing views in favor of those which were supported by evidence; their religious convictions did not at all impede their quest for truth. For these exemplary scientists, open-mindedness and valuing evidence were habits of the mind that helped in forging a fruitful interplay between religion and science. This occurrence was aligned with the arguments of scholars who upheld compatibility (e.g., Woolnough, 1996) rather than incompatibility (e. g., Mahner and Bunge, 1996) of science and religion.

The works of Faraday, Maxwell, Kepler and Newton serve as historical proofs that the harmonious blending of religious faith, philosophical beliefs, careful observation and scientific thinking can yield fruitful outcomes. They have shown that a prolific scientist can be both a positivist and a devout Christian. The harmonious co-existence of religious beliefs and scientific thoughts of our featured scientists incites further reflection and tempering of the perceived rigidity of the great divide and incompatibility of the personal and irrational religious experience and the impersonal and rational scientific endeavor. These reflections can also extend to science classrooms: Both teachers and students can be informed by our analysis to develop awareness of how scientific endeavors can be conducted within the context of an individual's personal religious beliefs. This can help in establishing a science classroom that respects and utilizes students' diverse beliefs as resources rather than barriers for advancing scientific understanding and skills while carrying out science activities, such as problem solving.

The results of this review can be used as resource by science teachers to increase students' interest in science lessons; promote problem solving skills, such as problem finding; and encourage the development of students' scientific dispositions. Given our paper's focus on how the personal beliefs of the scientists powerfully shaped their problem finding and theory-building trajectories, we hope to enrich students' understanding of the contextual dimension, particularly the human element of scientific undertaking. During science teaching, exposing students to this human aspect of the scientific enterprise may help them see science, not only as an intellectual activity, but also as a human and spiritual endeavor. This approach may help reduce the students' perceived conflict between science and religion (see Taber et al., 2011) and bring about an attitude that fosters "inclusiveness," rather than "exclusiveness" of science. Development of a more positive attitude towards science is particularly timely during this time, when science is usually perceived as an uninteresting, irrelevant and difficult discipline by students (Ornek, Robinson, & Haugan, 2007; Sjøberg & Schreiner, 2005). A more humanized approach in presenting science can help enhance students' motivation to study and appreciation of science.

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