The construction of a narrative that not only describes but also accounts for the development of science from antiquity to modernity is, to say the least, a challenging task. Success in this type of project requires the historian to demonstrate mastery of a diverse set of scientific theories from a range of cultural contexts. Moreover, the historian must advance some thread, which unanachronistically binds scientific developments together while still accounting for the evolution of the scientific tradition through the millennia. This task is so daunting that few historians attempt it.

In his essay, “The Idol of Prescriptive Normativity,” Zeller approaches this task with courage and finesse. He presents a pronounced shift in the philosophy undergirding the construction of scientific theories. Zeller argues that normative notions—e.g., the good, the beautiful, and the simple—play a new and problematic role in the modern scientific tradition. While, according to Zeller, natural philosophers such as Aristotle and Newton applied normative notions retroactivity to their cosmological theories, in physics today normative notions are prescriptive. In order for today’s scientific communities to accept a theory, the theory must be elegant. By bringing Francis Bacon’s *The New Organon* to bear on the philosophical assumptions of today’s scientific communities, Zeller describes the limitations and dangers of prescriptive normativity. That Zeller has the ability to not only reflect on the history of science but also apply historical lessons to future scientific developments is commendable, and it confirms for me that IHUM has the ability to nurture our students’ careers in science and technology.

—*Jacqueline Feke*
The concept of normativity has played a significant role in the history and development of science. In many instances, scientists have included normative notions in their explanations of the physical universe. In 350 B.C.E. Aristotle assigned an entirely normative structure to his geocentric universal model, and over one thousand years later, Isaac Newton incorporated similar normative notions into his proposed heliocentric universal astronomy. Moreover, modern scientific theories and discoveries, such as Maxwell’s Equations, special relativity, and E8 unification theory were all profoundly influenced by conceptions of normativity.

This paper examines the presence and historical development of normativity in science by considering Aristotle, Newton, and later theorists (e.g., Maxwell, Einstein, Lisi). A thorough analysis indicates that the normative notions incorporated into the early physical theories of Aristotle and Newton are different from those incorporated into modern science. Whereas the normative notions invoked by earlier scientists were descriptive (i.e., theories were developed and then normative notions were applied [to the theory itself or to the objects the theory reflects]), the normative notions invoked by mod-

1 How these theories were influenced by normativity is discussed in detail later in this paper.
ern scientists are primarily prescriptive (i.e., scientists predetermine which normative notions accurate theories must incorporate and then formulate theories). As demonstrated in this paper, the progression in scientific practice from description to prescription has the potential to severely limit scientific exploration and discovery.

**From Description to Prescription: An Evolution of Normativity**

Below is a depiction of the typical Aristotelian universal astronomy (figure 1).

![Figure 1: The Aristotelian Universe.](https://example.com/figure1.png)

A slightly altered version of this universal astronomy (Christian Aristotelianism) was a widely accepted world system until the scientific revolution. As evidenced by his commentary in *De Caelo* (*On the Heavens*), Aristotle incorporates normative notions of perfection and value into his proposed universal model. Aristotle addresses the normative notion of perfection in describing the motions of the planets. He highlights that the planets move in circular orbits and that the circle is geometrically perfect or complete (269a 19-32). Additionally, he assigns a normative value system to his astronomy. He claims, “…there is some other body separate from those around us here, and of a higher nature in proportion as it is removed from the sublunary world” (269b 14-17). Simply put, Aristotle maintains that “better,” or more
valuable, bodies are located closer to the periphery of the universe.\(^2\) Aristotle’s contention that more valuable bodies are located closer to the periphery of the universe is consistent with Aristotelian physics, which maintains that the sublunary realm is imperfect since the elements (earth, water, air, fire) are in a constant state of transition, while the aether that pervades the superlunary realm is unchanging. Aristotle’s discussion of his proposed universal model in *De Caelo* suggests that his incorporation of normativity was purely descriptive. Only *after* formulating his theory of the heavens did Aristotle point out that there are normative notions of perfection and value inherent in the motions and arrangements of the heavenly bodies. There is no evidence in *De Caelo* that suggests that Aristotle maintained that the planets *must* move in circular orbits *because* the circle is perfect or that the universe *must* have a structure consistent with any preconceived normative values. Mohan Matthen and R. J. Hankinson, professors of philosophy and scholars of Aristotle, echo this viewpoint in their paper “Aristotle’s Universe: Its Form and Matter.” They contend that, even though Aristotle “makes extensive use of degrees of perfection to explain some of the structural features of the universe,” there is nonetheless, “a distinctly empirical train of thought in Aristotle’s cosmology” (Matthen & Hankinson, 417). Aristotle’s conclusions (regarding the motions of the planets and cosmological structure) were drawn exclusively from observational or logical considerations.

Though Isaac Newton’s universal model (figure 2) deviated from Aristotle’s (in that the sun was at the center of the solar system and the universe was infinite in extent), Newton’s incorporation of normativity was similarly descriptive. Newton incorporates the normative notions of perfection and beauty into his infinite heliocentric cosmology through the harmonious motions of the planets. He describes his universal model as the “most elegant system of the sun, planets, and comets…” (Newton, 90). He claims his model is mechanically and geometrically perfect in that the planets have “those just degrees of velocity, in proportion to their distances from the sun and other central bodies, which were requisite to make them move in concentric orbs about those bodies” (Koyré, 186). Additionally, there is beauty and perfection associated with the mathematics of the Newtonian

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2 When Aristotle’s model was adopted by the church hundreds of years later, the phrase “Coelum Empireum Habitaculum Dei et Omnium Electorum,” meaning “the dwelling place of God and all of the elect,” was written nearest the periphery of the universe to signify that God is the most valuable being.
universe; by combining Newton’s law of universal gravitation \( F = -\frac{GMm}{r^2} \) with his three laws of motion, one can derive elegant equations of motion governing the planets (e.g., planets sweep out equal areas in equal time; \( T^2 \) is proportional to \( R^3 \)).

Furthermore, Newton (like Aristotle) assigns a normative, purposeful structure to his proposed model of the universe. Although Newton is not able to specify the normative purpose of his universe’s structure (i.e., explain—like Aristotle did—why the universe is structured as it is), he offers proof that his universe is structured purposefully and could not have arisen from mere probabilistic mechanical interactions. He evidences that out of all the possible planetary motions that can exist in a system with more than two attracting bodies (e.g., ellipses, parabolas, hyperbolas), the planets in his model move with the rarest and most regular motions, while other bodies, like comets, move irregularly. Newton contends that the harmonious motions of the planets are evidence that an intelligent being (referring to God) purposefully structured the universe because such harmonious motions are not “explicable by mere natural causes” (Koyré, 185). He maintains that his proposed universal astronomy “could not have arisen without the design and dominion of an intelligent and purposeful being” (Newton, 90). Consequently, Newton concludes that God

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3 It is interesting to note that Newton’s design argument is even more convincing after considering Henri Poincaré’s solution to the famous n-body problem. Poincaré concluded that the future motions of planets are increas-
purposefully arranged the planets and set them in motion (Koyré, 186).

Newton’s incorporation of normativity, like Aristotle’s, is exclusively descriptive. Newton’s universal model was not derived from conceptions of normativity, but rather from mathematical, logical, and physical considerations; only after postulating his theory of the universe did Newton describe its structural features in terms of normative notions. Interestingly, modern scientists have strayed from Newton’s and Aristotle’s practice of first formulating a theory of the universe and then describing it in terms of normative notions. Instead of describing aspects of physical theories in normative terms, modern scientists prescribe certain normative laws to which any accurate physical theory must adhere. Simply put, whereas the scientists of yesterday would first formulate a theory and then analyze its normative features, contemporary scientists first promulgate specific normative properties that they believe any accurate theory must have and then go about deriving theories consistent with their conceptions of normativity.

As evidence that the normative notions invoked by modern scientists are primarily prescriptive, consider the 2007 scientific paper *An Exceptionally Simple Theory of Everything*, by American theoretical physicist Garrett Lisi. Even though the content of the paper is highly technical and primarily concerned with developing a theory that will unify the fundamental forces of nature, the introductory paragraphs provide insight into the role normativity plays in modern science. In considering what types of mathematical equations can govern the universe, Lisi proclaims “there is a classic principle for restricting the possibilities” (1). He writes, “The mathematics of the universe should be beautiful. A successful description of nature should be a concise, elegant, unified mathematical structure consistent with experience” (1). Essentially, Lisi maintains that the mathematics of any accurate description of nature must possess prescribed normative properties of beauty and elegance.

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4 He attempts to unify physics by providing insight into how we can physically interpret the dynamics of the 1-form and Grassmann valued parts of E8 Lie Algebra superconnections.

5 My italics.
Lisi's contention that any accurate theory must possess certain properties is not unique; rather, most members of the greater scientific community (e.g., Albert Einstein, James Maxwell, Brian Green, Paul Dirac, etc.) share Lisi's belief that any accurate description of the universe must incorporate prescribed notions of beauty, perfection, elegance, symmetry, determinism, simplicity, and unity. In his 2007 work *Why Beauty is Truth: A History of Symmetry*, Ian Stewart, professor of mathematics at the University of Warwick, comments that, “Mathematical beauty is expected to be a prerequisite for physical truth” (xiii). Albert Einstein, the father of modern theoretical physics, echoed this contention in claiming, “the only physical theories that we are willing to accept are the beautiful ones” (Farmelo, xiii). Hermann Weyl, a German mathematician who made profound contributions to both pure mathematics and the physical sciences, was influenced by normative conceptions of beauty so much so that he claimed, “My work always tried to unite the true with the beautiful; but when I had to choose one or the other, I usually chose the beautiful” (Chandrasekhar, 52). Weyl’s choice to pursue the beautiful over the true is somewhat radical, even amongst scientists.

As demonstrated above, there has been a definite shift in the types of normative notions invoked by scientists. Whereas earlier scientists incorporated normative notions into their theories after formulation, modern scientists predetermine which normative notions their theories must incorporate prior to formulation. Since descriptive normativity is applied only after scientific theories are logically or empirically formed, its invocation neither enhances nor hinders scientific discovery. Prescriptive normativity, in contrast, has the potential to thwart the scientific pursuit of knowledge. By searching only for theories that are consistent with predetermined normative properties, scientists are restricting exploration and discovery.

**Prescriptive Normativity: At Odds With the Furtherance of Scientific Discovery**

Scientists who practice prescriptive normativity believe that any accurate description of nature must be consistent with predetermined normative notions. Francis Bacon, esteemed philosopher and author of *The New Organon* (an inquiry into how to obtain certainty in the natural sciences), would likely argue that such a belief is scientifically unfounded. Bacon contends that in order for a scientific conclusion to be founded, it must be based in empirical arguments (i.e., must be
confirmed by experimentation). He claims that all accurate scientific knowledge we currently possess can be attributed solely to “chance and experimentation” (90). Consequently, he holds that the only way to obtain knowledge of the material world is to perform a multitude of experiments and then generalize findings via induction; only after performing various experiments, constructing tables of instances, and intimately interacting with nature can one generate accurate conclusions. Bacon asserts that other methods for generating scientific conclusions (i.e., syllogistic reasoning) are not sufficient since “the subtlety of nature is greater many times over the subtlety of argumentation” (93). But, “axioms duly formed from particulars [specific experiments and observations],” he claims, “easily discover the way to new particulars, and thus render the sciences active” (93). Considering that there is no experimental evidence supporting the belief that accurate descriptions of nature must adhere to specific normative notions, Bacon would likely dismiss this belief as unfounded.

Furthermore, in *The New Organon*, Bacon warns that unfounded conclusions (i.e., intellectual fallacies) may curtail scientific discovery. Bacon appropriately dubs these intellectual fallacies “idols,” because just like the false idol of the golden calf mentioned in the Bible, intellectual fallacies are respected, and even worshipped by humans despite a lack of underlying substance. Bacon divides the idols into four different categories: (i) idols of the tribe (biases of human understanding), (ii) idols of the cave (biases of individual preference), (iii) idols of the marketplace (illusions of understanding created by words), and (iv) idols of the theatre (biases and illusions of understanding created by received philosophical systems). In speaking of the idols collectively, Bacon writes, “The idols and false notions which are now in possession of the human understanding, and have taken deep root therein, not only so beset men’s minds that truth can hardly find entrance, but even after entrance is obtained, they will again in the very instauration of the sciences meet and trouble us…” (95). Evidently, Bacon had the foresight to recognize the potentially negative impact of idols on current and future scientific quests for truth. He acknowledges that idols not only thwart current scientific endeavors but also inhibit the successful revamping of scientific practice.

Prescriptive normativity fits in especially well with the Baconian concept of the idol. Scientists have come to accept as true the premise that all accurate theories of the universe must incorporate prescribed notions of beauty, perfection, elegance, symmetry, sim-
plicity, and unity. Yet, as mentioned above, this premise is unfounded empirically. It follows that the idol of prescriptive normativity\(^6\) (i.e., the unfounded belief that all accurate theories must have prescribed normative properties) is at odds with the furtherance of scientific discovery. By searching only for theories that mesh with specific normative notions, scientists may in turn pass over the greatest truths of all. In order to push scientific discovery to the next level, it is important that theorists expand the scope of their search to a whole array of possibilities — not just those theories that possess carefully prescribed properties. It would be a beneficial exercise for theorists to assume that the laws of nature are \textit{not} necessarily normative and that the theories that are beautiful, elegant, symmetric, and unified are the exceptions, rather than the rule. Such a simple change in perspective has the potential to revolutionize science.

Beyond the philosophical and epistemological considerations associated with prescriptive normativity’s role in the scientific method, there is also one practical consideration worth mentioning. Specifically, conceptions of normativity vary from scientist to scientist and it is often difficult to determine which theories incorporate normative notions and which do not. For example, even though nearly all modern scientists affirm that symmetry is beautiful, some mathematicians may find asymmetric equations to be the most beautiful of all. Since conceptions of normativity vary so much, it is imprudent for scientists to proclaim that the universe must have certain normative properties when normative properties can be interpreted in contrasting ways.

\textbf{Counterargument: The Benefits of Prescriptive Normativity}

Opponents of the belief that prescriptive normativity limits scientific exploration would argue that prescriptive normativity actually benefits science and should remain an important consideration in the scientific method. James Clerk Maxwell, for example, derived the namesake Maxwell’s equations from purely normative arguments. Specifically, Maxwell reasoned that the equations of electricity and magnetism \textit{ought to be} symmetric and therefore introduced the famous displacement current term into Ampere’s Law so that the equations governing electricity and magnetism in a vacuum would be a sym-

\footnote{Specifically, the idol of prescriptive normativity can be considered an “idol of the tribe,” as is addressed in the counterargument section of this paper.}
metric set of partial differential equations. In commenting on Maxwell’s discovery of the displacement current, English physicist Norman Campbell writes, “Suppose you found a page with the following marks on it—never mind if they mean anything [figure 3]. I think you would see that the set of symbols on the right side are ‘prettier’ in some sense than those on the left; they are more symmetrical. Well, the great physicist, James Clerk Maxwell, about 1870, thought so too; and by substituting the symbols on the right side for those on the left, he founded modern physics and, among other practical results, made wireless telegraphy possible” (155-156).

\[
\begin{align*}
\nabla \cdot \mathbf{E} &= 0 \\
\nabla \cdot \mathbf{B} &= 0 \\
\nabla \times \mathbf{E} &= \frac{1}{c} \frac{\partial \mathbf{B}}{\partial t} \\
\nabla \times \mathbf{B} &= \frac{1}{c} \frac{\partial \mathbf{E}}{\partial t}.
\end{align*}
\]

Figure 3: The equations on the left are Maxwell’s equations in free space without displacement currents. The equations on the right are Maxwell’s equations in free space with displacement currents. All equations are written in CGS units.

This phenomenon – deriving paramount theories from normative considerations – is not unique to Maxwell. Albert Einstein’s theory of special relativity, for instance, was also derived out of symmetry arguments (Stewart, ix-x). Additionally, Herman Weyl’s nuanced unification of gravitation and electricity resulted from conceptions of normativity regarding the direction and length of a vector (Afriat). With such prior successes of prescriptive normativity in mind, it is not surprising that prominent scientists argue that all accurate theories of the universe must have a normative structure and that prescriptive normativity can play a beneficial role in the scientific method. After all, this conclusion is grounded in years of experience; many accurate scientific theories of the past few centuries have incorporated prescribed normative notions.

In *The New Organon*, Bacon explains how such prior successes of prescriptive normativity likely encouraged scientists to fallaciously conclude that the entire universe is normatively structured. He sug-
gests that such a false conclusion exemplifies the “idols of the tribe.” Bacon writes, “The idols of the tribe arise because the human understanding is of its own nature prone to suppose the existence of more order and regularity in the world than it finds. And though there be many things in nature which are singular and unmatched, yet it devises from them parallels and conjugates and relatives which do not exist” (97). Essentially, Bacon maintains that having observed a few instances in which the laws of nature are well-ordered, humans are falsely disposed to generalize such observations and conclude that the universe as a whole is normatively structured.

As Bacon acknowledges, there may exist specific, well-ordered laws of nature (e.g., Maxwell’s equations in free space and special relativity) that encourage scientists to conclude that the entire universe as a whole is well-ordered and normatively structured. Nevertheless, this conclusion is overreaching, and there is substantial evidence indicating that the laws of nature are not necessarily well-ordered and do not necessarily possess prescribed normative properties. Consider the generalized form of Maxwell’s equations, for example. Though it is true that Maxwell’s equations are symmetric in free space (due to the introduction of the displacement current), they are completely asymmetric in the presence of electric charges (figure 4). To “correct” this asymmetry, many scientists have tried to prove the existence of magnetic monopoles (which would make the equations symmetric), but all attempts to date have been futile and wasteful — scientists have dedicated countless hours and immense funds to the discovery of magnetic monopoles to no avail. Additionally, consider quantum mechanics. Since the theory of quantum mechanics is probabilistic in nature, most scientists agree it is devoid of the normative notions of beauty, elegance, symmetry, and determinism that any accurate theory ought to have. In fact, quantum mechanics is a cantankerous, probabilistic mess, lacking even the slightest trace of what most scientists consider beautiful or elegant. Yet, quantum mechanics is far and away the most accurate theory of subatomic interactions, having been experimentally confirmed without reservation. Upon consideration of such successful — yet not normative — theories, it is hard to argue that all accurate depictions of the universe must be normative in nature.

7 Many scientists and philosophers consider quantum mechanics the least normative of all existing theories for reasons such as uncertainty relationships and tunneling probabilities. Additionally, solutions to most quantum mechanical problems are considered “messy” in that solutions often involve Hermite polynomials and Bessel functions.
Concluding Remarks

Perhaps, the example of quantum mechanics best elucidates how the idol of prescriptive normativity has the potential to limit science. While deliberating quantum theory in Copenhagen, Einstein (in addition to other theorists) rashly and unjustifiably rejected the wave-mechanical formulation of quantum mechanics (the currently accepted theory) on purely normative grounds. He believed that such an interpretation of quantum mechanics could not be correct since any accurate theory of the universe should not be probabilistic in nature. In famously proclaiming, “I, at any rate, am convinced that He [God] does not throw dice,” Einstein nearly deprived the scientific community of arguably the most successful theory of the 20th century (Clark, 340). Simply because the wave-mechanical formulation of quantum mechanics was not consistent with the received scientific assumptions of the time (i.e., accurate theories ought to be deterministic in nature), it was “vetoed” by many prominent physicists.

In his 1962 landmark publication, The Structure of Scientific Revolutions, Thomas Kuhn explains the scientific community’s resistance to changes in assumptions (paradigm shifts) and how such resistance can have a negative impact on science. Kuhn writes, “Normal science, the activity in which most scientists inevitably spend almost all their time, is predicated on the assumption that the scientific community knows what the world is like” (5). Kuhn proposes that since the scientific community is willing to defend the assumptions of normal science at all costs, normal science “often suppresses fundamental novelties because they are necessarily subversive of its basic commitments” (5). In the same vein, because modern scientists so staunchly affirm that accurate theories ought to have prescribed normative properties, potentially revolutionizing, non-normative theories may be repressed.

Kuhn maintains, however, that the essence of “normal research” assures that novelty will not be repressed for long (5). He claims that eventually, some “anomaly” will come along that cannot be reconciled with the assumptions of normal research (6). Accordingly, scientists will abandon the fundamental assumptions of normal research for new assumptions; such a change in “professional commitments,” Kuhn defines as a scientific revolution (6). Evidently, quantum mechanics was not anomalous enough for scientists to abandon the assumptions of prescriptive normativity, as prescriptive normativity still plays an important role in the scientific method. As a scientist
myself, I can only hope that some time in the near future, another “anomaly” will arise, impelling scientists to put an end to the limiting, closed-minded, and underproductive pursuit of knowledge, which follows from the idol of prescriptive normativity.

Works Cited


