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The "Real" Scientific Revolution: 14th Century England's Contribution to Modern Scientific Thought

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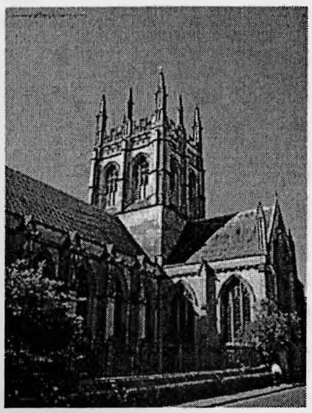

At first glance, the fourteenth century truly appears to be calamitous. Famine, disease, war, and poor leadership plagued England to the point where one must wonder if anything positive emerged from this time period. These bleak descriptions, however, fail to depict society writ large because they ignore indisputable advancements and achievements in medieval society, arguably the most important being science.

Often, history asserts that the thinkers of the Renaissance, such as Galileo, Kepler, and Copernicus, are the forerunners of modern scientific inquiry because they used experimentation and mathematics to explain natural phenomena. However, M.A. Hoskin and A. G Molland argue, ""The Scientific Revolution" of the seventeenth century cannot adequately be assessed without an appreciation of the achievements and limitations of those…on whose shoulders Galileo and his contemporaries stood."[i] It is necessary then to study those natural philosophers that worked feverishly in the scientific field during the fourteenth century because it was then that the *real* birth of scientific thought occurred. Experimentation, mathematical formulae, and observational analyses were integral parts of an emerging scientific method from which later scientists worked. This paper will thus focus on the important legacy of scientific works introduced at Merton College, Oxford, which became a microcosm of scientific discovery that inaugurated the modern era of science.

The origins of scientific thought in Europe lay in the early twelfth century, when cathedral schools emerged as a predecessor to universities. It was in this environment that ideas emerged regarding the possibility of change explained by "'a common course of nature.'"[ii] Curiosity was evidently emerging across Europe as individuals sought to learn about the world, which stimulated the translations of ancient texts. There was difficulty doing so because most texts by figures such as Aristotle, Euclid, and Plato were only available in Arabic translations. Although these languages were lost in the West, universities that cropped up in Spain were centers of Arabic study. Thus scholars, such as Adelard of Bath, Plato of Tivoli, Robert of Chester, and Gerard of Cremona, traveled there and began to work with these texts and translate them into Latin.[iii] These translations provided a vital foundation for the rise of medieval universities.

Universities became centers of learning in thirteenth century medieval Europe where scholars discussed and disputed newly translated ancient texts. Curricula used by Western universities, which led to the development of a Master of Arts, focused mainly on courses in logic, physics, astronomy, and mathematics. Translated works studied incorporated many of Aristotle's logical and scientific works, including *Physics, On the Heavens and World, Meteorology,* and *On Generation and Corruption.* The study of mathematics mainly consisted of Euclid's *Element* and Boethius' *Arithmetic.*[iv] These texts inspired and influenced scholars to openly discuss whether or not the ancients were in fact correct. One can see their influence best at Oxford's Merton College, a center of scientific thought in the fourteenth century.

The origins of Merton College arguably date to the eleventh century with the teaching and scholarship of Adelard of Bath, a man often described as "'the greatest name in English science before Robert Grosseteste and Roger Bacon.'"[v] Adelard's historical significance lay in the fact that he was one of the few Western individuals to translate important classical works. One such work was Euclid's *Elements*, which as previously stated, was a key text for the study of mathematics at medieval universities. This is merely one example of the substantial amount of translating he contributed to the academic advancement of rising universities.[vi] His translations also proved beneficial in his own writings, the most famous being his *Questiones Naturales*, which was a scientific work dealing with the natural sciences.[vii] This work was a composite of the expanded knowledge he received from these translations.

Adelard was also a renowned teacher in England during the tenth century. He was an early forerunner to key figures that played an important role in the Mertonian scientific tradition. Although there is very little biographical information regarding Adelard's life, one discovers his teaching career through fragmented notes in some of his contemporaries' works. For example, a text used at Trinity College lists him as one of three major geometers in England.[viii] Charles Burnett states, "He was evidently the key figure at the beginning of a scientific movement that developed in England throughout the twelfth century and culminated in the work of Robert Grosseteste in the early thirteenth century."[ix] He was truly an innovator during his time, and impacted how scholars in England viewed and understood the natural sciences.

Within Oxford University, Merton College emerged as a center for the scientific community that built on the work of Adelard and others. Walter de Merton, the founder of the college, intended to make "his College a foundation for encouraging learning amongst the secular clergy as distinct from the religious orders. He was raising up a rival to the monastic system."[x] This mission caused a religious struggle at Oxford that led to a fringe group breaking off in order to study science. That religious group was the Grey Friars, a branch of the Franciscans who were named for their rough, grey robes. It would be these men who became extremely influential members in the field of science.

The general mission of the Franciscans was merely to imitate Christ in word and deed. Their founder, St. Francis of Assisi, never envisioned his followers as educators in any sense; however education was blossoming. It did not seem practical for the friars to remain uneducated and in jeopardy of lagging behind their lay counterparts. Robert Grosseteste, one of the prolific teachers of the Grey Friars even warned "them plainly that walking in ignorance meant walking in shame."[xi] In order to achieve this secular education, the Grey Friars had to fight an ideological battle because they were only allowed to study theology; those that wanted a degree in the arts were viewed rebellious.

These radical friars moved away from strict theological study and instead toward practical study of natural science. One will see the great contributions they made to the scientific community thanks to the unique climate at the Merton School during the twelfth and thirteenth centuries.

Robert Grosseteste was an early forerunner who began scientific work at Oxford in 1214 and lectured the infamous Franciscans studying at the University. Grosseteste wrote various commentaries on Aristotelian works, including the *Posterior Analytics* and *Physics*. Within these commentaries, Grosseteste declared that "The object of...science...was thus to discover and define the form or 'universal' or 'nature', in the sense of principle, origin, cause of behavior and source of understanding, which could become the start of demonstration."[xii] He accepted the opinion of Aristotle that universals could in fact be abstracted from particular instances; however, these instances produced, in Grosseteste's opinion, a hierarchy of certainty on whether or not the universal could be known.

Grosseteste valued the study of science in order to understand nature and even divided science into three categories: physics, mathematics, and metaphysics. It should be noted that Grosseteste asserted that mathematics was the only *certain* science whereas others left room for error, misunderstanding, and confusion.[xiii] Despite the uncertainty inherent in two of the branches, he studied all three avidly and contributed many findings to the scientific community. His impact was evident in his creation of an early scientific method and his work with mathematics, and optics.

Grosseteste spent a significant amount of time establishing a proto-scientific method. In natural sciences Grosseteste held that "in order to distinguish the true causes from other possible causes, at the end of composition must come a process of experimental verification and falsification."[xiv] Essentially one must rely on experiment, analysis, and experience in order to come to a conclusion. For Grosseteste it was important to eliminate any possible causes of a particular problem. His scientific method was based on two important arguments: the uniformity of nature and the principle of economy. The former basically held that all like things in nature will act the same. The latter assertion is based on Grosseteste's statement that it "is better which is from fewer because it makes us know more quickly."[xv] In simpler terms, his theory on economy asserts that which is the simple explanation is more appealing than one that is more complicated. These scientific principles proved quite influential to scientists, such as Roger Bacon and William of Ockham.

Before moving on to his students and followers, it is valuable for one to gain an understanding of the practical findings Grosseteste made with his scientific forethought. One area where he particularly shined was in optics. Prior to the thirteenth century, there was little knowledge or understanding of optics; Adelard of Bath did not even have access to important Greek and Arab works.[xvi] By the time Grosseteste was writing he did have crucial translations, including Euclid's *Optica* and Aristotle's *Meterologica*. Although modern-day scholars of optics and physics would scoff at Grosseteste's incomprehensible descriptions of light, its value lay in the fact that understanding optics was approached from a mathematical point of view for the first time.[xvii]

Grosseteste asserted in *Concerning Lines, Angles, and Figures* that "all causes of natural effects must be expressed by means of lines, angles, and figures, for otherwise it is impossible to grasp their explanation."[xviii] For Grosseteste, these natural effects were essential to the study of optics. He believed that light was the first 'corporeal form' of original materials and was responsible for motion and causation, which had the power to act in the universe and affect change. He called this the "multiplication of species;" a simple way to explain this is through example. If light travels to something and illuminates it, then that light is multiplied and has moved through the body in intervals. The light is now what Grosseteste would call a "species" because it has emanated from the object and has multiplied. For him, this process formed the basis for studying optics because it is the visible reaction that can be examined.[xix]

Grosseteste also attempted to understand the idea of refraction of light, which he then applied to his study on the rainbow. He explained refraction as:

> the ray incident at unequal angles deviates from the rectilinear path that it had in the first substance, which would be maintained if the medium were uniform. And this deviation is called refraction of the ray.[xx]

This definition when applied to experimentation helped him argue against the Aristotelian opinion of the rainbow, which was based on reflection. In order to prove Aristotle's theory wrong, Grosseteste explained the shape of the rainbow through observation. He declared:

> "Nor can a rainbow be produced by the reflection of the rays of the sun…because if that were so the shape of all the rainbows would not be an arc…Therefore rainbows must be produced by the refraction of rays of the sun in the mist of a convex cloud"[xxi]

According to Grosseteste, the convex cloud had multiple layers in it, which would allow the light to be refracted multiple times, thus producing the shape of a spectrum of colors.[xxii] He explained that if it were reflection, then the rainbow would appear bigger and higher when the sun was higher in the sky. Similarly, it would be smaller and lower when the sun was closer to Earth. He observed the changes in the rainbow at different times of day to justify his claim relying solely on experience and experimentation. He noticed that if the sun was rising or setting, the rainbow would be semicircular and larger. At any other point in the day, however, it appeared only part of a semicircle and much smaller.[xxiii]

Grosseteste also established a theory of color, which would explain why there were variations of color in the rainbow. He asserted that it was due to the amount of rays of light; the more rays present allowed for brighter colors, whereas fewer rays displayed only the darker colors on the light spectrum. Although his theory regarding the rainbow was not wholly correct because he ignored reflection altogether and attributed the shape of the bow to the denser clouds, he nevertheless tried to methodically explain phenomena, which was a great scientific improvement. He reduced the problem down to simple terms and then experimented using math and observation. This set the stage for Grosseteste's followers, namely Roger Bacon.

Roger Bacon was a member of the fringe group of Franciscan friars at Oxford, and a student of Robert Grosseteste; thus, it is unsurprising that he understood science in a similar way. He pursued his education with great intensity and was suspected of heresy for the new ideas he had concluded during his studies. Eventually, Pope Clement IV commanded Bacon to write down his ideas in what became his most famous work, the *Opus Maius*.[xxiv] The discussion on Roger Bacon will mainly focus on his scientific findings in the *Opus Maius* because it is arguably his most prolific scientific work.

Bacon had two aims when writing the *Opus Maius*: to show how philosophy could be practically utilized and to reform how those in the thirteenth century learned based on the relative importance of the sciences.[xxv] In this treatise, he presented his work in almost an encyclopedic format whereby he broke down different subjects into parts. The most applicable sections to this paper are Part IV and V, which discuss the importance of mathematical knowledge and how to apply mathematical principles to the study of astronomy, optics, and even motion. One will see in his work that he valued experimental science and above all mathematics to explain phenomena present in the world.

In Part IV, Bacon wasted no time in establishing the preeminence of mathematics above all the sciences. He opens with the following statement:

> Of these sciences the gate and key is mathematics…Neglect of this branch now…has destroyed the whole system of study of the Latins…he who is ignorant of this cannot know the other sciences nor the affairs of the world.[xxvi]

He believed that this area science was of utmost importance to study for many reasons, including an individual's innate capability to understand its logic and the ease that one can comprehend it. According to Bacon, it is most important because "we are able to arrive at truth without error…since in this subject demonstration by means of a proper and necessary cause can be given."[xxvii] Mathematics allows one to work out problems and access their validity through trial and error. The ability to do so was crucial to Bacon because he valued these methods as the basis of arriving at true knowledge. This understanding of thirteenth century science was extremely similar to his teacher, Robert Grosseteste, who likely imparted the value of experiment and observation to his student.

Bacon's math is extremely difficult to understand, but his findings are not. Therefore, one must concentrate on his scientific conclusions, and not the math behind them, in order to truly appreciate his great accomplishments. For example, in the area of optics, he attempted to explain vision and optics to a greater extent than his predecessors had. He explained sight using the multiplication of species theory, which is reminiscent of Grosseteste. He declared, "lines along which multiplication of species occurs do not have length alone…but all of them also have width and depth," which provides for visibility of an object; If something lacks width, depth, or length, then it cannot be seen.[xxviii] He explained that these objects, however, could only be seen through intromitted rays coupled with visual rays from an individual's eyes.[xxix] He essentially synthesized and built off of what other scientists, such as Aristotle and Alhazen, had already said; however, he believed his explanation was correct after examining all materials and knowledge available to him.

Another interesting endeavor presented in Bacon's *Opus Maius* was his attempt to plot places using longitude and latitude. He was able to do so by overcoming some of the difficulties that occurred when representing the earth on a flat plane.[xxx] He tried to describe the shape of the world through the use of diagrams. He first explained that the habitable world from east to west was "much more than half the circumference of the Earth, and more than the revolution of one half of the heavens.[xxxi] From this mathematical supposition, he thus introduced his idea of longitude and latitude. His method essentially entailed drawing a line parallel to the equator and reading off its value on the colore, which are the celestial circles that pass through the both equinoxes and solstices. He then plotted longitude using a meridian that went through a particular city and then used that meridian to compare its location at the equator.[xxxii]

This method allowed for him to use arcs and circles to better describe coordinates on a flat map. Although there were issues and complications that Bacon did not take into consideration because of the lack of technology and knowledge on the subject, his attempt was significant because he was one of the first individuals who used math to try and create a world coordinate system centuries before it was correctly used. The use of coordinates to plot not only land, but also celestial regions was examined in the fourteenth century by Richard Wallingford and later by Galileo during the Renaissance.

Finally, Part V of Bacon's work dealt with the issue of whether or not a vacuum exists. Aristotle previously asserted that a vacuum could not possibly occur for various reasons because the laws that govern the natural world would not apply. One of his most prominent arguments against a void lay in the fact that bodies that weighed different amounts would, in the absence of resistance, fall at the same time; this simply was not logical to Aristotle. [xxxiii] Bacon, however, tried to refute this Aristotelian argument. In his *Opus Maius*, Bacon understood the possibility of a vacuum in mathematical terms. He claimed, "For a vacuum rightly conceived of is merely a mathematical quantity extended in the three dimensions, existing *per se* without heat and cold, soft and hard…and without any natural quality."[xxxiv] Bacon did not prove the existence of a vacuum, but merely the possibility of that existence, which Aristotle denied. Bacon's work would later inspire Dumbleton to discuss the idea of a vacuum.

Prior to moving on to the fourteenth century Mertonian scholars known as the Oxford Calculators, one final figure must be noted. That figure is William of Ockham whose "importance in the history of science comes partly from…improvements he introduced into the theory of induction, but much more from the attack he made on contemporary physics and metaphysics."[xxxv] His ideas regarding induction were based on two ideas. The first explained that only certain things in the world could be gained through the senses, which he called substances. Ockham called this "intuitive knowledge."[xxxvi] Everything else not included in intuitive knowledge was not real and represented concepts or qualities.

The second idea is one that he is most famous for: Ockham's razor. Simply put, the best explanation is the simplest because it removes any superfluous information that impedes knowing what is real.[xxxvii] Ockham's razor was not an original thought, but actually echoes Grosseteste's theory of economy. Using these two ideas, Ockham proposed that "in most cases a singular contingent proposition cannot be known evidently without many apprehensions of single instances."[xxxviii] It was possible, however, to arrive at the best possible answer by removing all false suppositions. Ockham applied these aforementioned ideas when he analyzed the physics of motion.

In his *Treatise on Motion*, Ockham asserted, "that no other thing is required in addition to body and place," which explained the basis of his understanding of motion. [xxxix] His definition essentially asserted an object's motion was ite continuous existence from one instant to the next of a permanent body. This understanding of motion actually led to a primitive definition of inertia, which he explained as:

> The moving thing in such a motion (i.e projectile motion), after the separation of the moving body from the prime projector, is the very thing moved according to itself and not by any separate power, for this moving thing and the motion cannot be distinguished. [xl]

This definition was the foundation from which future scientists, such as Jean Buridan and later Isaac Newton, formed their definitions of impressed force. Also, one sees Ockham's influence in the work of the Oxford Calculators explained the physics of motion using mathematical principles.

Tracing the research and work of earlier scientific figures in England and more specifically at Oxford illustrates that as early as the twelfth century strides were being made to explain the world using reason, logic, and of course mathematics. It was thus a transitional period whereby these men took the philosophical explanations of ancient writers and tried to either prove or disprove them using experimentation and observation. The strides these natural philosophers made in science did not halt in this generation; rather they set the example for future scholars who utilized their scientific approaches, and actually expanded on them by mathematically analyzing natural phenomena using more complex mathematical formulae. The work of the Mertonian scholars in the fourteenth century evidently shows this advancement, and also serves to support that there was indeed growth during this turbulent time.

The first prominent Mertonian of the fourteenth century was Thomas Bradwardine who became a fellow at Merton College in 1323 and stayed in residence there until 1335. One of his first works written at Merton College was the *Geometria speculativa*, which was a compilation of Aristotle's works on geometry. Although this treatise was used as a textbook for students, and held no original findings, it nevertheless is an important text in Bradwardine's scholarship. Through the analysis and compilation of Aristotelian texts, he was able to form his own opinion on proportions, which he understood to be based on a logical division of ratios.[xli] This analysis formed the basis of his most influential work, *Tractatus de Proportionibus*, which was an original discourse that attempted to resolve the problems he saw in how Aristotle related velocity, force, and resistance.

Bradwardine's *Tractatus de Proportionibus* "performed a crucial service to the development of mechanics, for in it we find the juncture of two important traditions of mechanics, the philosophical and mathematical."[xlii] When writing this work, Bradwardine sought to discover a mathematical function that would explain Aristotle's law of motion that "velocity was proportional to the power of the mover divided by the resistance of the medium."[xliii] There was an issue, however, that "if the power was smaller than the resistance it might fail to move the body at all."[xliv] Aristotle never explained that problem; however, later writers reasoned that the velocity was proportional only to the excess of power when compared to resistance. When the power was greater than one, motion would occur.[xlv] Reason was not enough for Bradwardine, which led to his mathematical treatise.

In order to explain Aristotle's principle mathematically without any discrepancies, he first detailed all necessary mathematical definitions, properties, and types of proportions. For instance, he focused on explaining rational and irrational proportions and how each applied to the different branches of mathematics.[xlvi] He even went as far as breaking down all possible structures for proportions. He then used these mathematical principles to explain correctly how change in velocity correlates to the force and resistance. The resulting theory is as follows: "The proportion of the speeds of motions varies in accordance with the proportion of motive to resistive forces, and conversely...This is to be understood in the sense of geometric proportionality."[xlvii] Using this proportional explanation, Bradwardine improved on the Aristotelian theory by avoiding its inherent pit falls. If force is greater than resistance, then motion occurs; if resistance is equal to or greater than the force, movement is not possible. Thus, Bradwardine's principle remained in line with the discourse of the day, but branched out using mathematical analysis to avoid any intellectual attacks on his work.[xlviii]

The mathematical and scientific jargon used in Bradwardine's treatise is not easily appreciated by the modern scholar; however, it proved instrumental to other natural philosophers who sought to "reduce all motion to local motion and to explain their variation according to the Bradwardine function." The Mertonian scholars, which included William Heytesbury, John Dumbleton, and Richard Swineshead, indeed did extensive work using Bradwardine's theory, resulting in the revolutionizing of the study of dynamics and kinematics. Each man contributed greatly to this revolution; however, the scholarship is conflicted on the chronology of their works. Therefore, this paper will analyze individually the contributions of each scholar in the following order: William Heytesbury, John Dumbleton, and Richard Swineshead.

William Heytesbury was affiliated with Oxford beginning in 1330. His main work, *Rules for Solving Sophisms*, used proportions to explain degrees of qualities and how they applied to motion. The idea that qualities could be understood quantitatively was not a novel idea, but actually dated back to the time of Aristotle. Heytesbury understood this concept by viewing an object as individual parts that made up the whole. It is evident in his writings, as well as in his fellow Mertonian's, that the Aristotelian understanding of quality and quantity could be mathematically applied to acceleration and velocity, thereby explaining different types of motion.[xlix] Heytesbury's *Rules for Solving Sophisms* was one of the first works that used this application, which his contemporaries later referenced and improved upon.

In his treatise, Heytesbury made it clear that he was working with premises that could be described and explained using only logic and math. He first differentiated between uniform and non-uniform motion. He stated uniform motion occurs when "an equal distance is continuously traversed with equal velocity in an equal part of time" whereas non-uniform motion can "be varied in an infinite number of ways, both in respect to the magnitude, and with respect to time."[l] Using these definitions, he formed various sophisms whereby he tried to show how velocity and acceleration altered each type of motion. These explanations are extremely difficult to follow, therefore, one needs only to note his most famous case, "The Mean Speed Theorem," which elucidates how uniformly difform motion occurs.

In order to understand the aforementioned theory, one must grasp the concept of uniform acceleration first. Heytesbury defined this idea as an equal extension of velocity gained in an equal amount of time. He then applied this definition, along with that of instantaneous velocity, and arrived at "The Mean Speed Theorem." Heytesbury explained that:

> when any mobile body is uniformly accelerated from rest to some given degree [of velocity], it will in that time traverse one-half the distance that it would traverse if, in that same time, it were moved uniformly at the degree [of velocity] terminating that latitude. For that motion, as a whole, will correspond to the mean degree of that latitude, which is precisely one-half that degree which is its terminal velocity.[li]

In simpler terms, Heytesbury asserted that an object that is uniformly accelerated would travel the same distance as one that has the same degree of velocity, as long as it is half of the final velocity of the accelerated object.[lii] Although Heytesbury's assertion offered the true nature of local motion, he was not able to completely prove it. Other scholars at Merton however worked with this definition and attempted to arrive at a clearer conception of how to explain an object's motion. Thus, one will see that the "Mean Speed Theorem was a collaborative work that is attributed to all Oxford Calculators.

John Dumbleton was Heytesbury's contemporary, but his work is not often valued as highly because he lacked the mathematical genius for which the Oxford Calculators were famous; often his arguments would be weakly supported or nonexistent. This statement does not insinuate however that he is less important within the Mertonian tradition because his most famous work *The Summa of Logical and Natural Things* extensively discussed the intension and remission of qualities, also called latitude, and how it applies to motion. Thus, his scholarship is worth mentioning in this narrative on scientific discourse of the fourteenth century.

The *Summa* is a large compilation of treatises that are divided into ten parts; part one concentrates on logic and parts two through ten handle different aspects of the natural sciences. His greatest focus, however, was on the problems the Mertonian scholars were grappling with during that time, namely the function of motion and how to explain it logically.[liii] Dumbleton explained the intension and remission of qualities through the Bradwardian understanding of proportionality, concluding that velocity and acceleration adhere to geometric proportionality. Understanding the variables of motion in such a way provided him with the basis for his conclusion on the measurement of local motion.[liv]

Part III Chapter ten of Dumbleton's work explains, albeit convolutedly, how to measure local motion. He purported:

> It is proved that a latitude [velocity] corresponds to its mean degree [of velocity]. It is demonstrated in the first place, however, that if some latitude of velocity terminated at rest [and uniformly acquired] is equivalent to a degree [of velocity] greater than its mean, then it is refuted that the less half of the latitude terminated at rest corresponds to [a degree of velocity] less than the mean of the same half.[lv]

This definition is similar to that of Heytesbury's, but the ways in which he confirmed its validity differed substantially. Heytesbury used sophisms to explain the "Mean Speed Theorem," whereas Dumbleton relied more on geometrical diagrams and proofs. For example, he stated, "If C is greater than B, then R is greater than D."[lvi] Each letter represented a different part of motion, such as acceleration and velocity; this is merely one example of the type of math used by Dumbleton, which was quite complicated and extensive. Although Dumbleton made an effort to use geometrical proofs correctly, he never definitively arrived at the end result of the proof, which left his treatise substantially vulnerable to attacks. It would thus be the work of Richard Swineshead, perhaps the greatest of all the Oxford Calculators, that remedied the flaws of both Dumbleton and Heytesbury, thus producing the most advanced explanation of the "Mean Speed Theorem."

Prior to moving on to Swineshead, one final unique topic of Dumbleton's scholarship should be discussed: the possibility of the existence of a void. As previously mentioned, Aristotle denied the possibility of a void because it was against the laws of nature. Bacon, however, confronted Aristotle's belief with a theoretical proposition that it *could* be explained mathematically. Dumbleton too worked to disprove the Aristotelian understanding like his forbear had. He used the movement of celestial bodies to explain his argument. Dumbleton stated, "to maintain contact celestial bodies would, if necessary, abandon their natural circular motions as particular bodies and follow their universal nature or 'corporeity', even though this involved an unnatural rectilinear movement."[lvii] Dumbleton understood the planets as needing one another, so if an instance occurred that broke with the laws of Aristotle, then an unnatural motion would occur that could not be explained by Aristotelian logic. The planets would necessarily cause a void in order to follow their internal nature. Dumbleton obviously never observed an unnatural occurrence of the planets, but it nevertheless illustrates that this conundrum of "nature abhors a vacuum" was still debated in the fourteenth century.[lviii]

The final Oxford Calculator to be discussed is Richard Swineshead who is often cited as *the* Calculator because of his treatises known as the *Liber calculationum;* a work that corrected much of the ambiguity present in Dumbleton's *Summa.*[lix] David Lindberg writes, "Swineshead set down what clearly seems to be both the most brilliant application and the most brilliant development of Bradwardine's function that the Middle Ages was to see."[lx] Swineshead great achievement centers on the examination of falling bodies towards the center of the Earth, which proved that a body acts as a single entity and not as separate parts.

He declared in his treatise *On Falling Bodies*, "When an earthy body is in such a position that part of it is on the other side of the Centre, it is reasonable to enquire whether that part will resist the descent either of the whole or of the part on this side of the Centre."[lxi] In this statement, he essentially said that once a body passes the center it becomes its own resistance, which would impede its motion. This resistance is contingent upon, however, whether the part below the center of the world is a separate entity altogether. Swineshead applied Bradwardine's theory through complicated and convoluted propositions, which resulted in the conclusion that if the body does act as separate parts of the whole, its center could never overlap with the center of the world; this he declared is impossible.[lxii] Instead, he purported:

> the whole and the part have the same natural place and both desire it…the part desires the same place when it is part of something as it does when it is by itself…the part beyond the Centre will naturally recede from the Centre, because it is part of a while and its desire is part of the total desire.[lxiii]

Swineshead's innovation thus clarified many of the debates his contemporaries were having about the motion of objects.

On Falling Bodies was not Swineshead's only major contribution to the scientific disputations of the time. He also wrote extensively on the intention and remission of qualities. This topic had already been discussed and analyzed by the other Mertonian scholars; however, Swineshead's explanation in *Intension and Remission of Qualities, Remission of Forms*, is arguably the clearest and proves how qualities could be understood quantitatively. He offered various opinions describing intension and remission, but rejected many of the one's already in existence. The one he most favored however asserted that "the intension of any quality is measured by the proximity to the most intense degree of its latitude. Remission in this position is measured by he distance from the most intense degree."[lxiv] Although he favored this premise, it was not the best explanation of the function of intension and remission, which thus drove him to find the answer on his own.

Swineshead extensively wrote out various propositions to show how difficult it was to illustrate the measurements of intension and remission; however, the three main propositions that best serve his purpose are as follows:

1. Whether uniform acquisition of intention follows from uniform loss of remission
2. Whether remission is increased equally proportionally and with equal velocity as intension is decreased
3. Whether two things which begin from zero degree of remission to acquire remission equally fast continue to remain equally remiss. [lxv]

Although he ultimately tried to negate each of these premises, he came to the conclusion that they were mostly correct, save one component of proposition number two. The issue that arises in the second premise derived from the fact that intension and remission are not the same, and thus cannot be proportionally compared. Swineshead provided the soundest argument that qualities could in fact be treated quantitatively.[lxvi]

All of the Oxford Calculator's greatly impacted the scientific community in the fourteenth century, which was mainly theoretically based. Therefore, much of their work did not contribute to many of the pragmatic problems facing those in the fourteenth century. There were other natural philosophers, however, associated with Merton who used scientific inquiry and mathematical knowledge to address practical issues and created instruments that led to advancement in society. One such individual was Richard Wallingford who was affiliated with Oxford in the early fourteenth century. The value of his work lay in his invention of the mechanical clock and the alboin, devices that greatly improved the study of astronomy.

Wallingford was an abbot of St. Albans, and it was in this role that he gained the opportunity to create the mechanical clock. He actually spent so much money on his invention that King Edward III complained he did not put enough resources into the church. Wallingford responded by frankly stating, "there would be many abbots after him who could build churches but none who could complete the clock."[lxvii] He believed that he was the only person who could accomplish such a feat because he had an extensive background in mathematics and astronomy, fields that many religious felt threatening to their beliefs. Wallingford, however, used his knowledge to create many scientific works that aided him in his mechanical endeavors.

His most famous writings, *Quadripartitum* and *Exafrenon pronosticacionum temporis*, both demonstrate the importance of applying trigonometry when studying astronomy. He used this math to calculate many coordinates of stars and planets, which he then represented in his inventions. His clock, for instance, had the ability to track the seasons, stars, planets, and of course time.[lxviii] His device was without known precedence because it used an astrolabe-type design that worked in reverse of contemporary astrolabe arrangements.[lxix] His other major invention that used theories of mathematics was the alboin, a device that plotted celestial coordinates; this instrument served in replacing more laborious, manual calculations. It is evident that Wallingford's practical applications of math actually revolutionized how individuals examined the celestial region.[lxx]

All of the aforementioned Mertonian scholars impacted scientific thought in substantial ways throughout the fourteenth century. Their work with dynamics and kinematics arguably was their greatest contribution because it revolutionized how natural philosophers measured and calculated speed. Although these men are famous for their scientific endeavors during such a turbulent time in history, they were not the only individuals experimenting; there were also men in Paris working in the area of dynamics. The two most influential natural philosophers in Paris were Jean Buridan and Nicole Oresme. One will see that these two individuals worked with similar ideas as the Mertonian scholars and left their own legacy that set the stage for the scientific revolution in the sixteenth and seventeenth centuries.

John Buridan was affiliated with the University of Paris and is often sited as the founder of the school of mechanics there.[lxxi] His major contributions to this niche were his theory of impetus as it relates to projectile motion and his explanation on a body's acceleration in free fall. His elucidation on the theory of impetus built off of the already existing work presented in Ockham's *Treatise on Motion*. Ockham's work had not led to substantial work until Buridan because his contemporaries did not agree with him. Buridan however sought to answer the question of "whether a projectile after leaving the hand of the projector is moved by the air, or by what it is moved."[lxxii] He believed Ockham's premise was in fact correct, and thus tried to prove it using his own theories.

Buridan falsifies each theory held by his contemporaries, such as air could propel a moving object, through the use of logic. He instead asserted that the mover imparted force on the object moved, called persistent impetus, which would cause the object to move with the same velocity until acted upon by an external force. A projectile, for instance, was slowed through air resistance and the force of gravity downward. If there were no resistance, then the object would theoretically project forever.

Buridan then related the quantity of matter to how far a particular object would project. He asserted:

> I can throw a stone farther than a feather…[because] all forms and natural dispositions is in matter and by reason of matter. Hence, the greater quantity of matter a body contains the more *impetus* it can receive and the greater the intensity with which it can receive it.[lxxiii]

The more matter an object has allows for it to retain a greater amount of impetus, thus resulting in a greater distance traveled. His association of quantity of matter, which would later be called mass, with that of force explained the deviations in amount of space traversed by a falling object. This idea was the foundational basis used by Galileo in his law of inertia, which he purported during the Scientific Revolution in the seventeenth century.

Buridan made use of the impetus theory in his own time by applying it to the explanation of a falling body's acceleration. Prior to Buridan, the rate at which a body accelerates during a fall was wholly ignored; often the fall was merely examined in regards only to an object's weight. Buridan saw these explanations as weak, which led him to equate the weight to the amount of impetus gained and retained in the falling body.[lxxiv] He declared, "a heavy body not only acquires motion unto itself from its principal mover, i.e. its gravity, but that it also acquires unto itself a certain impetus with that motion."[lxxv] Through this acquisition of impetus, the object actually moves faster because the fall is now caused by its own weight and the motion downward. Until some sort of resistance acts upon it, the body will continually increase its acceleration. Buridan's genius in the area of dynamics rivals that of the Oxford Calculator's of the time, and shows that even on the continent advancement was in fact occurring.

Oresme was Buridan's successor at the University of Paris and worked with many of the same principles. He actually altered the argument put forward by Buridan regarding the nature of impetus. For Oresme, impetus derived from the initial acceleration, which then allows the object to increase its speed. He stated in Book II of *De caelo*, "Because it is accelerated in the beginning, it acquires such an impetus and this impetus is a coassister for producing movement. Thus with other things equal, the movement is faster."[lxxvi] One sees an evident difference between Oresme's proposition and Buridan's because Oresme's explanation relies on both velocity and acceleration to create impetus.[lxxvii]

Oresme also left a lasting mark in other areas of natural philosophy. For example, he tried to extend the application of Bradwardine's Function using a series of proofs to work with ratios and proportions. He also extensively contributed to the field of cosmology through his work on the possibility of a vacuum. He discussed the vacuum in "The Possibility of a Plurality of Worlds," and came to the conclusion that "if two worlds existed, one outside the other, there would have to be a vacuum between them for they would be spherical in shape."[lxxviii] Essentially, Oresme asserted that their motion was individual in nature and thus did not rely on the other to move. Therefore, there had to be some type of space between them in order to prevent them from acting on one another. His work with voids eventually led scientists such as Newton and Samuel Clarke to work with the plausibility of voids in the seventeenth century.

During the thirteenth and fourteenth centuries, an evident scientific revolution occurred, which led to advancements in the fields of mathematics, physics, astronomy, kinematics, and dynamics. The origins of this revolution are found in the rise of universities, which caused men to congregate and dispute the ideas of the great minds of the past. These institutions became the centers of scientific thought during this time. The greatest example was in fact Merton College, which proved to be controversial place during the thirteenth century because it emphasized the importance of studying the natural sciences in order to explain the world. Men early associated with this place, including Grosseteste, Bacon, and Ockham, paved the way for future scientific thought by illustrating the importance that observation and experimentation played in one's understanding the world. Collectively they helped established a new mindset whereby one needs more than sheer logic to explain natural phenomena. The stage was thus set for the natural philosophers in the fourteenth century to build off of these ideas and work toward a new body of knowledge based on scientific inquiry.

Modern scientific inquiry inarguably began in the fourteenth century, which has been made evident in this paper. Each natural philosopher's contributions have been examined in order to show how substantial their work was for future scientists. Though many of their propositions and findings have since been disproved, they are nevertheless important to understand. Without the introduction of certain ideas, such as the intension and remission of qualities, "The Mean Speed Theorem," and the theory of inertia, scientists who came later would have had no foundation on which to stand. The work of fourteenth century scholars is often forgotten when compared with the great minds of Galileo, Kepler, and Copernicus who are idolized in history. It should be remembered, however, that their work relied on their scientific forebears who started to look at the world through a new lens. Thus, men like Bradwardine, Heytesbury, Dumbleton, and Swineshead deserve to be remembered in history as the fathers of modern science because without their genius and drive, later scientific thought would have been significantly impeded.

Endnotes

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[i] M.A. Hoskin and A.G. Molland, "Swineshead on Falling Bodies: An Example of Fourteenth-Century Physics," *The British Journal of the History of Science* 3 (1966), 150. For a similar claim see Edward Grant's *The Foundations of Modern Science in the Middle Ages* (New York: 1995) pp. 170: "A scientific revolution could not have occurred in Western Europe in the seventeenth century if the level of science and natural philosophy had remained what it was in the first half of the twelfth century."

[ii] Edward Grant, *The Foundations of Modern Science in the Middle Ages*, (New York: Cambridge University Press, 1995), 21.

[iii] Charles Haskins, *The Renaissance of the Twelfth Century*, (Harvard University Press, 1927), 286.

[iv] Edward Grant, *Physical Science in the Middle Ages* (Philadelphia: University of Pennsylvania Press), 22.

[v] Charles H. Haskins, "Adelard of Bath," *The English Historical Review* 26 (Jul., 1911), 491.

[vi] Charles H. Haskins, "Adelard of Bath," 496.

[vii] E.A. Synan, "Adelard of Bath," *New Catholic Encyclopedia* 1 (Detroit: Gale, 2003), 113.

[viii] Charles Burnett, "Adelard of Bath," *Oxford Dictionary of National Biography*, (Oxford: Oxford University Press, 2004), accessed on April 25, 2012, http://www.oxforddnb.com/view/article/163?docPos=1.

[ix] Ibid.

[x] H.J White, *Merton College, Oxford,* (London: J.M. Dent, 1906), 8.

[xi] Charles Edward Mallet, *A History of the University of Oxford,* (New York: Barnes and Noble, Inc., 1968, *61.* For further reading on the history of the Oxford Friars please see A.G Little's *The Grey Friars in Oxford.* Clarendon Press, 1892. Little goes in depth about the time directly before the topic discussed in this paper. The curious reader should pay close attention to Chapter three entitled "Franciscan Schools at Oxford."

[xii] A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science*, (Oxford: Clarendon Press, 1953), 53.

[xiii] A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science*, 59.

[xiv] A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science,* 82.
[xv] A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science,* 86.
[xvi] David C. Lindberg, "Robert Grosseteste and the Revival of Optics in the West," in *A Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 384
[xvii] David C. Lindberg, ed., *Science in the Middle Age*, (Chicago: University of Chicago Press, 1978), 359.
[xviii] Robert Grosseteste, "Concerning Lines, Angles, and Figures, trans. By David C. Lindberg in *A Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 385.
[xix] A.C. Crombie, *Augustine to Galileo: The History of Science*, (Melbourne: William Heinemann, Ltd., 1954), 71.
[xx] Robert Grosseteste, "Concerning Lines, Angles, and Figures in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 384.
[xxi] Robert Grosseteste, "On the Rainbow," in *A Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 388.
[xxii] Carl Boyer, "Robert Grosseteste On the Rainbow," *Osiris* 11 (1954), 250. A.C. Crombie discusses the impact that Grosseteste's research on the rainbow had on future scientists in *Grosseteste and Experimental Science*, Oxford 1953. One will see the progression of his theory in the fourteenth, fifteenth, and sixteenth centuries.
[xxiii] Ibid
[xxiv] Frederic Harrison, "Friar Roger Bacon," *The North American Review* 202 (1915), 243.
[xxv] Lynn Thorndike, "The True Roger Bacon," *The American Historical Review* 21 (1916), 245.
[xxvi] Roger Bacon, *The Opus Maius*, trans. by Robert Belle Burke, (New York: Russell & Russell, Inc., 1962), 116.
[xxvii] [xxvii] Roger Bacon, *The Opus Maius*, 124.
[xxviii] Roger Bacon, "The Opus Maius," in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 395.
[xxix] Thomas Glick, Steven J. Livesey, and Faith Wallis, eds., *Medieval Science, Technology, and Medicine: An Encyclopedia*, (Great Britain: Routledge: 2005), 374.
[xxx] David Woodward, "Roger Bacon's Terrestrial Coordinate System," *Annals of the Association of American Geographers* 80 (1990), 109.
[xxxi] Roger Bacon, *The Opus Maius*, 313.
[xxxii] David Woodward, "Roger Bacon's Terrestrial Coordinate System," 111.
[xxxiii] Edward Grant, *The Foundations of Modern Science*, 63,
[xxxiv] Roger Bacon, *The Opus Maius,* 363.
[xxxv] A.C. Crombie, *Augustine to Galileo: The History of Science*, 230.
[xxxvi] A.C. Crombie, *Augustine to Galileo: The History of Science*, 231.
[xxxvii] John E. Murdoch, "What is Motion?" in *A Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 228.
[xxxviii] A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science*, 174.
[xxxix] William of Ockham, "Treatise on Motion," in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 230
[xl] William of Ockham, "Treatise on Motion," 234.

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xli A.G. Molland, "The Geometrical Background to the "Merton School": An Exploration into the Application of Mathematics to Natural Philosophy in the Fourteenth Century," *The British Journal for the History of Science*, 4 (1968), 116.
xlii Thomas Bradwardine, *Tractatus de Proportionibus* trans. by H. Lamar Crosby, (Madison: University of Wisconsin Press, 1961), vii.
xliii A.C. Crombie, *Robert Grosseteste and the Origins of Experimental Science*, 179.
xliv Ibid.
xlv Ibid.
xlvi Thomas Bradwardine, *Tractatus de Proportionibus*, 22.
xlvii Thomas Bradwardine, *Tractatus de Proportionibus*, 113.
xlviii Thomas Bradwardine, "Tractatus de Proportionibus," in *A Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 303.
xlix John Longeway, "William Heytesbury", *The Stanford Encyclopedia of Philosophy (2010).*
l William Heytesbury, "Rules for Solving Sophisms" in *Science of Mechanics in the Middle Ages*, ed. Marshall Clagett, (Madison: University of Wisconsin Press, 1959), 235.
li li William Heytesbury, "Rules for Solving Sophisms," 239.
lii Grant, *The Foundations of Modern Science*, 101.
liii James A. Weisheipl, "The Place of John Dumbleton in the Merton School," *Isis* 20 (1959), 451.
liv Ibid.
lv John Dumbleton, "The Summa of Logical and Natural Things," in *Science of Mechanics in the Middle Ages*, ed. Marshall Clagett, (Madison: University of Wisconsin Press, 1959), 305.
lvi Ibid.
lvii A.C. Crombie, *Augustine to Galileo: The History of Science*, 240.
lviii Ibid.
lix George Molland, "Richard Swineshead," *Oxford Dictionary of National Biography.*
lx John Murdoch and Edith Sylla, "The Science of Motion" in *Science in the Middle Ages*, (Chicago: University of Chicago Press: 1978), 227.
lxi M.A. Hoskin and A.G. Molland, "Swineshead on Falling Bodies: An Example of Fourteenth-Century Physics," 155.
lxii John Murdoch and Edith Sylla, "The Science of Motion," 229.
lxiii M.A. Hoskin and A.G. Molland, "Swineshead on Falling Bodies: An Example of Fourteenth-Century Physics," 168.
lxiv Richard Swineshead, , "Richard Swineshead and Late Medieval Physics I: The Intention and Remission of Qualities," ed. Marshall Clagett, *Osiris* 9, (1950), 141.
lxv Richard Swineshead, "Richard Swineshead and Late Medieval Physics I: The Intention and Remission of Qualities," 159-160.
lxvi Ibid.
lxvii John David Bond, "Richard Wallingford: (1292-1335)," *Isis*, 4, (1922), 460-461.
lxviii John David Bond, "Richard Wallingford: (1292-1335)," Ibid.
lxix J.D. North, "Wallingford, Richard, *Oxford Dictionary of National Biography.*
lxx Olaf Pederson, "Astronomy," in *Science in the Middle Ages*, (Chicago: University of Chicago Press: 1978), 326.

[lxxi] Marshall Clagett, introduction to "The Impetus Theory of Projectile Motion," in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 275.
[lxxii] John Buridan, "The Impetus Theory of Projectile Motion," in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 275.
[lxxiii] John Buridan, "The Impetus Theory of Projectile Motion," 277.
[lxxiv] Edward Grant, *The Foundations of Modern Science in the Middle Ages*, 97.
[lxxv] John Buridan, "On the Cause of Acceleration of Free Falling Bodies," in A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 281.
[lxxvi] Marshall Clagett, *Science of Mechanics in the Middle Ages*,(Madison: University of Wisconsin Press, 1959), 552.
[lxxvii] Edward Grant, *The Foundations of Modern Science in the Middle Ages*, 99.
[lxxviii] Nicole Oresme, "The Possibility of a Plurality of Worlds," A *Source Book on Medieval Science*, ed. Edward Grant, (Cambridge: Harvard University Press, 1974), 552.

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