Josiah Parsons Cooke Jr.: Epistemology in the Service of Science, Pedagogy, and Natural Theology

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Abstract: Josiah Parsons Cooke established chemistry education at Harvard University, initiated an atomic weight research program, and broadly impacted American chemical education through his students, the introduction of laboratory instruction, textbooks, and influence on Harvard's admissions requirements. The devoutly Unitarian Cooke also articulated and defended a biogeochemical natural theology, which he defended by arguing for commonalities between the epistemologies of science and religion. Cooke's pre-Mendeleev classification scheme for the elements and atomic weight research were motivated by his interest in numerical order in nature, which reflected his belief in a divine lawgiver.

Keywords: *Biography, philosophy of education, epistemology of science, natural theology, chemistry and religion.*

1. Introduction

Today, Harvard University's Department of Chemistry and Chemical Biology is among the finest in the world, counting three Nobel laureates and 17 members of the National Academy of Sciences among its 37 faculty (Jacobson 2010). Its road to this distinction began inauspiciously in 1850 with the appointment of a 23-year old largely self-taught chemist, Josiah Parsons Cooke, as Erving Professor of Chemistry and Mineralogy. Over the intervening 44 years, Cooke's strenuous and fruitful efforts as a teacher, department builder, researcher, and science popularizer significantly advanced chemistry instruction both at Harvard and throughout the Unites States. His efforts were so successful that after his death Harvard President Charles W. Eliot claimed Cooke "created the Chemical and Mineralogical department of Harvard University" (Eliot 1895, p. 23), while his doctoral student Theodore W.

Richards won America's first Nobel Prize in Chemistry for work begun under his direction.

Outside of scientific circles, Cooke was perhaps best known for his lectures on *Religion and Chemistry* (1864), a post-*Origin of Species* natural theology based on the chemistry of earth's surface and atmosphere. While many of Cooke's examples were simply updated versions of those used by earlier writers, his argument was distinctive in that Cooke explicitly grounded it in a particular scientific and religious epistemology. Unfazed by Hume's criticism of natural theology, Cooke not only admitted his argument was not foolproof; he used the analogical and inductive nature of natural theology to argue for its validity. In his apologia for *Religion and Chemistry*, *The Credentials of Science: The Warrant of Faith* (1893), the devoutly Unitarian Cooke developed an elaborate argument for commonalities between scientific and religious rationality to support his claim that denying the validity of religious knowledge undercut science as well.

In this article, we seek to explore Cooke's epistemology in the context of his research, natural theology, and educational work. We will see that his epistemology of science informed his educational reforms while his belief in an orderly universe influenced his atomic weight research. Because Cooke received an idiosyncratic chemical education and, like most 19th-century American academic scientists, functioned primarily as an educator, we will begin by considering how his educational work shaped his philosophy of chemical education and interest in the epistemology of science.

2. Self-educated chemical educator

Josiah Parsons Cooke Jr. was born on October 12, 1827, to Josiah Parsons Cooke Sr., a Boston Lawyer, and Mrs. Mary (Pratt) Cooke, the daughter of a Boston merchant. He became interested in chemistry after attending lectures by Professor Benjamin Silliman Sr. of Yale at Boston's Lowell Institute. While still a boy, he equipped a small laboratory in his family's shed where he repeated Silliman's demonstrations and taught himself chemistry by performing experiments from Edward Turner's *Elements of Chemistry* (Jackson 1895). He subsequently attended Harvard, graduating with an A.B. degree in 1848. However, since Chemistry was given scant attention in Harvard's curriculum at the time, his boyhood self-studies formed the bulk of his chemical education. Indeed, later in life Cooke would half-jokingly call himself a "self-made chemist" (Storer 1895, p. 20).

In 1849, after a year of traveling in Europe, Cooke began his career at Harvard as a Tutor in Mathematics, although given the lack of chemical instruction Cooke was asked to teach Chemistry only few weeks after beginning work. He quickly demonstrated exceptional skill, vividly illustrating his lectures with apparatus and materials from his boyhood home laboratory. This facilitated his appointment as Erving Professor of Chemistry and Mineralogy in the following spring, after his predecessor, John Webster, was hanged for murder. Formally, Cooke was expected to provide "consumable materials necessary for performing chemical experiments" at his expense, but in practice he furnished apparatus as well (Eliot 1895, p. 25). Thus Cooke spent the following year in Europe buying equipment, chemicals, and mineral samples (Jackson 1895, p. 3). He also attended Regnault's and Dumas' public lectures, which provided his only formal education in chemistry.

Much of Cooke's early work involved developing Harvard's chemistry program. Within a year of his return from Europe, he increased chemistry's prominence in the curriculum by successfully petitioning for its inclusion in the freshman, sophomore, and senior curricula,[1] arranged a survey of Harvard's mineral collection, and equipped a small research laboratory, where he provided laboratory instruction to select undergraduates (Eliot 1895, p. 30). Over the next six years, Cooke's tireless advocacy for chemistry and diligence as an administrator helped him to convince Harvard's administration to expand the department's laboratory space, equipment, and mineral collection. His administrative ability was augmented by his equally effective fundraising. Cooke even developed a 'matching funds' system wherein Harvard's administration agreed to fund half the cost of expansions if he raised an equal amount from private donors. The scale of these efforts was so vast that Cooke personally raised a significant portion of the construction costs for the 1857 construction of Boylston Hall, Harvard's first chemistry laboratory and anatomical museum (*ibid.*, p. 88).

Boylston Hall's new lab facilities enabled Cooke to introduce instruction in chemistry by Liebig's laboratory method in 1858, albeit as an elective course.[2] However, Cooke was not content with this success. For the rest of his life, he continued to expand the role of laboratory work in Harvard's curriculum, added new elective courses,[3] and augmented the department's lab space, equipment, and mineral holdings. In 1871 he arranged the merger of Harvard's chemistry department and the Lawrence scientific school, after raising the funds for a 3rd floor for Boylston Hall. In 1888-90 near the end of his career, Cooke freed space in Boylston Hall for organic chemistry labs by raising funds to expand the university museum so it could hold his vast mineralogical collection (*ibid.*, p. 38). As early as 1874, Benjamin Silliman Jr. could claim that "under the voluntary or elective system now in vogue at Harvard, and of which Prof. Cooke has been an earnest and successful advocate, that University has now the largest number of under-graduates devoted to studies in their well-appointed chemical laboratories, which have been assembled in any [academic] institution in this country" (Silliman 1874, p. 196).

Cooke's greatest contribution to chemical science arguably comes from his wider impacts in the field of chemical education. F.H. Storer, a onetime assistant who helped establish chemistry education at the Massachusetts Institute of Technology, regarded Cooke as "first and foremost" among the "great chemical teachers" in America (Storer 1895, pp. 21-2). While Storer's evaluation was partly due to Cooke's status as an extremely articulate and well-liked classroom teacher who "literally packed them in the aisles" (Rosen 1982), it was largely the result of the many students and assistants he trained throughout his career. Among his first research students, Charles W. Eliot, was instrumental in establishing Harvard as a first-class university after having first helped establish chemistry instruction at MIT, while Frank Austin Gooch, Henry Barker Hill, Charles Loring Jackson, and Theodore W. Richards made outstanding contributions to chemical education and research (Gaffney *et. al.* 2004).[4]

Cooke widely influenced American Chemistry education through his lectures, textbooks, and lecture demonstration apparatus. He traveled throughout the northeastern seaboard of the United States giving popular lectures on scientific and other topics, some of which were published in the American magazine *Popular Science Monthly* (Lockyer 1894a, p. 480). He gave eight lecture series at Boston's Lowell Institute alone between the years 1855 and 1893. These spanned an incredibly diverse range of subjects including Chemistry, Natural Theology, Electricity, Mineralogy, "the necessary Limitation of scientific thought", and "Photographic Sketches of Egypt" (Lowell 1894, p. 19).[5]

Cooke's textbooks are noteworthy in several respects. He was the first to introduce stoichiometry, nomenclature, and other types of problems into American chemistry texts (Jensen 2003). As early as 1857 he published *Problems and Solutions to Accompany Stöckhardt's Elements of Chemistry*, which contained stoichiometry problems and guidelines for writing formulas and reactions. His *Elements of Chemical Physics* (1860), which described in detail the common physical methods employed by chemists, and *First Principles of Chemical Philosophy* (1868), a comprehensive description of chemical theory, included a wealth of problems and examples at the end of most subsections. Although Cooke's contemporaries noted that these texts were disliked by students because they "required them to think" (Jackson 1895, p. 6), they raised the standard of American chemical instruction.[6] In 1874 Benjamin Silliman Jr. of Yale noted that "Professor Cooke has been largely instrumental in changing the older didactic methods of chemical instruction formerly in use, rendering them more exact and searching by a free use of the blackboard in the lecture room and laboratory" (Silliman 1874, pp. 195-196).

Of Cooke's scientific books *The New Chemistry* (1875), a series of lectures he gave at the Lowell Institute in 1872 to "an intelligent audience" trained in the dualistic system of Lavoisier and Berzelius, perhaps exerted the greatest popular impact (Cooke 1875, p 5.). In this work Cooke described the atomic-molecular approaches to chemistry developed since chemists' acceptance of Avogadro's hypothesis in the early 1860s. A review of *The New Chemistry* in *The North American Review* commented that it was not only highly accessible, it was the only English language book that presented the "wealth of new facts […] buried in the chemical journals of the last ten years" (Anonymous: 1874a), while *Popular Science Monthly* simply noted that "no other book in the whole range of science is so greatly needed as this" (Anonymous 1874b, p. 500). This highly popular work would eventually pass through five editions and be translated into most European languages (Jackson 1895, p. 8).

In building a reputable chemistry department, Cooke wrestled with chemistry's role in a classical liberal arts culture which traditionally held the natural sciences in low esteem. According to his student and later assistant Charles Loring Jackson, Cooke emphasized writing reactions to make chemistry more acceptable to Harvard's "literary community", while his efforts at increasing chemistry's prominence in Harvard's curriculum, which effectively placed it on an equal footing with the humanities, required his considerable skill "as a debater and a strategist" (Jackson 1895, pp. 4 & 8).

Cooke explicitly articulated his vision for the role of science in a liberal arts education as part of his support for Harvard president Charles Eliot's curricular and entrance requirement reforms. Eliot was Cooke's first research student, protégé, and colleague, first as a tutor in mathematics and later as Harvard's first assistant professor of chemistry. Not only did Eliot's experience in Cooke's laboratory help awaken him to the inadequacy of Harvard's recitation-based curriculum, some of his educational reforms were likely directly inspired by Cooke (Hawkins 1972). For example, Eliot's advocacy of the elective system and belief that education should be fitted to each student's individual abilities were anticipated by Cooke in the preface to his *First Principles of Chemical Philosophy* (1868).[7]

Cooke and Eliot recognized that improvements in science teaching created a rift between the goals and methods of classical and science education. Consequently, they sought to remove Harvard's Greek language admission requirement, making it possible to admit students with preliminary scientific training that could not be obtained in contemporary classical schools. Many faculty, fearing further expansion of science and technology in the curriculum or unable to conceive of liberal education without Greek, vigorously opposed the change. In response Cooke contended that science could advance liberal education just as well as classically liberal disciplines. In his "Remarks on the Greek Question" (1883, in Cooke 1885, pp. 203-213) and "Further Remarks on the Greek Question" (1884, in Cooke 1885, pp. 214-226), Cooke, who himself had difficulty learning classical Greek and Latin, argued that scientists should be trained using discipline-appropriate methods, even if these differed from those of the classical schools. This was consistent with Harvard's liberal arts mission because effective science education had the same aim as true literary education – to "train or culture the intellectual faculties" (*ibid.*, pp. 215-216). It was critical to use the correct pedagogy because neither scientific nor literary education is intrinsically liberal. Only science curricula that shape character by equipping students to rightly "observe, interpret, and rule natural phenomena" are truly liberal (p. 206).

Cooke's ideal liberal science education reflected his epistemology of science, as he indicated in the prefaces to his textbooks and addresses on "The Elementary Teaching of Physical Science" (1878, in Cooke 1885, pp. 71-85), "Scientific Culture" (1881 and 1884, in Cooke 1885, pp. 1-44, 227-266), and *The Credentials of Science: The Warrant of Faith* (Cooke 1893, pp. 195-208). He argued that "experimental science can never be made of value as a means of education unless taught by its own methods, with the one great aim in view to train the faculties of the mind so as to enable the educated man to read the Book of Nature for himself" (Cooke, 1885, pp. v-vi). This could not be done by requiring students to memorize and regurgitate chemical facts. Such methods were not only ineffective; they missed the point. Scientists are engaged in studying nature. Consequently they must be able to understand and "appreciate the methods and inductive logic of physical science" (Cooke 1870, *First Principles of Chemical philosophy 2nd ed.,* p. iv) and possess the "sharpness of perception, accuracy in details, and truthfulness" needed to observe, report, and interpret natural phenomena (Cooke 1885, p. 28). Cooke believed students could only develop these faculties by engaging natural phenomena firsthand, preferably through a course of laboratory instruction or, less desirably, a series of lecture demonstrations. His lectures in *The New Chemistry* (1875) and *Religion and Science* (1864) illustrated this methodology. He skillfully used demonstrations, diagrams, historical anecdotes, and life illustrations to lead listeners through the crucial experiments and ideas underlying atomic-molecular theory.

Cooke's laboratory-based approach is also reflected in that Cooke felt textbooks should only be used to "[supplement] some course of laboratory or lecture-room instruction" (Cooke 1870, *First Principles of Chemical philosophy 2nd ed.*, p. iv). Consequently, he developed numerous lecture demonstrations (Bliss 1940, p. 358) and published several to encourage their use in high schools and colleges. These include an apparatus for projecting the atomic emission spectra in a lecture room (Cooke 1865) and demonstrations illustrating the law of combining volumes (Cooke 1867).

At Charles Eliot's invitation, Cooke extended his laboratory-based approach to American secondary education through "The Pamphlet", a list of sixty experiments that prospective Harvard students must perform to qualify for admission (Rosen 1956, Rosen 1982, Cooke 1886). Although this list was not popular with contemporary high school teachers, it stimulated publication of "secondary school texts that emphasized both the quantitative and theoretical aspects of the science" (Rosen 1982). Cooke's own text, *Laboratory Practice: A Series of Experiments on the Fundamental Principles of Chemistry* (1891), detailed 83 experiments intended to help "prepare students for the further study of natural science in Harvard College" (p. 9). Because Cooke desired to make laboratory education accessible to communities with meager resources, he provided instructions for constructing apparatus from household and other easily obtained supplies.

Another issue Cooke took up was the relationship of science to American society. In his 'The Nobility of Knowledge' (Cooke 1885, pp. 45-70) and '"Nobilesse Oblige"' (*ibid.*, pp. 267-288) Cooke urged that American universities should not be viewed primarily as teaching institutions but centers for enriching America's intellectual and cultural life through research and literary endeavors. The problem was that American scientists, unlike their European counterparts, often labored under heavy teaching duties which greatly hampered their ability to engage in research and make discoveries. Consequently, Cooke strongly advocated the development of a system of public support for research by funding fellowships and professorships, so that scientists and other scholars could devote the main part of their lives to increasing human knowledge. Further, the bulk of support should be concentrated in a relatively small number of centers since these could exert greater cultural influence and would benefit from the intellectual stimulus of internal competition as well as enhanced cross-fertilization and refinement of ideas.

3. Natural theologian and philosopher of science

Cooke was concerned with the popular perception of conflict between science and Christianity in American society after the 1859 publication of Darwin's *Origin of Species*. Although Cooke first opposed evolution, he quickly recognized its explanatory power and believed that further advances would probably confirm it, at least in part.[8] As a devout Unitarian Cooke was also concerned over the "short-sighted" and "unchristian" tendency of many clergymen to depreciate science and its findings, a dangerous tactic given science's increasing explanatory power and influence in 19th-century culture (Cooke 1864, p. 2).[9] Thus, in early 1861 while many American protestant intellectuals were either abandoning traditional natural theologies or, like Cooke's colleague Louis Agassiz, criticizing Darwin's theory, Cooke delivered ten lectures before the Brooklyn Institute entitled "Religion and Chemistry: Proof of God's Plan in the Atmosphere and Its Elements", subsequently published under the same title (Cooke 1864).

Cooke spent the bulk of *Religion and Chemistry* trying to illustrate "abundant evidence of design in the properties of the chemical elements alone" because of which "the great argument of Natural Theology rests upon a basis which no theories of organic development can shake" (*ibid.*, p. viii). He used two complementary arguments, both of which were common in earlier natural theology.[10] The first involved design or special adaptations, in which the cumulative and "remarkably linked" properties of the solar system, earth's atmosphere, individual elements and compounds, and the biogeochemical cycles that allow for organic life suggested a "Divine Intelligence" (3^{rd} ed. Cooke 1880, pp 225-226). The second was the argument from general plan, in which the order and symmetry of scientific laws suggested that they were "manifestations of one grand comprehensive thought, which God is slowly working out in nature" (3^{rd} Cooke 1880, p. 260). Since both of these arguments were found in earlier natural theology, the chief novelty of Cooke's argument came from its connection to his scientific and religious epistemology.

According to Cooke, science and religious knowledge are fundamentally different. Science uses cognitive reasoning, describes the physical and material universe, and develops theories that, while imperfectly representing material reality, can be accurately formulated. In contrast, religion largely appeals to "the heart", deals with realities that transcend the physical and material, "stand[s] above man's intellect, and can only be shadowed forth in types and symbols" (Cooke 1880, pp. 312-3). Noting that scripture retains "the forms through which it was first revealed", Cooke argued there is no reason to expect the "letter of revelation to agree with the language of science" (*ibid.*). Consequently, the Judeo-Christian scriptures should not be used as a "textbook of science" either by employing particular passages to reject scientific findings or a materialist worldview to "impose an equivocal or mysterious meaning on its simple and obvious statements" (*ibid.*, pp 327-8).

Cooke recognized that the fundamental differences between scientific and religious knowledge had two consequences for natural theology. First, it limited the usefulness of the design argument as a tool for convincing skeptics. Second, science's picture of nature provided grounds for assuming a malignant deity as well as a benevolent one. Thus Cooke, like many mid to late 19^{th}-century natural theologians, believed that natural theology built upon scientific discoveries alone could not "prove the fundamental truths of Christianity" to the "unaided intellect" but rather only served to provide logical grounds for an Intelligent First Cause (*ibid.*, p. 329). Like his Harvard colleague Asa Gray, Cooke aimed to illustrate the compatibility between Christianity and science by presenting science theistically, not by proving theism from science.[11] Thus Cooke claimed that his examples confirm and illustrate, not establish, religious truths (*ibid.*).

One issue Cooke considered is the extent to which natural theology could be used to confirm Christianity as opposed to a generic brand of theism. It is clear that he did not expect natural theology to establish the full content of Christian doctrine. Still, he thought it possible to confirm the general "truth of Christianity" from "its adaptation to the spiritual needs of man" (*ibid.*, p. 5). The difficulty was figuring out how to subject any correspondences between Christianity and 'nature' to empirical study, a problem that caused him to place "the doctrines of Christianity as a system of revealed religion" outside the scope of natural theology since they do not deal with natural phenomena (Cooke 1893, p. 26). Instead he focused on individual human psychological experience and the historical experience of the Christian church, arguing "the movements of history are phenomena of nature" (*ibid.*).[12]

Given Cooke's reservations about traditional natural theology, it seems strange that the bulk of *Religion and Chemistry* is devoted to the atmosphere and its chemical constituents. However, this is to overlook the pastoral functions of 19th-century natural theology, which often used rhetoric to appeal to the heart as well as the mind (Brooke & Cantor 2000). Indeed, Cooke was extremely clear about addressing his arguments to believers and his natural theology texts largely follow the rhetorical style of the lectures on which they are based. Thus while he could not prove God's existence using science, his accumulated examples were intended to 'confirm', 'illustrate', and 'enforce' "the admitted truths of [Christian] revelation" to those with a preexistent faith (Cooke 1880, pp. 10-11). He also sought to combat "practical materialism" by making men "feel that the material is but a form of the spiritual" thus "ennobl[ing] and sanctify[ing]" scientific and technological progress (*ibid.*, pp. 10-12).

Cooke also had theological grounds for believing his arguments could convince non-believers. The Christian doctrine of Creation led him to expect that humans, who are created in the image of their Creator, can discern evidence of that Creator's existence and character in His Creation, including the physical and material universe (Cooke 1893, p. 212). Thus when a person recognized "special adaptations" in nature analogous to "the results of human intelligence, only of an infinitely higher order", they should reason by analogy that these were evidence of "an infinitely wise and omnipotent Designer" (Cooke 1880, p. 234). This is true even if the "special adaptations" are eventually shown to arise from evolutionary mechanisms or other natural processes since it "requires the same intelligence to create a universe by a process of development as by a single creative fiat" (*ibid.*, p. 249). Similarly, in Cooke's moral "argument from general plan", human intelligence could recognize "an intelligent creator" in the orderliness of the material universe and natural laws (*ibid.*, p. 259).

More importantly, Cooke understood the importance of science-based natural theology for countering science-based arguments for atheism. This is evident in how he used his epistemology of science to address potential objections to his natural theology. He defended natural theology's use of analogy, by which he meant any type of inductive reasoning based on points of similarity, by arguing that it is routinely used in the sciences. Thus rejecting the validity of analogical arguments in natural theology would effectively undercut the rationality of modern science. This was an important point for Cooke, because he believed it invalidated materialist scientific arguments for atheism, which Cooke considered the greatest practical threat to Christianity in a scientific age. Other types of objections, such as Humean skepticism or Comte's denial of the knowability of final causes, might be logically unanswerable. However, these were of little practical concern since they represented an approach to reality at variance with ordinary human experience (*ibid.*, pp. 236-7). Furthermore, for Cooke the strength or weakness of analogies was relatively unimportant. Not only could illustrations be multiplied to give a more potent cumulative argument, Christian teachings were also in a limited degree subject to experimental testing through collective human experience.

As might be expected from the pastoral and theological character of Cooke's natural theology, it was generally well-received by North American mainline churchmen. Favorable reviews in Presbyterian (Hodge 1881, p. 427), Episcopal (S. 1881), Methodist (Anonymous 1881a), Congregational (Sewall 1865), Quaker (Rhoades et. al. 1865), and Unitarian (Hill 1881) periodicals expressed appreciation for his criticism of scientific arguments for atheism. The conservative Presbyterian leader Archibald A. Hodge even praised Cooke for showing that "Hume and Kant did a great service to Natural Religion by their criticisms of the teleological argument for the existence of God" (Hodge 1881, p. 427). Its popularity may be gauged from the fact that *Religion and Chemistry* eventually passed through three editions and was regarded by Cooke's scientific peers as the most well-known of his works (Lockyer 1894b, pp. 551-2).

Not all of his contemporaries were so enthusiastic. Charles Eliot considered it inappropriate for Cooke to combine science and theology in public lectures (Hawkins 1972, p. 20). More importantly, Cooke's loose use of language and rhetoric in his otherwise philosophically sophisticated argument left him open to criticism. Although Cooke deliberately tried to avoid excessive anthropocentrism, his work is at times reminiscent of William Paley's

Natural Theology and *The Bridgewater Treatises*. Indeed, a significant number of Cooke's examples are updated, enlarged, and more engaging versions of those offered by William Prout in his Bridgewater Treatise *Chemistry, Meteorology, and Digestion Considered with Reference to Natural Theology* (1834).[13] Consequently, in his *Critique of Design Arguments* (1883) the Ohio geologist Lewis Hicks criticized Cooke for making eutaxiological arguments subsidiary to design ones as well as for his loose use of the term 'analogy', which Cooke sometimes seemed to equate with induction. The American philosopher Chauncey Wright produced a measured review of *Religion and Chemistry* (1865), part of which he later republished as *Natural Theology as Positive Science* (1877). He contended that Cooke's argument was a paralogism since it did not account for the reciprocal nature of life and the environment in natural selection. Wright also considered it inappropriate to use science, which Cooke admitted cannot prove final causes, to argue for theism.

Cooke's scientific and religious epistemology was further developed in lectures to theological students at Union Seminary in New York and Boston's Lowell Institute in 1887, which were later published as *The Credentials of Science: The Warrant of Faith* (1st edition 1888, 2nd edition 1893).[14] In these lectures he accepted Hicks' criticism of his rhetoric but rejected the latter's sharp distinction between design and general plan arguments. More importantly, Cooke charged Hicks with failing to recognize the necessity of inductive reasoning in religion. He admitted that Christian apologists who formulated natural theology design arguments as deductive ones begged the question of God's existence. To produce a self-consistent natural theology that adequately accounts for science's successful but limited ability to accurately model reality, it would be necessary to reformulate or re-envision these arguments as inductive ones.

As might be expected, Cooke's principal aim was to demonstrate that science and religious knowledge were both acquired through inductive reasoning and that, consequently, "the inductions of natural theology are as legitimate as the inductions of physical science" (Cooke 1893, p. 34). Thus Cooke spent a considerable part of *The Credentials of Science* arguing for Whewell's view of induction.[15] Like Whewell, he argued that Aristotle's view of induction as any "kind of inference through which we arrive at general principles" better described scientific reasoning than Bacon's "rules" (*ibid.*, p. 30).[16] This induction involves imaginative reasoning, inference, and other "intuitive act(s) of the mind working upon previous knowledge or experience, and familiar acquaintance with natural phenomena", occurs "more or less spontaneous[ly], and cannot be regulated by methods or directed by rules" (*ibid.*, p. 158). Consequently, Cooke strenuously resisted giving any precise definition of induction. Instead, he merely sought to illustrate its characteristic features using an account of the discovery of the universal gravitation that largely followed Whewell's *History of the Inductive Sciences* (1857). He also drew on Whewell in discussing two ideas that he would later argue represent similarities between scientific and religious epistemology: the role of intellectual culture in theory acceptance and the recognition that scientific insights sometimes come about through a sort of pro-inductive 'conjectures and refutations' in which even the "wild guesses" of "cranks" can be submitted to "the test of observation or experiment" (*ibid.*, pp. 63-4).

If Cooke viewed induction as the key to knowledge generation, deductions served to "trace the connections, develop the consequences" and otherwise raised the "general standard of knowledge" to the level of the new induction (*ibid.*, pp. 93-4). His view of deductive science bears a slight resemblance to Kuhn's normal science. Its job is not to change the overall state of knowledge but to work out its implications. Thus, it "almost exclusively occupies the time and taxes the energies of the great body of scientific investigators" (*ibid.*, p. 94) using "methods […] rules […] syllogisms, equations, observations, experiments, and measurements of every kind" (*ibid.*, pp. 158-159). Further, the interplay between induction and deduction played an important role in his natural theology. He could argue that scientific deductions do not lead to 'certain' conclusions about nature because the latter are only as good as the 'inductions' they follow and limited both by unavoidable experimental error and the simplifying assumptions used to apply scientific theories to complex natural systems.[17]

Cooke also limited science's ability to model reality, partly due to his own experience with the chemical 'revolution' that occurred after the widespread acceptance of Avogadro's hypothesis. He sometimes advocated an instrumentalist view of scientific theories, emphasizing their usefulness in suggesting fruitful directions for research.[18] This does not mean that he thought scientific theories had no basis in reality. Like Ptolemaic astronomy, the adamantine ether and organic molecular structures are "conventional symbols of relations which are at present incomprehensible" (*ibid.*, p. 241).[19]

Having established the limitations of science, Cooke used the final chapter of *The Credentials of Science* to explain how Christianity corresponds to man's spiritual needs and experience. He did so by drawing parallels between the advancement of spiritual knowledge represented through Christianity "as a force in the world" (*ibid.*, p. 296) and the advancement of scientific knowledge exemplified by Newton's theory of universal gravitation: Just as "the way was prepared for Newton", "for centuries before [Christ's] coming, all that was purest and noblest in the world's thought was leading up to the expected Messiah" (*ibid.*, p. 292) sometimes "by methods not always direct, and by servants not always worthy" (*ibid.*, p. 300). "As modern science dates from Newton, all that is noblest and best in man, all that is pure and lovely in life" dates from Christ's coming (*ibid.*, p. 292). Christian doctrine presents "difficulties of conception", just as gravitation is difficult to reconcile with "the mode of action of other forces in nature" (*ibid.*, pp. 292-3). Nevertheless, the application of both the "Christian doctrine as a rule of life" and the Law of Gravity is "simple and definite" in practical situations (*ibid.*). Furthermore, both Christianity and scientific theories use symbols to represent "realities in their essence incomprehensible by man" (*ibid.*). Just as astronomers have explored the deductive consequences of Newton's inductive insight, sometimes with individual astronomers engaging in internal quarrels and false deductions, the Christian church has been unfolding the consequences of the truth revealed in Christ, sometimes with individual churches and believers "using power and influence as instruments of oppression and persecution" (*ibid.*). The continual testing and confirmation of universal gravitation is analogous to the church's continual testing of "the plan of redemption first exhibited by the life and death of Christ" in the "lives and deaths of saints and martyrs" (*ibid.*, p. 298).

A discussion of Cooke's natural theology would be incomplete without noting how he explained divine action and the problem of evil. Given his emphasis on limitations in human knowledge, he did not think it possible to definitively address either issue. Instead, he adopted a defensive stance by taking issue with materialists who treat natural laws as efficient causes. Laws merely describe how nature ordinarily behaves and "Divine interference in the course of nature" was both conceivable and incapable of scientific disproof (*ibid.*, p. 165). Further, empirically undetectable divine action was plausible because of the many variables that govern natural systems. The influence of these variables could be seen from the imperfect ability to describe real physical systems by natural laws.[20] For example, no real gas truly obeys the ideal relationship known as Boyle's Law. Reasoning by analogy, Cooke considered it possible that the universe operates like a cosmic Jacquard loom: It weaves fabric just like ordinary looms yet, in a manner not obvious to ordinary observers, produces patterns according to punch-card encoded instructions. Similarly, by adjusting one or more of the variable conditions in the complex "loom of nature" (*ibid.*, p. 194) God can influence or arrange events in a way that is difficult, if not impossible, for observers to follow.

Cooke's approach to the problem of evil also rests on natural theology's limitations in that science "has not shed one single ray to lighten the darkness" of "the mystery of evil and the mystery of suffering" (*ibid.*, p. 320). Like many Victorians, Cooke believed the answer to evil is the religious faith "that good will somehow be the final goal of ill" (*ibid.*).[21] The best natural theology could do is confirm the perspective that "in the spiritual world men rise to higher things through sorrow" by demonstrating its consistency with how God normally acts in nature. Thus even natural selection with its concomitant "wholesale destructiveness" could be used to illustrate the Christian doctrine of "perfection through suffering" (*ibid.*, pp. 317-9).

4. Atomic weight research as a search for numerical order in nature

Cooke's research work produced several noteworthy contributions to chemistry, particularly through development of an early classification scheme for the elements, investigations into the limits and validity of the law of constant proportions, and the refinement of methods for accurate determination of atomic weights.

While his research was largely intended to advance chemistry, it also grew out of his teaching duties and was influenced by his interest in finding order in nature. This is evident from his most important early paper, "The Numerical Relation between Atomic Weights with Some Thoughts on the Classification of the Chemical Elements" (Cooke 1854) in which he described a classification scheme for the elements that he, like Mendeleev later, had originally developed as a teaching aid.

Inspired by homologous organic compounds, Cooke grouped elements with analogous chemical properties into six "series". Because some of these bear significant resemblance to modern groups, his classification scheme is sometimes considered an imperfect precursor to the periodic table (Kauffman 1969, pp. 128-31). Nevertheless there are important differences between Cooke's and Mendeleev's work. First, Cooke allowed elements, notably oxygen, to be members of multiple "series". Second, whereas Mendeleev's table recognized periodically recurring chemical properties when elements were arranged by atomic weight, Cooke developed simple algebraic relationships involving multiples of whole or half-integers to relate the atomic weights of elements with similar properties.[22] In fact, his scheme did not really look at true periodic trends at all since his atomic weight relations were within, rather than between, groups.

Cooke viewed the key innovation of his paper as the "the numerical relation between the atomic weights" (Cooke 1854, p. 239). This is a critical point, because it reflects his early emphasis on numerical relations in nature. Of course the search for such relations was not unique to Cooke, being found in Döbereiner's triad scheme and forming the staple of element classification until Mendeleev. However, in Cooke's case the search for numerical order stimulated an atomic weight research program.[23] He thought that more careful measurements would confirm Prout's hypothesis and reveal additional approximate relationships (Cooke 1882, *Principles of Chemical Philosophy,* 5th ed., pp. 270-4).

Cooke's most notable studies used gravimetry and argentometry to measure the atomic weight of antimony (Cooke 1877, 1879, 1880, 1881).[24] He early recognized the importance of constant error (Cooke 1854, p. 244) and sought to eliminate or correct for it using multiple highly pure starting materials, measuring the solubility of precipitates, and studying other effects. Through a series of analyses, he revised the previously accepted value from 120.3 to 119.96 (with a relative weight of 1 for H). Although Cooke admitted that this result seemed to invalidate Prout's hypothesis, its large deviation from the currently accepted value of 121.760 (Weisser 2009) shows how the search for numerical order may have misled as well as informed his research. When Willard and McAlpine corrected antimony's atomic weight to 121.77 in the 1920s, they noted that the usually careful Cooke rejected a more accurate value of 121.84 on grounds "not adequately supported by his own experimental data" (Willard et al. 1921, Weisser 2009).

Despite his stated reservations, Cooke continued searching for integral atomic weights and even discussed numerical order in atomic weights in the 3rd edition of *Religion and Chemistry*. After noticing that the O:Br:Ag:Sb atomic weight ratios would be integral numbers if the relative atomic weight of H was taken to be 1.0025 rather than 1, Cooke and Richards re-measured the H:O atomic weight ratio twice (Cooke 1887, 1888). Because the resulting value of 1:15.869 did not agree with the desired 1:16 ratio within experimental error Cooke finally concluded, "although the exact value of the atomic weight of oxygen may hereafter be found to differ more or less from the number we have finally reached, the general result of our work has been to invalidate the hypothesis of Prout" (Cooke 1893, p. 147). Nevertheless he remained personally convinced of the meaning and significance of the "close approximation of the ratios of so many of the atomic weights to a proportion between whole numbers" (Cooke 1893, p. 147).

In addition to his chemical researches, Cooke made noteworthy contributions to mineralogy, including the discovery of the Danalites and analytical and crystallographic analyses of Chlorites and Vermiculites (Jackson 1902). The chlorite mineral Cookeite is named after him, as he was the first to discover its pyrognostic properties (Brush 1866, p. 248).

Cooke's scientific and educational accomplishments brought him early recognition including membership in the American Academy of Arts and Sciences, which he successively served as librarian, corresponding secretary, and president, as well as election to the National Academy of Sciences and the Royal Institution.

Cooke died in Newport, RI, on September 3, 1894, survived by his wife Mary of 34 years. He left behind no descendants, although his work lives on through Harvard's chemistry department, the accomplishments of his many students and their 'scientific descendants', and modern general chemistry curricula and textbooks.

5. Epilogue

While it can hardly be doubted that Cooke's epistemology of science has had a salutory effect on chemical education, it is more difficult to assess the impact of his natural theology. His belief in an orderly creation encouraged him to doggedly pursue fruitful avenues in atomic weight research but likely contributed to his report of an incorrect atomic weight for antimony. The success of his natural theology at reconciling faith and science in the minds of many contemporaries can be seen from favorable reviews of *The Credentials of Science: The Warrant of Faith* in Baptist (Samsom 1889), Presbyterian (Patton 1889), and liberal (Anonymous 1888) Christian periodicals. The editors of *The Expository Times* even suggested Cooke for a Gifford lectureship (Anonymous 1894). However, although Cooke's work continued to be cited appreciatively into the next century, several factors hindered its further development. Since these have relevance for contemporary scholarship on the relation between science and religion we briefly review them here.

Cooke's biogeochemical natural theology suffered from science's ambiguity with respect to religious knowledge. This meant that his argument could be easily ignored, particularly after the secularization of American academia. Indeed, a quarter century later when another Harvard chemist, Lawrence Joseph Henderson, presented an updated and secularized version of Cooke's biogeochemical argument in *The Fitness of the Environment: An Inquiry into the Biological Significance of the Properties of Matter* (Henderson 1913)[25] he seemed unaware of Cooke's work. Worse still, this ambiguity meant that some of Cooke's insights could be given interpretations counter to those he intended. For example, his notice that natural laws imperfectly represent nature could be used to counter his argument from general plan. Indeed, Nancy Cartwright's claim that natural laws' inability to represent real systems exactly calls for a 'dappled world' with no universal laws, is also motivated by the view that universal laws imply a lawgiver (Cartwright 1983 & 1999, Jaeger 2010). However, few scientists support so radical a view of natural laws. Thus versions of Cooke's natural theology survive, although now that chemistry is considered the 'central' rather than fundamental science these are now usually framed in terms of physics and cosmology. When some of Henderson's arguments were reformulated in terms of the universe's fundamental physical constants by John Barrow and Frank Tipler in *The Anthropic Cosmological*

Principle (Barrow & Tipler 1986), some theists found their arguments supportive of the existence of a Creator.

Perhaps the most important factor in the decline of Cooke's natural theology was his weakly-developed philosophy of religion. As some reviewers of *The Credentials of Science* remarked, Cooke wrote from a scientist's perspective and his epistemology of religion was weak on details. Further, the lack of any well-developed contemporary epistemology of religion made it difficult to further develop Cooke's work, a fact the Princeton theologian Charles Woodruff Shields noticed at the time (Shields 1889, p. 418).

Finally, much of Cooke's inductive epistemology fell out of vogue when early 20th-century philosophy of science narrowed its focus on logical positivism and justification. Thus, any revision of Cooke's program had to await Kuhn, Lakatos, and Feyerabend's work, which renewed interest in the logic of discovery and fostered acceptance of non-algorithmic approaches to scientific rationality. Indeed, the next serious effort to argue for the rationality of religious knowledge based on a common epistemology of science and religion was carried out by one of Feyerabend's students, the philosopher-theologian Nancey Murphy. In her *Theology in the Age of Scientific Reasoning* (Murphy 1990) she attempted to demonstrate that theology followed Lakatos' research program model of scientific rationality. However, Murphy's aim and methodology differed significantly from Cooke's. Not only did Murphy hope to harness the power of a definite scientific methodology to lend force to her affirmation of theological rationality, she was also primarily concerned with countering Hume, whose critiques Cooke regarded of little practical relevance. Interestingly, Murphy seems to have recently softened her emphasis on methodology, focusing, as Cooke did, on the importance of knowledge generation in religious communities over time (Murphy 2011).

Any approach that seeks to avoid reducing the philosophies of science and religion to their respective sociologies or acknowledge the possibility of genuine religious knowledge could learn from Cooke's work, particularly his recognition of differences between scientific and religious knowledge and the limited capability of natural theology. Despite its drawbacks, Cooke's natural theology writings represent a salutary attempt to explore the relationship between science and religion while respecting the knowledge claims of both.

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Notes

1 At this time all Harvard undergraduates took the same courses. Harvard transitioned to an elective system during Eliot's presidency.

2 According to his contemporaries, Cooke adopted the laboratory method due less to Liebig than his boyhood 'chemical education'.

3 According to Eliot (1895), by 1873 these included descriptive chemistry, mineralogy, quantitative analysis, and organic chemistry. In 1892-93 Cooke gave a course on 'Chemical Philosophy and the History of Chemistry.'

4 The chemist-philosopher Charles Sanders Peirce also studied chemistry under Cooke (Siebert 2001).

5 Cooke cultivated a lifelong interest in photography. As a student in the 1840s he was among the first Americans to produce Calotypes, today the oldest in North America (Banta 2007). Less than two years before his death he lectured at Boston's Lowell institute on "Photographic Sketches of Egypt" (Lowell 1895).

6 William B. Jensen believes these texts were "by far the most scientifically sophisticated ever produced by an American Chemist during the 19th century" (Jensen 2011, p. 17).

7 In this preface Cooke praises Eliot and Storer's *A Manual of Inorganic Chemistry* (1867) as the exemplar of his laboratory method, a work they had dedicated to Cooke "their teacher in chemistry […] in token of gratitude and friendship".

8 Cooke recognized evolutionary theory's explanatory power but objected to Darwin's presentation of it, which he felt did not discourage materialist interpretations.

9 Cooke even held weekly religious meetings in his home through which he influenced several students who later became notable religious figures in New England, including William Reed Huntington and Francis Ellingswoood Abbot (Northup 1993, Ahlstrom *et al.* 1987, pp. 23-24).

10 The sub-title of the 3rd edition, *A Re-statement of an Old Argument*, indicates that Cooke did not view his natural theology as genuinely new.

11 See Roberts (1988) and Moore (1979) for a discussion of Asa Gray's support of Darwin and relationship with Agassiz.

12 Although space precludes a full analysis, Cooke's natural theology of religious experience shares several features with some contemporary epistemologies of religion developed in response to the success of science. See Roberts 1988, pp. 157-173 for a summary of these views.

13 Cooke's examples also depend on Arnold Henry Guyot's *The Earth and Man*, Faraday's *Six Elementary Lectures on Chemistry* (*i.e.* 1827 Christmas Lectures), and John Tyndall's *Heat as a Mode of Motion*. Interestingly, he did not refer to George Fownes' *Chemistry as Exemplifying the Wisdom Beneficence of God* (1844) or George Wilson's *Religio Chemici* (1862).

14 All quotes are from the 2nd edition.

15 See Snyder (2006) for a fuller description of Whewell's views and a refutation of the claim that Whewell advocated a hyopthetico-deductive scientific methodology.

16 Cooke tellingly notes "practically no great originator in science ever followed Bacon's rules, or any other rules; although under the circumscribed conditions of ordinary experimental work every physical investigator naturally resorts to a method of elimination in seeking the cause of any accidental disturbance, such as a leak in his apparatus, or a break in his electrical connections" (Cooke 1893, pp. 30-1).

17 Cooke was skeptical of scientific "theories of creation" due to a perceived difficulty of applying current theories to unknown past conditions and dissatisfaction over their presentation in materialistic terms.

18 Cooke also used instrumentalism to defend atomic-molecular theory in the scientific literature (Cooke 1878).

19 Cooke did not fully work out the metaphysical implications of scientific ideas in his natural theology works, where he largely argues for the instrumentality of scientific theories from personal incredulity. Additional insight into his view on this issue are given in Cooke 1889 where he argued that atomic theory did not eliminate the historical difficulties chemists faced in identifying and defining substances as elements. At the time Cooke wrote it was still unclear whether atoms were truly elementary or could be broken up into more fundamental particles. In contrast, it was well known that different elements had similar chemical properties while allotropes sometimes showed great differences in reactivity. Consequently, the identification of elements with atom types, while useful, did not really answer the question of what, exactly, was a fundamental substance.

20 Cooke implicitly acknowledged the difficulty of precisely defining natural laws by distinguishing three types: fixed laws (such as the 'laws of motion') which appear inviolate, determinate laws like the ideal gas laws which describes the 'ideal' properties of a gas that no real gas actually possess, and indeterminate laws such as equations for the solubility of salts in water which are merely empirical relationships describing a single physical phenomenon. Cooke thought that the fixed laws might either change over time or be the result of more complex underlying causes while the determinate and indeterminate laws illustrate the human inability to perfectly understand complex natural systems.

21 Cooke was quoting from Tennyson's *In Memoriam* (section 54, stanza 1) which he believed contained "a truer appreciation of the difficulties which beset the questions [of natural theology]" than academic philosophy (Cooke 1864, p. viii).

22 For example Cooke's 'nine series' consists of elements with atomic weights that roughly obey the equation $w = 8 + n9$: *e.g.* oxygen (n = 0, 8 expected, 16 observed), fluorine (n = 1, 17 expected, no observation), 'cyanogen' (n = 2, 26 expected, 26 observed), chlorine (n = 3, 35 expected, 35.5 observed), bromine (n = 8, 80 expected, 78 observed), iodine (n = 13 , 125 expected, 126 observed). Confusion over Cooke's inclusion of oxygen can be removed by considering that the formula of water was then given as HO.

23 This was evident from the beginning of Cooke's research career. Even in his 1854 paper Cooke speculates that constant error is responsible for deviations from his numerical laws.

[24] Cooke's interweaving of education and research is seen in his inclusion of the kerosene stove-derived tube furnace and other apparatus from his 1887 paper on the relative atomic weights of hydrogen and oxygen in Cooke 1891.

[25] Revised to disentangle design from teleology in *The Order of Nature* (1917).

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