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Questioning Nature in Late Middle Ages. A History of Method, Praxis and Innovation

Cuestionar la naturaleza en la Baja Edad Media. Una historia de método, praxis e innovación

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Abstract
This essay traces the interconnections between *method, praxis and innovation* with their epistemological consequences at the end of the Middle Ages. In the wake of scholastic *natural philosophy*, this vibrant process marks a milestone in the history of science. During the Thirteenth and Fourteenth centuries a profound transformation takes place in the way of observing nature through a meticulous data collection, experiments and subsequent analysis. In this cultural framework, the Franciscans analyze the realities of the world with an extremely original pragmatic dynamism. This approach gives priority to a practical sense of thinking through a transformative action which opens the doors to a pioneering scientific method and contributes to a long series of innovations. A positive result is an advanced didactics—especially developed by Buridan, Oresme and their followers—that will have a great impact on a continental level, changing the common ground of European science.

Keywords: History of Science, Medieval Philosophy, Medieval History, Philosophy of Science, History of Franciscan Thought

Resumen
Este ensayo traza las interconexiones entre *método, praxis e innovación* con sus consecuencias epistemológicas al final de la Edad Media. A raíz de la *filosofía natural* escolástica, este proceso vibrante marca un hito en la historia de la ciencia. Durante los siglos XIII y XIV se produce una profunda transformación en la forma de observar la naturaleza a través de una minuciosa recopilación de datos, experimentos y análisis posteriores. En este marco cultural, los franciscanos analizan las realidades del mundo con un dinamismo pragmático sumamente original. Este enfoque da prioridad a un sentido práctico del pensamiento a través de una acción transformadora que abre las puertas a un método científico pionero y contribuye a una larga serie de innovaciones. Un resultado positivo es una didáctica avanzada —especialmente desarrollada por Buridán, Oresme y sus seguidores— que tendrá un gran impacto a nivel continental, cambiando la base común de la ciencia europea.

Palabras clave: historia de la ciencia, filosofía medieval, historia medieval, filosofía de la ciencia, historia del pensamiento franciscano

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Synopsis

During the Thirteenth and Fourteenth centuries a powerful cultural movement, propagator of a series of innovations in both general thought and *curriculum studiorum*, gains momentum. In the midst of an atmosphere of intense and fruitful discussions, the foundations of a profound process of transformation in the way of observing nature through a systematic collection of data, experiments and subsequent analyses are gradually laid.[1]

In addition, numerical theories, brought from his North-African travels by Leonardo Fibonacci,[2] are disseminated and, even without being still perfectly applied, entered progressively into the centers of study.[3] The universities of Oxford and Paris can be considered substantial sources of European culture and, as a result of mutual influence and power, they propagate their innovative ideas throughout Europe, essentially changing the epistemological approach to the study of the "arts" and starting a newfound process in the way of questioning nature.

Nature and Faith

The Thomistic attempt of harmonising Aristotelianism—in the wake of Albert the Great—and the Platonic-Augustinian vision of the Franciscan

[1] Hein, *Die Mathematik im Mittelalter,* 108-109.

[2] "Novem figurae indorum he sunt 9 8 7 6 5 4 3 2 1. Cum his itaque novem figuris, et cum hoc signo 0, quod arabice zephirum appellatur, scribitur quilibet numerus". Leonardo Fibonacci, *Liber Abaci*, Chapter I, Biblioteca Nazionale di Firenze (Conv. Soppr. C.I. 2616). See also: Leonardo Pisano detto il Fibonacci, *Liber abaci. Il libro del calcolo* (a cura di G. Germano e N. Rozza), Napoli: Paolo Loffredo Editore, 2019 and Leonardi Bigolli Pisani vulgo Fibonacci, *Liber abbaci* (Edidit Enrico Giusti adiuvante Paolo D'Alessandro), Biblioteca di Nuncius vol. 79, Firenze: Olschki, 2020.

[3] Sesiano, *An Introduction to the History of Algebra,* 93-124.

tradition bring together a common substrate of philosophical and theological concepts in a confluence,[4] albeit sometimes very problematic,[5] but without a doubt, immensely prolific.[6] From the Augustinian synthesis of man as a Trinitarian representation in which *understanding, memory and will* come to be united (among the faculties of the soul), it can be understood in the Franciscan approach that practical sense of philosophizing which is based on actual existence and transformed into action. Franciscan thinkers analyze the realities of the world with an extremely original pragmatic dynamism.[7]

Alexander of Hales (1185-1245) tackles the central theme of the radical contingency of the world and the temporality of creation, asserting that eternity is—at the same time—a category and divine property. The material world, then—even because of the consequences of the free will of contingent beings—should not be considered an eternal *a priori,* even if it is a manifestation of divine action[8]. In this context some ancient Greek doctrines, together with their pantheistic paradigms, begin to be questioned and confined to the space of the probable.[9]

A critical process towards Aristotelian thought has its origins during the previous century in England, linked to the theories of Robert Grosseteste (1175-1253) who, detracting value to the "demonstrative syllogisms", presents with the technique of the controlled experiment an innovative and cutting-edge method of research. The systematic application of mathematics on quantifiable, qualifying, and catalogued data constitutes the *sine qua non* condition for the success of the experiments. Grosseteste comes to support the so-called "economic laws of natural phenomena" according to which nature behaves and functions as quickly and in as organized manner as possible.

His disciple Roger Bacon (1214-1292) enriches this vision of scientific practice by emphasizing the role of observation and experience; this cultural

[4] Warner, *Knowledge for Love.*

[5] "If Thomas conceded the need for some equivocation in our theological discourse, Duns Scotus and, even more so, the so-called Nominalists of the fourteenth century objected to any equivocation, whether restrained or not. About that which one cannot speak without equivocation they preferred to remain silent. They aimed at an absolute transparency of the language of every science". Funkenstein, *Theology and the Scientific Imagination,* 57.

[6] See Robson, *The Franciscans in the Middle Ages* and Mormann, *A History of the Franciscan.*

[7] Tavares Magalhães, "The medieval university", 237-245.

[8] "Possibly inspired by contemporary psychological views on the relation between possible intellect and the "cogitative", the *Summa halensis* introduces a more neatly drawn distinction between material and possible intellect". Spruit, *Species intelligibilis,* 122.

[9] Schlüssler, *The Debate*.

innovation is easily recognized not only in the evolution of English thought but also in the rest of the continent. M. Colish defines this era as "*Aristotelian, Para-Aristotelian and Post-Aristotelian"*, thus indicating the new direction in the history of Western philosophy.[10] Such a dynamic approach is clearly evident in the encyclopedic work of Bartholomew the Englishman (1203-1272), whose *De proprietatibus rerum*—dated around 1240—deals not only with theological arguments but dedicates 16 of 19 chapters to scientific disciplines: from the universe and celestial bodies to time and motion; from air, water and their elements to earth and its surface and anthropo-geographical differences, with a meticulous listing of gems, minerals and metals. Investigating on animals and plants as well as on smells, tastes and substances, he pushes forward not only the knowledge about physiology, zoology and, especially, ichthyology, but also medicine with a specific commentary on diseases and poisons, whose recommendations were taken into consideration and used for centuries in medical practices.[11]

Bonaventure of Bagnoregio (1221-1274) adds that the philosopher is called not to create a multiplicity of idealistic and fragmented fictions of the Truth but "to discover it, to clarify it and to exhibit it".[12] That's why the *Seraphic Doctor* underlines that "philosophical science is nothing but evident knowledge of the truth as an object of research".[13] In conformity with these words, the assignment of the thinker is structured as a response to the complex and multiform reality of the world, which is—as he stated— "the house made for man",[14] that coexists in nature and with nature, demanding a behavior of respect and communion.

Despite the explicit *Condemnation of 1277* on the so-called dangerous naturalistic approach of an Averroist mold which has a curtailing effect on research and sciences, the teaching of John Duns Scotus (1265-1308)—professor in Paris in the early fourteenth century—foreshadows new and potential changes.[15] In his attempt to achieve a convergence between the Franciscan tradition (which is faithful to the traditional Augustinian neoplatonism) and the Dominican School (faithful to the Aristotelian-Thomist faith), he conceives of an original thesis that ends up distancing him from both.[16]

[10] Colish, *La Cultura nel Medioevo*, 513.
[11] Ventura, "Bartolomeo Anglico".
[12] Merino, *Historia de la filosofia franciscana*, 36.
[13] Bonaventure, *Collationes de septem donis Spiritus Sanctis*, col. 4. N. 5.
[14] Bonventure, *Breviloquium*, p. 2, c. 4., n. 5.
[15] Segura Novoa and Patriarca, "El enfoque franciscano y la ciencia".
[16] Haffner, *The Mystery of Reason*, 101-102.

Duns Scotus differentiates the knowledge objectives involved in the abstraction process and draws a great distinction between the understanding of physical entities on the one hand, and spiritual entities on the other.[17] In support of this formal distinction, he makes use of the "theory of intuition", which should not be interpreted as "mystical contemplation, psychological acuity or a vague and general sensation"[18] and hence acquires a very specific cognitive connotation. A structural study of phenomena—conceived in the field of the intelligible through natural conceptualization or mediated by the intuition of sensitive data—becomes essential for knowledge of reality. Hence the root of the definition of *haecceity* as a principle of the formal identification of spiritual and material beings.[19]

In this sense, the *matter*—according to Peter of John Olivi (1248-1298)—is not a limitation or an imperfection in itself.[20] Although he is aware of the intrinsic limit of any finite being, Olivi places his emphasis on its positive dimension because matter has within it the potentiality of perfectability.[21] A similar positive projection towards the material is found in the Franciscan tertiary Ramon Llull (1232-1316) which—in his work *Arbor Scientiae*— puts a cornerstone in the history of alchemy through his plan of unification between the centrality of Revelation, the need for knowledge and the discovery of the natural world.[22]

Inspired by the medical knowledge of the *School of Salerno*—in which a synthesis of the Greek-Latin tradition was supplemented by the most recent findings from Arab and Jewish investigation—a prophylaxis approach is developed, based fundamentally on practice and experience, thus paving the way for the culture of prevention and applied pharmacology. In this flourishing context, the *Pro conservanda Sanitate* ("On the Prevention of Health")—written by Vital du Four (1260-1327)[23]—presents itself as a medical compendium, providing a long and detailed series of advice and entries on diverse medical subjects in alphabetical order: from medicinal plants to treatment of common malaises, from epidemic diseases to remedies for general cases such as sleep and digestive disorders.[24]

[17] See Vos, *Philosophy of John Duns Scotus*.

[18] Colish, *La Cultura nel Medioevo,* 495.

[19] Park, "Haecceitas and the Bare Particular".

[20] Ritchey, *Holy Matter,* Chapter IV.

[21] Cross, "Absolute time".

[22] Badia Pámies, Santanach Suñol and Soler Llopart, *Ramon Llull as a Vernacular Writer* and Ramis Barceló, "Nuevas perspectivas para la historia del lulismo".

[23] The Franciscan Vital du Four became in 1312—like Bonaventure some decades earlier—cardinal and bishop of Albano.

[24] Matus, *Franciscans and the Elixir of Life.*

According to Vital du Four, a direct cognition of the concepts is possible through the understanding given by the actual existence and the personal interpretation of natural events.[25] He introduces a form of scientific principle of individuation that leads to the improvement of alchemical techniques and innovative forms of distillation. The search for a panacea, as a remedy for the most common diseases or as disinfectant, is by no means secondary and, paradoxically, the result is the production of an *eau-de-vie* which, as Vital du Four claims in the chapter of his treatise devoted to the *nature of the waters* (*natura aquarum*), is obtained by distilling red wine over low heat in an ampoule.[26] This "hot water" can under certain conditions produce a flame without consuming the substance it soaks like a wick.

Here is decisive the improvement of the *alembic* which, invented by the Persian scholar Al-Razi a few centuries before, is used for the distillation of liquids through evaporation by heating and subsequent condensation by cooling. Its original use, as well as the production of medicinal oils, is witnessed both by the Dominican Theodoric Borgognoni (1205-1298) in his *Praxis Chirurgica*—in which he deals with antiseptics, anaesthetics and surgery[27]—and by Taddeo Alderotti (1206-1295) in his *Consilia medicinalia,* that is the first manual for medical education at the University of Bologna.[28] The pursuit of healing elixirs or potions is common also to Arnald of Villanova (1238-1311), with his extensive catalogues of simple and compound antidotes,[29] and to John of Rupescissa (1310-1366) with his treatises *De quinta essentia* ("On the Fifth Essence") and *Liber Lucis* ("Book of the Light"), that were translated into many European languages and printed until the 16th century.[30]

Philosophy and Mathematics

On a philosophical level, the thought of Duns Scotus opens the doors of Paris to the reception of another Franciscan: William of Ockham. This period is also the most developed and influential of the *Calculators* (Richard and Roger Swinshead,

[25] Putallaz, "La Connaissance de Soi au Moyen Age.

[26] Wilson, *Water of Life,* 310.

[27] His treatise on veterinary medice titled "*Mulomedicina*"—especially devoted to the health care of the horses—deserves to be remembered.

[28] Siraisi, *Taddeo Alderotti and His Pupils.*

[29] Calvet, *Les* œuvres *alchimiques*.

[30] DeVun, *Prophecy, Alchemy, and the End of Time*.

John Dumbleton, William of Heytesbury, Thomas Bradwardine and others) that, gathered at Merton College, are characterized by their strictly mathematical approach applied to the physical sciences.[31] Following the teachings of Grosseteste and Bacon, they literally adopt the principle of the "Ockham's razor" and specialize explicitly in kinematics,[32] a subject of considerable study in both Paris and Padua. The Oxonian mathematicians—active between 1325 and 1350—also define the *mean speed theorem*, described by Edward Grant as "the most outstanding single medieval contribution to the history of physics".[33]

In the field of philosophy, a proto-scientific methodology coupled with the discoveries of the period opens up its own ways. They lead to a budding modernity and mindset in which, as Etienne Gilson affirms, "takes place a dissociation of reason and faith".[34] The logical-epistemological conception developed by Ockham causes such a revolution in medieval philosophical thinking that he is accused of heresy and called to face accusations in the papal court of Avignon. During this process of constant reformulation, human knowledge is divided into three areas: *intuition, abstraction* and *faith*.

If faith requires revelation and grace, the other two require only rational skills. Ockham avoids the *Scotian intelligible principles* in the development of his thinking and applies intuition to the simple knowledge of phenomenal beings.[35] The "immediate knowledge" is the litmus test for the learning of the physical objects which already provides a certain understanding of the existence of such objects separated from any process of deceitful and useless reasoning. Under this perspective any proposition to be true and acceptable must be immediately self-evident.[36]

If abstraction focuses on the relationship of ideas, intuition is based on experimental knowledge and "that cognition is the cause of universal proportion which is the principle of art and science".[37] Philosophy becomes empirical: everything is and must be verifiable. His insistence on the *economics of thought*—according to which it is useless to get lost in the labyrinths of a vicious intellectual speculation—makes obsolete many ideas that had been

[31] Dudley Sylla, *The Oxford Calculators and the Mathematics of Motion*.

[32] Toulmin and Goodfield, *The Fabric of the Heavens,* 213.

[33] Grant, *Physical Science in the Middle Ages,* 56.

[34] Gilson, *La Filosofia nel Medioevo*, 765.

[35] Spruit, *Species intelligibilis Classical Roots.*

[36] Davidson, "Eine Kohärenztheorie der Wahrheit und der Erkenntnis", 271.

[37] "illa de qua dictum est quod est cognitio experimentalis qua cognosco rem esse. Et *illa cognitio est causa propositionis universalis quae est principium artis et scientiae*", Ockham, *In II Sent*., q. 12-13 (Mss. Oxford, Balliol, Coll. 299).

vehemently discussed for years.[38] The distinction between essence and existence, as well as between matter and form then loses their traditional logical and metaphysical meaning, thereby becoming less worthy of study.

The universal concepts, being merely signs, are then susceptible to multiple interpretations, for this reason only individuals and particular entities are real. Such an ontological consistency guides Ockham along the same path already traced by Roscelin and leads him to argue, on numerous occasions, that the universality of *nomen* ("name") has a purely conventional meaning and lacks universal significance.[39] *Nominalism* has an irrefutable impact on the philosophical heritage, taking possession of the centers of culture and changing the way of thinking in a radical way.

Inside this current there is a methodology in which the terms are used in their strictest sense in order to avoid any duplication or ambiguity. In turn, they have a different semantic value according to the parts of the discourse, once the syntactic arrangements have been carefully analyzed. This is undoubtedly a proposal to draw a clear distinction between term and concept.[40] The term refers to any mental, oral, or written sign in a general sense, while the concept refers to intentional signs that coincide exclusively with a specific idea.[41]

In continental Europe, Ockham's thinking has a rapid spread, thanks to the influence and great mobility of the scholars of the Oxonian schools in several universities.[42] Among them, Walter Burley (1275-1345) and Richard Kilvington (c. 1302-1361) who, by following Ockham's systematic formulation,[43] reduce its speculative excesses and present in physics the *unity of the substantial form*[44] on which they lay the foundations to solve the problem of *qualitative change of substances.*[45] This recognized doctrine holds that it is the mutual replacement of qualitative forms in the subject which causes the decrease or increase of a quality in a succession of forms that disappear once they are displayed. The merit of Burley is to bring innovative solutions, developed with considerable success, to the theories of the movement and of the empty space in medieval physics.[46]

[38] Karger, "Ockham's Misunderstood Theory".
[39] Mensching, *Das Allgemeine und das Besondere,* 97.
[40] Bochenski, *Formale Logik*, 81.
[41] Perler, *Theorie der Intentionalität im Mittelalter*, 383.
[42] Weisheipl, "Ockham and Some Mertonians".
[43] Pellettier, "William Ockham on the Mental Ontology of Scientific Knowledge".
[44] See Hill, "Substantial Forms and the Rise of Modern Science".
[45] Emerton, *The Scientific Reinterpretation of Form*.
[46] Wood, "Walter Burley on Motion in a Vacuum".

This logical-empirical trend is reinforced in Paris with the teachings of Gregory of Rimini (1300-1358) who concentrates, summarizes and makes more accessible the Mertonian ideas of Walter Chatton (c. 1290–1343), Robert Holcot (c. 1290-1349), Thomas Bradwardine (c. 1290-1349), Adam Wodeham (c. 1295-1358), Richard Fitzralph (c. 1300-1360) and William Crathorn, deepening in the first instance the question of the object of scientific knowledge.[47] From a strictly speculative point of view, it is the work of Nicholas of Autrecourt (early 1300-after 1350) that takes the Parisian academy away from orthodoxy. Metaphysics itself becomes "object of a type of knowledge that cannot aspire to the certainty of faith nor to the experimental or logical one".[48]

The stimulating arrival of the Oxonian ideas in France causes strong tensions at the University of Paris and vigorous strife with the ecclesiastical authorities. An official document from the *Faculty of Arts* dated September 1339 states: "Recently, some have tried to teach both in public and in secret meetings, the doctrine of William of Ockham, as if it were accepted as an official doctrine" and decrees that "no one can dare to present this doctrine as an official, either by listening to it or explaining it in public or secrecy, or by convening private meetings to discuss it, and to refer to it during the explanation of the canonical texts and in the disputes".[49]

This prohibitive document shows the extent to which the thinking of the English Franciscan had entered the Parisian academy, influencing both public and private life. From these same words it can be inferred that scholarly circles present and discuss in depth their theories. It is in the midst of the vivacity of this context that philosophy undergoes a change in its contents and methodologies. The various expressions of Logic, Metaphysics, Mathematics, Astronomy, Physics, Philosophy and Theology are now beginning to take different forms; thus the areas and lines of demarcation between the different *arts* will be more clearly defined.[50]

For this reason, focusing primarily on arguments related to physical and mathematical issues, the *philosophy of nature* involves a change in the methodology of experimentation with epistemologically relevant consequences. Aristotelianism—although it could not be transformed *hic et nunc* in something like Newtonism—is embedded and melted into a new science with a completely different worldview.[51]

[47] Fiorentino, *Gregorio da Rimini*.
[48] Fumagalli Beonio Brocchieri and Parodi, *Storia della Filosofia Medievale*, 437.
[49] Quoted Bottin, *La Scienza degli Occamisti,* 135.
[50] Patriarca, "Die spätscholastische Methodik und die Dialektik der Naturbeherrschung".
[51] Grant, *The Foundations of Modern Science in the Middle Ages,* 107.

The Primacy of Physics

Among the institutions that gravitate around the Studium Parisiensis, the College of Navarra founded in 1305 by Joan I of Navarra, wife of Philip IV the Fair, shines for its fame and glory.[52] From the beginning, the College—in addition to hosting an academic community of "exceptional quality"[53]—is distinguished by a faithful devotion to the crown. The College is located in the Hotel de Navarra, a building that Queen Joan left for this purpose in the Rue de St. André des Arcs. Students are prepared by a resident faculty that deals with both their intellectual and spiritual formation.

Around 1315 the director of such a prestigious institution is John of Jandun (c. 1280-1328) who introduces the most recent political and social theories of his close friend Marsilius of Padua. The importance of the renewal of the curriculum as well as the preference for the exact and natural sciences is the central axis. It is in that challenging and austere environment that the old arts head towards the modernity.[54] John Buridan (c. 1293-1358) became rector of the University of Paris in 1328 and is universally considered the founder of its acclaimed School of Physics where all the previous scientific tradition is put into question, both the West and that coming from the Islamic and Jewish inquiry.

Immersed in the productivity of such an environment and applying new methods, the *corpus aristotelicum* is investigated thoroughly and critically. Little more than half a century after the condemnations of 1277 a metamorphosis of thought and practices begins to take place. Aristotle, commented and spoken about, is at the same time a starting point and an obstacle to research. Many of his ideas receive criticism and refutations. While Ockham's role as the main source of the Parisian School can not be denied, it must also be said that his nominalism in Paris is mitigated and purified from some of its most extreme theses. On the other hand, Buridan and his followers (Albert of Saxony, Henry of Hesse, Marsilius of Inghen, Themon[55] and Oresme) admit of the convergence between natural science and rational theology. In this way, they avoid an extremely skeptical nominalistic interpretation.[56]

In this circle the curiosity of knowledge is mainly directed towards the study of the earth, the stars, the movement of the bodies, gravity, emptiness

[52] Jean de Launoy, *Regii Navarrae Gymnasii Parisiensis Historia*.
[53] Artigas, "Nicolas Oresme, Gran Maestre del Colegio de Navarra".
[54] Grant (ed.), *Much Ado About Nothing*.
[55] Hugonnard-Roche, *L'œuvre astronomique de Thémon Juif*.
[56] Zupko, "Buridan and Skepticism".

and speed. The *theory of impetus* comes from the scientific reflection of John Buridan who, inspired by the criticisms of Francis of Marca and developing the ideas of Nicholas Bonet, defines the *impetus* as an actuating force transmitted from a starter-engine on the object that is placed in movement.[57] This energy is permanent and indefinite in time, unless the impulse is damaged or diminished by external resistances. According to Buridan, *impetus* can be calculated multiplying weight by velocity. In his *Questions on Aristotle's Physics* he states:

> When a mover sets a body in motion he implants into it a certain impetus, that is, a certain force enabling a body to move in the direction in which the mover starts it, be it upwards, downwards, sidewards, or in a circle. The implanted impetus increases in the same ratio as the velocity. It is because of this impetus that a stone moves on after the thrower has ceased moving it. But because of the resistance of the air (and also because of the gravity of the stone) which strives to move it in the opposite direction to the motion caused by the impetus, the latter will weaken all the time. Therefore, the motion of the stone will be gradually slower, and finally the impetus is so diminished or destroyed that the gravity of the stone prevails and moves the stone towards its natural place. In my opinion one can accept this explanation because the other explanations prove to be false whereas all phenomena agree with this one.[58]

This theory revolutionizes the physics of the Late Middle Ages and becomes a precondition for future discoveries. Buridan is convinced that "the certain knowledge of the truth is possible"[59] and it is this certainty that leads him to extend his ideas to the understanding and explanation of the movement of the celestial spheres, thus abandoning the theory of *Primum Mobile* ("First Mover")[60] and Dante's *motor intelligences.*[61] This security exerts a stimulus on the Parisian academic community and it generates a productive and fruitful series of mutual influences. From an epistemological point of view, Buridan, summarizing contemporary trends in the need for experimentation and obtaining resulting generalizations, argues that "they are accepted because they were seen as true in many cases, and as false in none".[62]

[57] Hentschel, "Zur Begriffs- und Problemgeschichte von 'Impetus' ".
[58] Quoted in Pedersen, *Early physics and astronomy,* 210.
[59] Buridanus, *Quaestiones in Metaphysicam Aristotelis*, Lib. II, quaestio I.
[60] Lang, *Aristotle's Physics and Its Medieval Varieties*.
[61] Binggelli, *Primum mobile*.
[62] Buridanus, *Quaestiones in Metaphysicam Aristotelis*, Lib. II, quaestio II, f. 9v, col. 2.

Method, Didactics and Innovation

Following in the wake already marked by Johannes de Sacrobosco, Gerard of Brussels, Hugo of Saint Victor, Dominicus Gundisalvo and by the contribution of the "School of Toledo",[63] a new geometric and trigonometric approach is given to the study of mechanics,[64] thanks to the stereographic projections of Jordanus de Nemore (1225-1260).[65] Such an approach causes a big leap forward in the field of kinetics, astronomy and kinematics.

Of particular importance is the pragmatic teaching of astronomical research proposed by Andalo di Negro (1260-1334). His algebraic works—along with those of Peter of Abano (1250-1316), Johannes Campanus of Novara (1220-1296) and Dominicus de Clavasio—contribute to a change of direction in continental universities, monasteries and *abacus schools,* whose teachings are fundamental in the formation of new commercial techniques and in the development of accounting as well as a modern economic science.[66] In this period, we are witnessing—under the same method —to the philosophical and theological condemnation of astrology with all its legacy of pagan beliefs and superstitions.[67] The *Alfonsine Tables*, while serving as a reference point, are questioned in the context of the mathematical verification of natural phenomena thanks to the didactic works of John of Ligneres, John of Murs and John of Saxony.[68]

It is not surprising the crucial development of optics in this vibrant historical juncture. According to Bonaventure of Bagnoregio, "light has [...] brightness [*claritas*] because it illumines; impassibility, because nothing corrupts it; agility, because it moves quickly; penetrability, because it passes through diaphanous bodies without damage to them".[69] Starting from the Bonaventurean structure, the origin of masterful results in the study of perspective, light and colors' theory can be found.[70] The treatises *On light* and *On rainbow* of Dietrich of Freiberg (c. 1250-1310) and the experimentations of Erazmus Ciołek Witelo (1280-1314)—to which Kepler will dedicate in 1604 one of his works on the fundamentals of the modern optics[71]—offer a detailed analysis of the

[63] Burns, *Emperor of Culture,* 59.
[64] Braunmühl, *Vorlesungen über Geschichte der Trigonometrie*, 92.
[65] Busard, *Jordanus de Nemore*.
[66] Maierù, Galluzzi and Santoro, *La tradizione latina.*
[67] Caroti, "Nicole Oresme's polemic".
[68] See Goldstein and Chabás, *The Alfonsine Tables of Toledo*.
[69] Bonaventure, *IV Sent.*, dist 49, p. 1. art. 2, q. 1.
[70] McAdams, *The Aesthetics of Light*.
[71] Kepler, *Les fondements de l'optique moderne*.

relationship between refraction and reflection as well as the first interesting intuitions on the composition of light, with connections to the later spectroscopy.

In this context, the manufacture of astrolabes and mechanical watchmaking by Richard of Wallingford (1292-1336)[72] and Giovanni de' Dondi (1318-1389)[73] is vital for the flourishing of a proto-modern instrumentation that is also based on the experiments applied to optical lenses, prisms and raw crystals.[74] Driven by the commercial revolution and the tremendous expansion of trading routes such an accurate approach in building devices and equipment is applied to nautical, maritime and meteorological knowledge.[75] The growing interest in putting together a set of scientific, technical, aesthetic and even historical information through symbolic representation such as *mappae mundi* is by no means to be considered an isolated case in that age.[76] A marvellous exemplar is the *Hereford Mappa Mundi*, painted between 1276 and 1283 and attributed to Richard of Haldingham. It reproduces the then known world on the basis of historical, biblical, classical and mythological notions.[77]

In the evolution from the *Tabula Rogeriana* (1154)—constructed by the Arab geographer Al-Idrisi as *Kitab Rugar* (باتك رجور) when he was at the court of the King Roger II in Sicily—to the *Liber Rivierarum* (1200), the compass and its magnetism has an enormous importance for the shoreline mapping and cartographic projections, which are the result of geometric, mathematical and empirical transformations of geographical points expressed in terrestrial coordinates. The first rudimentary divisions into loxodromic curves and spirals allow to identify the poles and to join any two points on the earth's surface, cutting all the meridians with the same angle. The *Carta Pisana*— dated around 1275—is considered to be the first nautical chart in which two wind roses are depicted: one in the western Mediterranean (from west coast of Sardinia) and one in the east (in the Aegean coast of Greece). It inscribes almost the entire Mediterranean within their respective circles. From each of the wind roses sixteen rhumb-lines branch out, corresponding to the directions of the winds.[78]

72 North, *God's Clockmaker.*
73 Cf. Bedini and Maddison, "Mechanical Universe".
74 Ilardi, *Renaissance Vision from Spectacles to Telescopes*. See Frugoni, *Il Medioevo sul naso*.
75 Block Friedman and Mossler Figg, *Trade, Travel, and Exploration in the Middle Ages*.
76 Edson, *Mapping Time and Space* and Edson, *The World Map, 1300-1492*.
77 Harvey, *Mappa Mundi*.
78 Pujades i Bataller, "The Pisana Chart".

Another fruitful consequence of this pragmatism is the *Compasso de Navegare*, an Italian work composed at the end of the Thirteen Century and divided in two connected parts: a portolan —which is a manual for coastal navigation based on experience and observation, containing detailed information on the nature of the currents, the depth of the seas, the presence of cliffs and related commentary—and a nautical map of the Mediterranean Sea. Even though it was written in vernacular Italian, the unknown author uses, in many cases, a sort of naval *lingua franca,* which contains highly technical terms of seamanship.[79] Such terminology and excellent technique are common to the three main cartographic schools: Genoa, Venice and Mallorca.

In Genoa the most significant proponents of the Italian portolan tradition are, undoubtedly, Giovanni di Mauro da Carignano (1250-1330) and Pietro Vesconte—active between 1310 and 1330 —whose chart, dating 1311 and representing the eastern Mediterranean, is the oldest signed nautical document of the Middle Ages.[80] For this reason, Vesconte is justly considered a pioneer in this field, and is responsible for influencing Italian and Catalan cartography[81] throughout the 14th and 15th centuries.[82] The chronicles report his activity in Venice where he produced a series of portolan charts and whose influence is visible in the statesman and geographer Marin Sanudo the Elder (1260-1338) and, especially, in Domenico and Francesco Pizzigano. Their famous portolan—dated 1367—is one of the largest maps of the era, in which are drawn parts of the Atlantic Ocean, the Scandinavian peninsula and the Caspian Sea.

The first and most prominent figure of the School of Mallorca is, allegedly, Angelino Dulcert —also known as Angelino Dall'Orto—whose portolan chart, dated 1339, represents in the same parchment northern Europe and significant parts of Africa and the Atlantic Ocean.[83] It is also notable by being the first chart in which is clearly depicted the island of Lanzarote as *Lanzarotus Malocelus*—named after the Genovese merchant and navigator Lanzarotto Malocello (1270-1336), who first arrived in the Canarian archipelago in 1312.

[79] Debanne (ed.), *Lo compasso de navegare* and Motzo, *Il compasso da navigare*.

[80] Allen*, Eastward Bound,* 138.

[81] See Bouloux, *Culture et savoirs géographiques*.

[82] See Richard L. Pflederer, *Census of Portolan Charts & Atlases* (privately published, 2009) and *Census of Portolan Charts and Atlases* (2009), *Catalogue of Portolan Charts and Atlases of the British Library* (2001), *Catalogue of Portolan Charts and Atlases of the Huntington Library* (2004), *Catalogue of Portolan Charts and Atlases of the Newberry Library (2005), Catalogue of Portolan Charts and Atlases of the National Maritime Museum* (Greenwich, 2006), and *Catalogue of Portolan Charts and Atlases of the Archivo di Stato di Firenze* (2013).

[83] Campbell, "Portolan Charts from the Late Thirteenth Century to 1500".

The portolan is also very impressive for the drawing of an island called Antilia and another one called Brazil.[84]

To the Mallorcan School belong also the Jewish cartographer Abraham Cresques (1325-1387) and his son Jehuda Cresques, whose *Catalan Atlas* is originally produced on 6 sheets, finely illuminated in various colors including gold and silver, and with descriptions in Catalan language where astronomical, astrological and cosmological indications are put along with commercial references such as the three main Silk Roads.[85] This historical document represents also a balance of geopolitical powers in the Euro-Asian basin with their pre-modern thalassocratic empires from the Tyrrhenian and Adriatic coasts to the Baltic towns,[86] from the Dardanelles and the Marmara Island to the Black Sea and the Caspian trading centers,[87] where the Italian *Maritime Republics* of Genoa, Venice, Pisa, Ancona, Noli and Ragusa[88] were facing the growing influence of Barcelona, Valencia and the Crown of Aragon[89] in the southern hemisphere and the Hanseatic League in the northern one.[90]

Here, the *Book of the Consulate of the Sea,* published in Catalan around 1330, and the *Statutes of the Sea*, published in Ancona around 1380, deserve, therefore, to be briefly remembered. They are legal codes—which inspired by the Byzantine tradition and previous canons such as the Trani's *Ordinances and Custom of the Sea* (1063), the *Amalfi Laws* and the Ragusa's *Liber Stuarum* (1272)—have systematized naval legislation creating a model for international mercantile law. In this interconnected world of travels, discoveries and business,[91] money starts to change its role with an integrated system of banks—tremendously innovative in Florence—that had a dense network of agencies and branches in Europe and the Near East and emitted *promissory notes* leading to a new form of financial transactions.

Not accidentally the ethical reflection on the value and intrinsic dangers of the monetary alterations, made by the sovereigns or the States through an aggressive policy of seigniorage, as well as on the legitimacy of the interest rates connected to the risk (therefore, not usurary) and on the need of insurance tools is an issue that unites many jurists, philosophers and theologians from

[84] Wittmann, *Las islas del fin del mundo*.
[85] M. Baig i Aleu, "Un nuevo documento sobre Guillem Soler".
[86] Murray (ed.), *The Clash of Cultures*.
[87] Chekin, *Northern Eurasia*.
[88] The power of Amalfi and Gaeta was already in decline in the Thirteenth Century.
[89] Ryan, *A Kingdom of Stargazers*.
[90] Harreld (ed.), *A Companion to the Hanseatic League*.
[91] Read Aznar Vallejo, *Viajes y descubrimientos*.

the Franciscan Alexander Bonini (1268-1314) to Nicholas Oresme (c. 1323-1382), who with his treatise *De origine, natura, jure et mutationibus monetarum* ("On the origin, nature, law, and alterations of money") marks a decisive watershed in the history of finance and anticipates the so-called Gresham's law.[92]

The Development of the Graphic Representation

The passionate search of Nicholas Oresme takes place within this stimulating environment. As a member of the College of Navarra and a student of Buridan, he gives a natural continuation to the logical foundations and the mathematical postulates of Merton College. He also studies successfully and with sophisticated argumentation the relationships between *speed, strength and endurance*. Already Thomas Bradwardine, eminent exponent of the Oxonian school, had postulated that the relationship between two speeds is proportionate to the strength and endurance from which they are originated.

It follows that "to achieve twice the speed it is not enough to double the strength, or to halve the resistance, but it is necessary to square the relationship between strength and resistance".[93] Using modern mathematical language, what we have expressed in words is nothing less than an exponential function that describes the variation of speed depending on the exponent to which the ratio of strength and resistance should be raised. Oresme does not limit himself to accept the proposed ideas; instead he carries out different arithmetic and geometric tests, going further in the study of *uniformly accelerated motion*.

In fact—following the path marked in 1335 by W. Heytesbury in *Regulae solvendi sophismata*[94]—Oresme develops in his famous *Treaty about the configurations of the qualities and movements*, written around 1350, an original and innovative method for the graphical representation of movement, that served as a natural precursor of Cartesian theories and analytical geometry. Convinced that knowledge is based on the senses, he considers essential the use of imagination as well as of graphic representation. It assumes that each value that can reach different intensities over time can be represented as a straight line placed vertically. A horizontal line, however, represents the distance travelled by the body whose quality is studied. At each point of that line a vertical line is drawn, whose height is proportional to the intensity of the quality. In

[92] Patriarca, *Il pensiero economico di Nicola d'Oresme.*
[93] Fumagalli Beonio Brocchieri and Parodi, *Storia della Filosofia Medievale*, 447.
[94] Heytesbury, *Regulae solvendi sophismata*, f. 39.

Oresme's opinion this representation can be extended for every imaginable intensity and, above all, for the relation between movement and time.

Thus, in the description of a rectilinear motion, Oresme has the idea of graphically representing the speed of movement of the object as a function of time. In a horizontal line he marks the gradations proportional to time and, above each graduation, plots a perpendicular whose length is proportional to the speed of the object at the corresponding moment. Taking into account that part of the plane affected by the subsequent perpendiculars, he concludes that the area of the surface that the perpendicular leaves behind—raised above each gradation in the given time range—is proportional to the distance traversed by the object during that time interval.

It follows, at this point, that in a rectilinear movement of uniform acceleration the increase of speed of the object is proportional to the duration of the course during which such an increase takes place. It is therefore attributed to Oresme the *fundamental law of the uniformly accelerated rectilinear motion*. This geometric method also has a remarkable pedagogical value as it came under frequent use in all European universities.[95] Oresme applies his considerations to the study of celestial spheres and he delves into concepts of commensurability and incommensurability.

Distancing himself from the Aristotelian scientific tradition, he raises the hypothesis of an earth's movement on itself in twenty-four hours. This "discovery", although not grounded on solid arguments, places Oresme in the Olympus of the Physicists, turning him into the natural precursor of Nicholas Copernicus. Oresme is not satisfied with vague or misleading descriptive expressions but he devotes himself with determination to formulate scientific and mathematically acceptable definitions. In the work entitled *De proportionibus proportionum* he presents the notion of power of a rational and irrational fractional exponent, albeit in an incipient form. Through the mediation of the Franciscan John of Casale (1320-after 1374) and Blaise of Parma (1365-1416) the dissemination of Oresme's ideas was very successful.

Conclusions

The *Quaestio de velocitate motus alterationis* by John of Casale (1355) is, in fact, considered to be a sum of knowledge on speed and movement. Even in 1505 the

[95] See Taschow, *N. Oresme und der Frühling der Moderne*.

Italian mathematician Bassano Politi brings together, in the same publication, the works of John of Casale with those of Thomas Bradwardine, Oresme and Blaise of Parma, in order to maintain and support his mathematical investigation introduced in the *Questio de modalibus* and in the *Tractatus proportionum introductorius ad compases*. This detailed and graphicly rich work shows didactically the evolution of physics. Some studies have shown that Galileo himself was aware of the doctrine and methodology proposed by these authors.[96]

In this historical context, the subtle abstraction, duly cleared of misunderstandings and ambiguities, is put at the service of a redefinition of classical syllogisms, leading to a series of surprising implications and deductions. The resulting rationalization is the expression of a greater clarity and a more defined epistemic logic, with the unequivocal consequence of rigor and veracity. Latin itself becomes more direct and laconic, because of the predominant influence of the vernacular languages and their independent codes.

Moreover, in the framework of the building process of the nation-states and their identity's policies, the translations play a major role in this era.[97] Undeniable is the great work of John Trevisa (1342-1402), whose translation of *De Proprietatibus Rerum* by Bartholomew the Englishman should not be ignored for the formulation and definition of a scientific vocabulary.[98] Many other translations of these treatises of *natural philosophy* will follow, reinforcing the common background to the European sciences.

Concluding this historical exploration, it can be said that the radical rupture between the so-called *pure sciences* and the other *arts* had not yet taken place. Especially in terms of cosmology and astronomy a sound interconnection is still very tangible with a deep religious sensibility. Both disciplines continue to be of enormous significance, not only for the definition of the liturgical calendar, but also for the natural references to the infinite, with all their mystical and transcendental importance.[99] Therefore, it cannot be denied that there have been crucial steps in the history of science and innovation, which opened the doors to a modern *Weltanschauung* that in the Renaissance would find its major expressions.

[96] Gilbert, *Un Grand Scholastique Normand* and Pisano and Bussotti (eds.), "Homage to Galileo Galilei 1564-2014".

[97] Fowler, *The Life and Times of John Trevisa*.

[98] Edwards, "The Text of John Trevisa's Translation".

[99] See Pedersen, *The Two Books* and Pedersen, *The Book of Nature*.

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