Newtonian medicine and its influence in José Celestino Mutis's General Plan for Medical Studies

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Sebastián Molina-Betancur
sebastian.molina@unibg.it
Dipartimento di Lettere, Filosofia e Comunicazioni
Università degli Studi di Bergamo
Via Pignolo, 123
24121 Bergamo
https://orcid.org/0000-0002-3250-3409

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Abstract

This paper presents the development of a Newtonian approach to medicine in the eighteenth century by studying the case of its appropriation in the Viceroyalty of New Granada by the Spanish botanist and savant José Celestino Mutis (1732-1808). First, I briefly depict the academic milieu in which Mutis presented his ideas on modern medicine in his *General Plan for the Medical Studies* in 1804, claiming that they were greatly influenced by Boerhaave's appropriation of Newtonian medicine. Next, I explain in detail the emergence of this approach to medicine by considering the works of Archibald Pitcairne, George Cheyne and James Keill. Afterwards, I characterise Boerhaave's use of Newtonian physical principles for explaining both physiological and chemical phenomena. Lastly, I lay the foundations for explaining that Mutis's introduction of Newton's ideas was a complex enterprise, encompassing Newton's mathematics and physics not only as strict theoretical elements related to natural philosophy but also as they were related to the medical and chemical fields.

Keywords

Newtonianism, Newtonian medicine, Colonial Science, José Celestino Mutis, Herman Boerhaave

The introduction of modern medicine in New Granada's academic milieu

José Celestino Mutis is mostly known for his activities as Director of the Royal Botanical Expedition to New Granada (hereafter, Botanical Expedition) between 1783 and 1808. In spite of its focus on natural history, it is well-known that the Botanical Expedition was also committed to the gathering of meteorological, astronomical and medicinal data, aiming to study the particular nature of the northern territories of South America and its utility for the Spanish Monarchy.[1] In this sense, in the recent years, historians of science have depicted Mutis's Botanical Expedition as an enterprise with multiple levels of complexity in which the inherent difficulties of gathering data in the tropical regions of New Granada were merged with the Spanish pretension of using the expedition as a mechanism of political and economic control.[2]

Mutis was also highly committed to multiple pedagogical activities in Santafé de Bogotá as of his arrival in 1761, rather than being limited to the duties of the Botanical Expedition. For instance, in 1762, he established the first chair in mathematics of the Viceroyalty. In his lectures, Mutis presented the basic tenets, concepts and problems of the discipline framed within his defence of its utility for the study of nature.[3] He did so under the model of Newton's physics, which he considered the ultimate exemplar of scientific rationality. In this context, Mutis became the most committed Newtonian of New Granada, defending Newton's physics from the attacks of the ecclesiastical orders dominating Santafé's academic milieu and describing it as the most proper foundation for deploying the political implications of the promotion of the useful sciences by the Spanish Monarchy in the Americas.[4]

As regards the promotion of modern useful sciences, Mutis was an advocate of the reformist projects advanced by the royal prosecutor in Santafé's court, Francisco Antonio

Moreno Escandón who, in 1774, designed a curriculum for New Granada's colleges. The main purpose of this plan was to settle the conditions for the modernisation of New Granada's university education.[5] These conditions would be materialised in the creation of a public, secular university that would replace the scholastic structure that had dominated New Granada's academic panorama since the sixteenth century.[6] As part of the reforms, Moreno Escandón proposed a re-establishment of the curriculum for the course of medicine at the *Colegio del Rosario;* the only institution with royal authorisation to teach medicine and graduate physicians in the Viceroyalty. As Emilio Quevedo, Camilo Duque, Pedro María Ibañez and Andrés Soriano Lleras comment, the course of medicine that José Vicente Ramón Cancino established in 1753 had been founded on Galen's, Hippocrates' and Avicena's works probably brought to the Viceroyalty by friar Cristobal de Torres, founder of the *Colegio del Rosario* .[7] Thus, Moreno Escandón's plan aimed to modernise New Granada's medical education by introducing several ideas of modern medicine, arguably following Mutis's suggestions.

However, the reforms never were fully implemented because of ecclesiastic opposition and later on in 1779, Moreno Escandón's plan was completely abolished by the Spanish authority, leaving the unreformed course closed.[8] The course was finally reopened in 1802, thanks to the pressure of the Director of the *Colegio del Rosario*, Fernando Caicedo — a student of Mutis in the 1760s —; being appointed Miguel de Isla (another acolyte of Mutis) as its interim professor.[9] In 1802, in order to re-inaugurate the course, Viceroy Pedro Mendinueta y Múzquiz ordered Mutis to draft a study plan. I shall argue in this paper that, in his study plan, Mutis introduced modern medicine in New Granada, founded on the theoretical and methodological principles advanced by Boerhaave.

In general, Boerhaave adopted an eclectic approach to physiology, combining elements of mechanics and chemistry as he suggested that bodies consist of universal-mechanical properties and several particular-chemical ones. By claiming this, he adopted some features of so-called Newtonian medicine, which I would like to illuminate in this paper, as an attempt to determine the Newtonian character of Boerhaave's medicine underlying Mutis's *General plan*. In this way, I intend to lay the foundations for explaining that Mutis's introduction of Newton's ideas in New Granada was not limited to the lectures on mathematics and physics he gave at the *Colegio del Rosario* in the 1760s and 1770s. Conversely, I shall argue that Mutis's introduction of Newton's ideas was a more complex enterprise, encompassing Newton's mathematics and physics not only as strict theoretical elements related to natural philosophy but also because they related to the medical and chemical fields. In other words, I shall argue that by using Boerhaave's works as textbooks for his *General plan*, Mutis embraced a Newtonian conception of medicine in which mathematics, physics, and chemistry are central to the explanation of physiological phenomena.

This paper contains five sections. Firstly, I discuss briefly the general features of Mutis's appropriation of Newton's experimental physics in New Granada from his lectures on mathematics at the *Colegio del Rosario*. Secondly, I present Mutis's *General Plan*, emphasising its characterisation of the use of physics, mathematics and chemistry to explain physiological phenomena and their role in therapeutics. In so doing, I argue that Mutis followed the theoretical principles Boerhaave established in his *Praelectiones academicae in proprias institutiones rei medicae* (1708) and *Aphorismi de cognoscendis et curandis morbis* (1709), which Mutis interpreted as the application of Newton's physics to medicine. Thirdly, I explain the main features of Newtonian medicine and how Newton's conception of attractive forces was applied to physiological phenomena in the early eighteenth century. Fourthly, I describe the historical transformation of Newtonian medicine from a strict iatromathematical approach to a rather experimental one in the work of James Keill. Lastly, I account for the scope and limitations of Boerhaave's application of Newton's physics in medicine and chemistry by focusing on his characterisation of the general and particular properties of the human body.

Mutis's Newtonianism in his lectures on mathematics in New Granada

Mutis arrived in New Granada in 1762 as physician and surgeon of the recently appointed Viceroy Pedro Messía de la Cerda. However, as he himself describes it in his *Diary of Observations*, as soon as he arrived in Santafé de Bogotá, the capital city of the Viceroyalty, he also was required to give lectures on mathematics.[10] For that purpose, the Director of the *Colegio del Rosario,* José Joaquín León y Herrera, persuaded the viceroy to establish the first course on mathematics of the viceroyalty. Being appointed chair in mathematics, Mutis translated into Spanish several excerpts of Wolff's *Elementa Matheseos Universæ,* Descartes's *Géométrie* and 's Gravesande's *Physices Elementa Mathematica*, which he used as textbooks for his lectures, presenting them as *mamotretos* for his students at the *Colegio del Rosario*.[11] Likewise, Mutis presented his particular conception of the utility of mathematics to study nature, informed by his own interpretation of Newton's methodological and theoretical pronouncements in his own original papers.

Mutis present his ideas on Newton's methodology in his two inaugural lectures for the course: *Preliminary Speech Pronounced in the Opening of the Course of Mathematics* (1762) and *Elements of Natural Philosophy, Containing the Principles of Physics Mathematically Demonstrated and Confirmed by Observations and Experiments: Disposed* *for Instructing the Youth in the Doctrine of the Newtonian Philosophy in the Royal College of the Rosary of Santa Fé de Bogotá in the New Kingdom of Granada* (1764).[12] In these lectures, Mutis argues that it is possible to know God's providence upon the creation and, consequently, to know the moral implications of our behaviour by applying mathematics to the study of nature. Interestingly, Mutis expanded these moral implications to encompass the moral obligations of the Spanish King as the designed ruler of the New World in the *Representaciones* from 1763-1764 to Charles III asking for royal support to establish a botanical expedition reveal.[13]

As regards Newton's methodology, Mutis presented in his lectures the general features of the application of the geometrical method of analysis and synthesis as Newton presented it in the *Opticks*. In *Elements*, Mutis characterised Newton's thought as opposed to both Aristotelian scholasticism and Cartesian hypothetical philosophy. According to him, the virtue of the experimental philosophy consisted in that it allowed to explain nature by the effects known through observations, which lead to know the causes producing them. Nevertheless, Mutis claims that observations are not sufficient to postulate the causes discovered as universal causes, making it necessary to appeal to mathematical explanations in order to account for the relationship between a specific cause with the multiple effects it may produce. In his opinion, "In order to proceed with complete certainty, [Newton] always used the analytic and synthetic methods to study nature, leaving aside any discussion."[14] Following Newton, Mutis argues that it is necessary to proceed from particular causes to the most general ones, in order to determine the first principles of nature and that such an investigation can be only managed by articulating an experimental approach to nature with a mathematical analysis of the observed phenomena.

This mathematical focus is particularly important because it allows to understand that, in Mutis's eyes, Newton's application of the geometrical method of analysis and synthesis to natural philosophy was fundamental as it led to know how God intervenes on the creation. The importance of this theological implication should not be overlooked, as it was a permanent concern for Mutis. For example, it appears in his translation of 's Gravesande's general axiom of his *Physices elementa mathematica,* where the latter establishes a theological foundation to the laws of motion: "For examining into things leads us to this axiom, which is the foundation of all reasoning in natural philosophy. Axiom. The Creator of the universe governs all things by laws that his wisdom determines or that spontaneously emanate from the nature of the things."[15]

Mutis further developed the theological implications of Newton's experimental physics in detail by following 's Gravesande's postulation of the theological foundation of Newton's physics.[16] By doing so, Mutis illustrated the importance of the articulation of mathematics and physics in his interpretation of Newton's experimental physics. It is also relevant to point out that the role of 's Gravesande in Mutis's appropriation of Newton's experimental physics is not limited to the establishment of the theological foundations of physics. Likewise, Mutis's use of 's Gravesande's characterisation of the laws of attraction also reveals his commitments with a Newtonian theory of matter which was decisive in his acceptance of the Newtonian medicine.[17]

In different lectures dealing with theoretical aspects of Newton's physics, i.e. the concept of attractive forces, the motion of bodies in conic sections, the system of the world and the laws of motion, Mutis illustrated how the methodological aspects of Newton's experimental physics made possible to account for natural phenomena. As he comments to Viceroy Caballero y Góngora in 1787, his lectures followed the model Wolff presented in his *Elementa Matheseos*.[18] In it, the subject was considered from the basic conceptual treatment of the definitions, progressively climbing to the most difficult topics of the differential and integral calculi. I have discovered that Mutis not only used Wolff's model for his lectures; he also used the *Elementa Matheseos* as a textbook, in a translated version that he probably prepared between 1762 and 1764. The translation, nowadays housed in the *Real Jardín Botánico* of Madrid, is contained in two different manuscripts, both of them entitled *Elements of Arithmetic*. In them, Mutis presented the basic arithmetical definitions in different degrees of detail and with the basic arithmetical operations.[19]

After teaching arithmetic, Mutis taught geometry. Surprisingly, instead of keep using Wolff's *Elementa Matheseos*, he switched to Descartes's *Géométrie* as textbook. The manuscript entitled *Commentaries to Descartes's Geometry* actually is an almost complete translation into Spanish of the Book I of the *Géométrie*, based on the commented edition of the Jesuit Claude Rabuel in 1730. Mutis's translation included Descartes's original version and Rabuel's commentaries to the entire first part.[20]

The strict mathematical content of Mutis's curriculum for his lectures on mathematics concluded with his views on the elements of differential and integral calculi. Unlike the evidence regarding the content of Mutis's manuscripts on arithmetic and geometry, which supports the idea that he lectured on these subjects by translating Wolff's and Descartes's works and used them as textbooks, in the case of his lectures on calculus we do not have enough evidence to determine Mutis's sources. Furthermore, we do not have yet appropriate evidence to claim without hesitation the extent of these lectures during the 1760s or 1770s. Among Mutis's manuscripts in the archives of the *Real Jardín Botánico* of Madrid, we only find one folio dedicated to the specific subject of calculus entitled *Elements of integral calculus*. However, despite what the title suggests, this folio does not deal with integral calculus at all; instead, it establishes the conceptual foundation for differential calculus. Perhaps this sheet was part of a longer manuscript in which Mutis presented the elements of differential and integral calculi. Its structure suggests that it follows the pattern of his lectures on arithmetic and geometry and, consequently, we may assume that it is the manuscript containing his lectures on calculus at the *Colegio del Rosario*. It is worth noting that in this single-folio manuscript, Mutis compared variables and constant quantities by postulating that the former are *evanescent quantities* tending to be equal to constant quantities in a determined period as the difference between them decreases; it means, when their difference tends to 0:

> If a variable z is increased or decreased from a random quantity, which we call Dz, becoming into $z \pm Dz$, it is a very evident principle that these two quantities $z, z \pm Dz$ will be getting closer to be equal as much as the difference between their quantities diminishes from z. It is also evident that they will be equal in the precise instant in which this difference is *vanished*.[21]

In this characterisation of the relation between a variable tending to be equal to a constant, we can see two key features of Mutis's understanding of calculus. Firstly, he referred to the differential between a variable and a constant with the symbol D: a usual notation in the late-eighteenth century, close to the Leibnizian notation of calculus. Secondly, Mutis used the term *evanescent quantities* to define the precise moment when the difference between two quantities instantaneously tends to 0 rather than to a finite quantity. It must be borne that the notion of "evanescent quantities" was a rather confused term during the late-eighteenth century, inherited from the Newtonian conception of the calculus of fluxions. In Newton's calculus of fluxions, a differential was produced when a variable, which is a fluent quantity – an evanescent quantity –, is matched to a constant in an instantaneous moment, or fluxion. In other words, the fluent quantities in a fluxion are precisely evanescent quantities. Nevertheless, the notion of evanescent quantities tended to be diffused in the eighteenth century, as it was soon abandoned by Newton and the Newtonians by adapting the Leibnizian notation to their own mathematical studies. [22] In this context, it is not clear why Mutis used the notion of evanescent quantities and the direct source for his appropriation of the term. However, by considering his eclectic articulation of the Leibnizian notation and the use of the Newtonian concept "evanescent quantities", we can see that he used different traditions to explain calculus. This eclectic approach to this subject was simplified in the study of the motion of bodies in conic sections, as Mutis – although still using Newtonian "fluxions" – decidedly used the Leibnizian notation. Nonetheless, Mutis's manuscript on integral calculus does not provide sufficient information regarding the specific elements of calculus that he introduced in his lectures in New Granada and how well he understood calculus; we can find evidence on these issues in other manuscripts found in the archives of the *Real Jardín Botánico*. Especially, in his lectures on conic sections and particularly the ones on hyperbolas.[23]

Likewise, Mutis presented and discussed the Copernican system in his lectures, using not only the Newtonian approach he advocated since the establishment of the chair of mathematics in 1762 but also a Galilean argumentative strategy in which he included both a defence of the theological implications of the Copernican system as well as Galileo's physical arguments to support it. Mutis mostly developed his arguments on this regard in his lectures *Apology of the Copernican system. Dissertation read at the Colegio Máximo de la Compañía de Jesús of Santafé de Bogotá city* (1767) and *Defence of Copernicus's heliocentric system in public conclusions given at the Colegio Mayor de Nuestra Señora del Rosario, in honor to the very excellent Viceroy Don Manuel Guirior and Doña María*

Ventura (1773).[24] While the former presents the arguments in a rather cautious manner, portraying the Copernican system as a valid mathematical hypothesis with no reality claims; the latter openly supports it as a thesis, using Galileo's physical arguments as they are present in the *Dialogo*.

Nevertheless, as important as Mutis's defence of the Copernican system is in the context of the eighteenth-century New World, its historical value relies on the social and cultural implications it had in Santafé's intellectual and university milieus. In 1774, Mutis was accused to the Inquisition of Cartagena de Indias by the Dominican friars from the *Universidad de Santo Tomás*. The development of this episode, however, proved to be fundamental for the modernisation of the university in New Granada as reformers such as Francisco Antonio Moreno Escandón and Viceroy Manuel Guirior saw in it an opportunity to criticise the old scholastic structure of the Spanish universities in the New World, replicating the policies that Charles III and his enlightened ministers had advanced in Spain as of the 1760s.[25]

All in all, the manuscripts containing Mutis's lectures on mathematics provide evidence to trace the scope of his Newtonianism and how his commitment with the defence of the useful science in the context of development of the Borbonic reformism and modernisation of the Spanish world informed it. In this scenario, Mutis saw in Newton's experimental physics a comprehensive set of methodologies and theories which could be applied to several subjects. Despite that in his lectures on mathematics during the 1760s, as I pointed out in this section, he strictly referred to its application in natural philosophy, the lectures also reveal that Mutis was aware of the implications of this Newtonian worldview in disciplines such as chemistry, botany or medicine.

Newtonianism, medicine and Mutis's *General Plan for the Medical Studies*

At the request of Viceroy Mendinueta y Múzquiz, Mutis wrote a report about the state of the medicine in New Granada in 1801 entitled *State of the Medicine and Surgery in the New Kingdom of Granada in the eighteenth century and means to solve its regrettable backwardness*. There, he described the health condition of the Granadians and the problems related to the treatment of their diseases.[26] After complaining about the "casual and arbitrary choice of the places where they [the Granadians] congregated," claiming that it was the main cause of their diseases,[27] he argued that in order to solve the population's health problems, it was necessary to pay attention to the state of the medical practises in New Granada, which he presented as retrograde.[28] In his opinion, the problems in the education of physicians at the *Colegio del Rosario* was the main cause of their slow development. In Mutis's words:

> The creation of lectures for the Faculty of Medicine has been nothing but an illusion. The complete lack of materials (*dotación*) and the fact that it is the only medical faculty has caused the indifference and its total abandonment by any professor, [who might be] interested in it as it was attached to the *Protomedicato*.[29]

Along with the lack of professional training in medicine in New Granada — and probably because of that —, Mutis stressed that the problems for public health were multiplied by the proliferation of healers, whose medical knowledge was merely empirical.[30] For him,

> Despite that all the barbarian nations have been deprived of the lights of the useful sciences, they do know the need for an empirical medicine, which is exercised almost instinctively to help their people; but if a civilised and educated nation were satisfied with such a help, it would confuse itself with the barbarians, running away from the common sense of the rational world.[31]

As a result of the report, Viceroy Mendinueta asked Mutis to create a plan for the course of medicine at the *Colegio del Rosario* seizing its reestablishment in 1802. The plan Mutis presented was entitled *General plan for the medical studies, set up according to the proportions of the country to the teaching of all its subordinated professions* (hereafter, *General plan*). The *General plan* postulated Mutis's strategies for establishing the conditions for a formalised medical education in New Granada, standing on the principles of modern physiology and surgery that Pedro Virgili – Mutis's professor during his time as a student of surgery in Cadiz – had introduced in Spain in the 1750s.[32] Mutis elaborated a curriculum in which he not only included the theoretical aspects of Boerhaave's *Institutiones medicae* and *Aphorismi* – as well as the therapies that the latter contained – but also a preliminary training in chemistry, mechanics, and mathematics which would allow to the students to understand the physiological elements underlying the medical knowledge.

After praising the training imparted at the *Colegios de Cirugía* that Virgili had created in Spain in the 1750s,[33] Mutis claimed that the plan was based on the principles of the reformed plans of the *Colegios* and Spanish universities, in which it was decided to "ban from the lectures of philosophy and medicine the ancient peripatetic-Arabian methods of teaching."[34] In his opinion, one of the central features of the new curricula adopted in Spain was the training of students according to the principles of the ancillary disciplines of medicine. It was done, in order to overcome the simple know-how that had characterised the medical practices of the peripatetic tradition in Spain and that had brought about social discredit of physicians and surgeons in Spain and its overseas territories.[35] Accordingly, Mutis began by establishing the connection between physics and medicine as the result of the possibility that the former discipline gives to the latter instruments for rationally explaining the physiological functions and possible causes of the diseases affecting the human body. Following Boerhaave’s commentaries in his *Institutiones medicae* and *Aphorismi* concerning the need for the physicians to have a complete understanding of the physiological functions of the body, Mutis established a curriculum based upon the chemical and mechanical study of the animal economy. For Mutis,

> It shall be impossible to call physician to the one lacking sufficient training in mathematical sciences, experimental physics, botany and chemistry. These are the ancillary disciplines that can provide the required knowledge to put the rational-dogmatic medicine in practise with certainty, according to the progress and success that has made it as outstanding and appreciated as it is nowadays.[36]

Certainly, such a characterisation of the role of the ancillary disciplines in the training of the medical students highlights the importance that both physics and chemistry had for Mutis in understanding the functioning of the human body. As I shall argue, the redefinition of the disciplinary boundaries between physics, chemistry and medicine to which Mutis refers in this passage reveals an important facet of his appropriation of Newton’s experimental physics: for him, the theoretical tenets and concepts of Newton’s physics were useful in accounting for the motion of bodies and the mechanical phenomena observed in nature; thus, by considering the human body as a machine, Mutis also defended the possibility of applying these tenets and concepts to the fields of physiology and therapeutics.

However, it is worth of notice that this was not the first time Mutis referred in New Granada to the role of Newton’s physics in the field of medicine. In his inaugural lecture of the course on mathematics at the *Colegio del Rosario*, he also presented medicine as a relevant field of application of mathematics as he used the well-known analogy of the human body as a microcosm in which the laws of nature act as they do in the macrocosm. In Mutis's words:

> Go all over, sirs, the extensive field of nature and you will not find something else that has produced more reflexions than the human body, correctly called small world, in whose creation the omnipotence of the Creator took great pains. Most of the laws according to which motions are performed in the world are also observed in the human body, as well as some other that are particular to it for the reasons of the life.[37]

Following Boerhaave's considerations regarding the twofold nature of the human body, with general physical laws and particular chemical properties regulating its behaviour, Mutis claimed that physiological phenomena can be explained by applying both physics and chemistry. As regards physical phenomena affecting the human body, Mutis praised Newton's physics depicting it as the only natural philosophical system capable of explaining natural phenomena because it is based upon observations and mathematical demonstrations.[38] In Mutis's opinion:

> Who would doubt that all progress in experimental physics is nothing but a consequence of observations, experiments and the exact application of mathematics? The most illustrious mathematicians of the past, as well as those of the present century, have illuminated physics with demonstrations and varied analytical calculations demanded to discover many truths that afterwards were consistent with experience. I should offer further proofs, more specific and determinate, if the entire corpus of Newtonian Physics were nothing but a continuous proof of what I have said.[39]

As physiological phenomena could be subsumed into physics, they constituted a fertile soil for highlighting the utility of the mathematical approach to physics that Newton developed and that Mutis was committed to in his teaching in New Granada. In this sense, provided that in Mutis's eyes Newton's physics was the only certain explanation of natural phenomena and the laws regulating their behaviour, the mathematical and physical foundation of medicine only could follow the theoretical principles it proposed.

In this way, in considering that the students of medicine must have a propaedeutic training in physics and mathematics in order to understand physiological phenomena, and that the physics Mutis taught in his lectures was actually Newton's physics, we can see that Mutis implied a formation in Newton's physics and its application of mathematical techniques for solving physiological problems. This formation, I shall argue, encompassed not only technical aspects regarding hydraulics and kinematics but also some ideas concerning Newtonian theory of matter in which attractive forces explained multiple physiological phenomena.

In the description of the lectures of the second year of medicine, we find the source of Mutis's conception of the human body as a *machine* in which both physical and chemical operations take place:

> This is the reason why professors believed with more or less caution, according to their attachment to their fields, that in order to understand the animal economy phenomena it was necessary to use the help that the natural sciences provide. Following the example of the immortal Boerhaave, who, based on anatomy, knew how to use in his physiology the help coming from other sciences, all the faculties of medicine (*escuelas de medicina*) both within and out of Spain continue to use this very same method.[40]

Boerhaave's influence on Mutis's plan is also evident in the fact that Mutis not only recommended the study of his works directly, but to do so with the comments of multiple interpreters, including, *inter alia*, Albrecht von Haller's *Elementa physiologiae corporis humani* (1775), Georg Erhard Hamberger's *Physiologia Medica* (1751), and Philipp Ambrosius Marherr's *Praelectiones in Hermanni Boerhaave Institutiones Medicas* (1785).[41] This panorama is completed in Mutis's description of the courses of the third year, in which he claims that students should learn by heart Boerhaave's *Aphorismi* on therapeutics[42], which implies that Boerhaave was not merely recommended as a source for the physiological analysis.

As we can see, the opposition between empirical medicine and theoretical medicine, as Mutis suggests, derives from the fact that the mathematical, physical and chemical study of nature supports the medical theoretical knowledge. He based this suggestion on Boerhaave's description of medicine in his *Institutiones Medicae*. Thus, in order to understand how Mutis deployed his Newtonianism in his *General plan*, we should take a look at Boerhaave's work to search for references to the mechanical and mathematical foundations of the medical practise. But first, let us study how the Newtonian approach to medicine emerged in the early eighteenth century.

Newtonian medicine: mathematical and experimental approaches to physiology

One of the most interesting aspects of Newtonianism in the eighteenth century is the implications it had for the development of different disciplines. To some extent, multiple disciplines tended to follow Newton's methodological and theoretical tenets and concepts, either because they could be subsumed under the mathematical principles that Newton proposed in the *Principia* or the experimental programme delineated in the *Opticks*.[43] This twofold influence of Newton's did not necessarily excluded one to another: in the early-eighteenth century, it was possible to find disciplines attempting to follow Newton's example by using both his mathematical principles and his method. The development of Newtonian medicine is a good example.

A Newtonian approach to medicine and physiology emerged in the early 1690s through the works of the Scottish physician Archibald Pitcairne, presented as lectures at the University of Leiden and as brief texts about the treatment of continual fevers.[44] Although Pitcairne read Newton's *Principia* in 1687, he had a more direct contact with Newton's ideas in 1692. He was appointed professor of practical medicine at the University of Leiden. On his trip from Edinburgh he stopped off in Cambridge, where he discussed with Newton himself the latter's manuscript *De natura acidorum* (1692), in which he presents several ideas regarding the role of forces in the theory of matter.[45]

In his lectures, Pitcairne embraced a mathematical approach to physiology inspired by Newton's *Principia*. One example is his inaugural lecture from 1692 in which he discussed the advantages of a mathematical approach to physiology, neglecting the position of what he called "a sect of philosophers." After establishing a historical relationship between medicine and astronomy,[46] Pitcairne introduces a detailed characterisation of the application of mathematics to medicine, which reveals other Newtonian aspects of his approach to physiology. In his opinion,

> It is evident to any one who has been a little more than ordinary conversant in the mathematics, or the practise of physic, that our knowledge of things is confined to the relations they bear to one another, the laws and their properties of powers, which enable them to produce changes in some things, and to become altered by other

> things: I speak of corporeal things. Now these powers, and their laws, are discovered by their mutual action and reaction upon each other.[47]

The "powers" producing physiological phenomena and their mathematical properties which can be postulated as laws, are evident from the visible changes that can be perceived from their mutual interactions.[48] Certainly, as Pitcairne claims, such powers depend on various causes but the physician should omit them for there is no mathematical certainty for determining them or how they act on the body to produce the physiological phenomena experimented. Nevertheless, it is not crystal clear what he meant by "powers." Anita Guerrini comments that it is possible that for Pitcairne "these 'Powers' (*vires*) were forces similar to what he could have inferred from Newton's essay 'De natura acidorum'."[49] Thus, she claims that Pitcairne inherited from Newton his particular conception of attractive forces acting to produce phenomena on both a macroscopic and a microscopic scale; which he applied in the field of medicine.

One of the most algid points of the Newtonian mathematical approach that Pitcairne had inaugurated was carried out by George Cheyne in the context of the fever dispute in Edinburgh in the 1690s.[50] In his *A new theory of continual fevers* (1701), Cheyne developed Pitcairne's ideas about sweating and perspiration in a more mathematical fashion, putting forward a strong iatromathematical position founded on the use of Newton's forces and methodology.

The mathematical character of Cheyne's study about continual fevers is revealed both in the form and the content of the theory itself. Presented in a geometrical way, Cheyne begins by establishing a couple of *Postulata* and *Lemmata*, deducing from them a general proposition, in which he explains the cause of fevers[51]: "The general and most effectual cause of all fevers, is the obstruction or dilatation of (the complicated *Nerve* and

Arterie, the excretory duct & conservatory, one, or rather all these; which, as shall be afterward shewn, make up) the *Glands*, and they receive their denomination as these or those *Glands* are more or less obstructed or dilated."[52] For Cheyne, fevers are the result of obstructions in the minutest vessels of the *Glands*, impeding the correct secretion of the morbific matter that the body produces. Thus, the last "appearance of continual fever" described by Cheyne allowed him to determine that the best way to treat it was fomenting the body's secretions.[53] Like Pitcairne, Cheyne used mathematical demonstrations to determine the effectiveness of each treatment proposed for overcoming continual fevers. In *Proposition III*, he postulated that "in a mixt fluid, consisting of greater and lesser cohesion of parts, of greater and lesser fluidity: that which has the least cohesion and greatest fluidity, is first separated."[54] Thus, he argued that the specific gravities of the particles composing the blood produce different degrees of cohesion, which makes it possible to explain how certain substances are only secreted by specific glands of the body. As Guerrini points out, it is possible to see the role of a Newtonian theory of matter characterised by the attraction of particles in Cheyne's description of the evidence for the most efficient mechanism of secretion.[55] Furthermore, the Newtonian nature of Cheyne's iatromathematical approach is evident in *Proposition II*, where he develops Pitcairne's idea of secretion as the combination of two forces in the flowing of the blood in a more sophisticated mathematical way.[56]

From mathematisation to experimentation in Newtonian medicine

So far I have explained the development of a Newtonian approach to medicine as the result of the articulation of a mechanical approach to physiological phenomena and their strictly mathematical treatment. By emphasising the mathematical elements of the demonstration, Newtonian physicians such as Pitcairne and Cheyne attempted to reduce every physiological phenomenon to geometrical terms, in order to achieve the same success in their demonstrations as Newton had in the *Principia*. However, at the beginning of the eighteenth century Newtonian medicine varied, shifting its mathematical focus to rather experimental aspects, inspired by the speculative character of Newton's Qu*eries* to the *Opticks*.[57]

Probably in the wake of the example of his brother, John Keill, who attempted to empirically demonstrate Newton's mathematical principles, James Keill tried to explain physiological phenomena in *An account on animal secretions* (1708) with some experiments founded on mathematical demonstrations.[58] In particular, Keill deploys his Newtonianism in explaining the problem of secretions.

Keill divides the explanation of animal secretion into two sections. Firstly, by postulating attractive forces as causes he explains how fluids to be secreted are formed. Secondly, he demonstrates how fluids are separated from the blood in the glands. Using empirical evidence provided by microscopic observations, Keill claims that blood is composed of two kinds of particles: red globules and other corpuscles, varying in form and magnitude. The main characteristic of the red globules is their ability to attract each other in such a way as to be, "swimming in a limpid fluid (…) unite like spheres of quicksilver, which, as they touch, run into one another."[59] The other particles composing the blood only unite one to the other "till some part of the fluid, in which they swim, has been evaporated by heat; and then they likewise attract one another, and form a coagulum, as the globules did."[60] We can see that Keill resorts to the differences of the attractive forces between particles in order to explain how specific particles of the blood attract each other. However, unlike Pitcairne and Cheyne, whose use of Newtonian attractive forces between particles to explain secretion is based on Newton's speculations on the theory of matter, Keill used microscopic evidence to explore the characteristic of the globules composing the blood.[61]

The Newtonian character of the consideration of the attractive forces between the particles of blood in Keill's *An account* appears when he compares this kind of attractive forces with the general attractive forces producing natural phenomena. According to Keill: "This power, by which the particles of the blood attract one another, is the same with that which is the cause of the cohesion of the parts of matter."[62] In this sense, he uses Newton's conception of attractive forces as a universal, causal principle for explaining not only macroscopic phenomena but also physiological phenomena in the constitution of blood:

> And since it will appear, that the whole animal oeconomy does likewise depend upon this attractive power; it seems to be the only principle, from which there can be a satisfactory solution given of the *phaenomena*, produc'd by the *minima naturae*; as that other attractive principle, which is of a different kind from this, and was first discovered by the incomparable Sir *Isaac Newton*, demonstratively explains the motions of the great bodies of the universe.[63]

Arguably, Keill considered here that attractive forces between particles produce every microscopic phenomenon. Thus, he extended the explicative power of Newton's attractive forces comparing them with mathematically-based experiments, as they are applied to physiological phenomena.[64]

As I explained above, the development of Newtonian medicine during the 1690s and the first decade of the eighteenth century can be divided into two periods. First, there was a period characterised by the emphasis on the mathematical demonstrations of the mechanical physiology. In this period, physiologists and physicians like Pitcairne and Cheyne tried to explain physiological phenomena, and particularly secretions, through the use of Newtonian forces, reduced to mathematical terms and mechanical laws. However, the difficulties for the transmission of the mathematical elements inherited from the Newtonian tradition provided an academic milieu where experimental – and not mathematical – demonstrations were used as the basis for the theoretical foundation of practical medicine. In this context, during the first decades of the eighteenth century, Newtonian physicians saw in Newton's *Opticks*, rather than in the *Principia*, the methodological model for studying physiology and developing their medical practises. As I shall explain in the next section, the works of Herman Boerhaave are clearly compatible with this version of Newtonian medicine.

Newtonianism in Boerhaave's medicine: universal and peculiar properties of bodies

Boerhaave's works on medicine, both practical and theoretical, have been considered fundamental by historians of science and medicine for explaining the development of this field during the eighteenth century, as they unify mechanics and chemistry in a medical system, building upon experiments and theoretical formulations.[65] In his *Institutiones Medicae*[66] and *Aphorismi*, he advanced the idea that bodies are composed of both universal and peculiar properties that make them behave in certain ways.[67] In *Institutiones Medicae*, for instance, he explains that the response of the body to a disease is the result of an automatic, involuntary motion, triggered by a mechanical reaction. Therefore, the study of the body for determining the functioning of its mechanical parts should be performed following the principles that hydraulics, hydrostatics and mechanics establish. In Boerhaave's words, the actions of the body "are performed agreeable to the *laws* or principles of *hydrostatics*, *hydraulics*, and *mechanics*; by which they ought therefore to be explained."[68] Accordingly, he argues that the explanation of the motions of the solid and liquid parts of the human body is based on mechanical grounds, because of the universal properties the human body shares with any other kind of bodies.[69] However, he also suggests that the human body is composed of some "peculiar properties", which are hardly discernible through a mechanical study of it. As he explains,

> But then, there are other principles not to be explained by these universal laws, but by some particular disposition in the certain body; these properties are called physical. But a physician ought to consider both the affections of bodies in general, as well as those only proper to the human body, that from a judicious comparison and just reasoning, he may never subject the human body to those laws only, to which the generality, but not all bodies, are liable.[70]

Thus, the physician should consider both mechanical and non-mechanical properties in order to determine not only the theoretical explanation of its functioning but, more importantly, the best therapies for its diseases. For Boerhaave, diseases may affect both the mechanical parts of the body — the solid and the liquid parts — and those parts whose functioning cannot be reduced to a mechanical explanation. The classification of these diseases can be clearly seen in *Aphorismi*, where he establishes a particular order to explain diseases from the simplest to the most complex.[71] I shall argue that in considering these "particular properties", Boerhaave adopted Newton's conception of attractive forces, thus making it possible for him to establish the articulation between chemistry, physics, and physiology that characterises his approach to physiology and that make of him a Newtonian physician close to the experimental approach that I explained in the section above. Let us take as an example the explanation of how fevers end in good health in order to illustrate the role of these "particular qualities" of the body in explaining the cure of a disease and how observations and experiments make it possible for the physician to determine the best therapy.

According to Boerhaave, in some cases, fevers end in good health when they overcome the material cause that produced them, breaking it and making it moveable.[72] This explanation, certainly, is based on mechanical principles with the underlying idea of fevers as obstructions. However, there are other occasions when fevers end in good health by overcoming the "particular quality" in the material cause that produced them:

> Or if the matter of the same disease being overcome by the power of the very fever, be loosen'd and render'd moveable, yet has retain'd one particular quality, which will hinder an equal circulation, and yet stimulates and irritates the vessels, and is for that reason drove out by some sensible evacuation which it occasions; such as sweats, spitting, vomitings, diarrhaeas, and urine, after the coction and height of the fever when the crisis is completed almost within fourteen days.[73]

For Boerhaave, there is a *particular quality* in the material cause of the fever which remains in the body, even after the material cause has been made movable through the mechanical action of the body or the effects of therapies. This quality "hinders" the normal flow of the blood, irritating the vessels. Fever, consequently, heats this quality, leading the body to its secretion in natural ways. The fire-like action of fever, heating the particular quality causing the disease, should not be overlooked as it highlights the role of chemistry as an ancillary discipline for medicine in Boerhaave's eyes.

In the chemical studies of his *Institutiones Medicae*, Boerhaave defines chemistry as "the observation of those changes which arise in different bodies from the application of certain degrees of fire."[74] It means that he attributes to fever the features of a chemical operation, taking place in the human body, through which qualitative transformations of substances are produced in the particular properties of matter. This definition is extended in his *A new method of chemistry*, where he states that:

> Chemistry is an art which teaches the manner of performing certain physical operations, whereby bodies cognizable to the senses, or capable of being render'd cognizable, and of being contain'd in vessels, are so changed, by means of proper instruments, as to produce certain determined effects; and at the same time discover the causes thereof; for the service of various arts.[75]

In this definition, there are some elements which are worth highlighting. First, Boerhaave's definition of chemistry establishes a disciplinary distinction that makes it possible to consider chemistry as an independent discipline from medicine. He based this characterisation on the idea that chemistry is not used just for creating pharmacopeia or for the analysis of the effects of the *materia medica*. By contrast, for him chemistry is capable of studying properties of the bodies through the analysis made with fire.[76] Another important aspect of Boerhaave's definition of chemistry is that he considers chemistry and mechanics as basic disciplines for physicians who intend to heal a disease through their knowledge of the functioning of the body. In this sense, "it is evident, that of all the sciences chemistry is best adapted for discovering these latent peculiar powers of bodies: whence we may safely conclude, that the chemical art is best and fittest means of improving natural knowledge."[77] Interestingly, he illustrated this characterisation of chemistry in the light of its utility for medicine, claiming that the former is used in medicine for the same purposes as in natural philosophy.[78] Finally, despite the theoretical potential of chemistry, Boerhaave considered it an important instrument for practical purposes, as he described it as the action of dividing material by means of an appropriate instrument: fire.[79] Thus, as the human body has some peculiar properties which should be explained through chemistry, he concludes:

> And as those skilled in mechanics and hydrostatics account for a multitude of appearances observed in the affair of health; and as other naturalists daily make other discoveries; so do chemists render many things intelligible, otherwise impossible to be learnt; insomuch that we must or necessity own, that many of the most important parts in all the medical physiology are only to be known by chemistry.[80]

The action of fire in Boerhaave's conception of chemistry reveals the influence of several Newtonian elements that is important to consider in order to know how he adopted Newtonianism in medicine. For him,

> Fire cannot penetrate into the last and least elements of bodies, but is repelled therefrom, as often as it attempts it; and this with the more force, by how much it endeavours to penetrate more forcibly. By this means there must arise a kind of attrition betwixt fire and other bodies; and consequently fire is never lodg'd in the proper substance of bodies, but only in the interstices, which are lest between the particles, even of the most solid bodies.[81]

Boerhaave claimed that fire is composed of the most solid and smallest particles of nature and it acts in the interstices of the particles composing bodies, separating them one from the other. The Newtonian character of this consideration of fire is revealed when he explains that the cohesion of particles is the result of some attractive forces between them. Let us consider, for instance, his explanation of the composition of blood. In his study of physiology in *Institutiones Medicae*, he argues that the fluids of the human body cannot be studied by means of hydraulics alone because "many of our fluids contain elastic globules, and all of them are compounded of oil, salt, earth and water, variously attracting and repelling each other."[82] Consequently, the fluids of the human body do not strictly follow the mechanical laws of hydraulics and hydrostatics. This position is clearer when Boerhaave explains that chemical reactions that fire cause can hardly be limited to mechanical causes: "On the contrary, it rarely happens that any menstruum exerts all its dissolving power mechanically. And hence, Sir *Isaac Newton*, in his researches has found reason, from observation, to add other necessary causes."[83] The non-mechanical character of Boerhaave's chemistry allows him to suggest that forces are explicative principles for the cohesion of particles. Consequently, chemical operations with fire make an analysis of matter by separating the particles which cohere as a result of their attractive forces. As Knoeff explains: "Not long after his graduation in 1690, after having read the first edition of Newton's *Principia*, Boerhaave started explaining his *affectionis corporae principium* and *occultae qualitates* in terms of Newtonian forces."[84] In point of fact, Boerhaave's works in the 1710s-1720s evidence that he appropriated Newtonian concepts, like attractive forces, and Newton's methodological principles, like the rejection of causal explanations in favour of mathematical demonstrations. Furthermore, these works reveal that Boerhaave held his conviction in the explicative power of Newton's physics in these decades, when he composed his major works on medicine and chemistry. For instance, in his *Sermo Academicus, de Comparando Certo in Physicis* (1715), he claimed:

> If it helps to assume arguments of this kind as principles, held for principles of all nature by the most ancient and wise of all the philosophers. The most ancient of them, those of Syrophoenicia, held for principles of production of all natural phenomena chiefly the atoms, space, and gravitation. This doctrine was derived and received by Leucipus, Democritus, Metrodorus of Chios, Epicurus, Lucretius and

> their acolytes, and was accepted by Gassendi and drive out by Descartes. This doctrine was in disgrace during the prevalence of his sect. Nevertheless it was revived and established to much greater advantage by the invincible mathematical arguments (*mathesi argumentis*) of that prince of all philosophers, Sir Isaac Newton.[85]

In short, for Boerhaave, it was necessary for the physician interested in knowing and explaining physiological phenomena to have an in-depth knowledge of both chemistry and mechanics in order to account for physiological phenomena and to develop proper therapies for diseases affecting specific parts of the body. Newtonian elements in Boerhaave's physiology and medicine are not limited to the use of the laws of motion in order to explain the physiological phenomena related to the solid and liquid parts of the body. By considering the role of chemistry in physiological and medical investigations, we can see how Boerhaave also used a Newtonian matter theory characterised by the presence of forces causing certain phenomena, which are only explicable in chemical terms with the use of fire. Thus, whereas analysis made with fire in chemistry allows the chemist to determine the peculiar properties of the bodies, the physician can use a chemical approach to physiology for determining how such properties affect the constitution of the human body; thus leading to the best therapy for a specific disease.

As we can see, the different features of Boerhaave's approach to medicine and physiology, his adoption of mechanical and chemical principles, his advocacy of mathematical and experimental methods, his endorsement of mechanical and attractive forces, the permanent reference to the chemical functions of the body, make it difficult to categorise him into one of the Newtonian approaches I described above. By considering his methodological pronouncements in the *Sermo Academicus* as well as his ideas on attractive forces in his works on chemistry and its role in medicine, we can argue that Boerhaave adopted a Newtonian theory of matter in which forces were fundamental to account for physiological phenomena happening in a chemical level. However, unlike Cheyne or Pitcairne, Boerhaave considered that such chemical operations were only knowable by means of experiments and observations as they were for the Newtonian physicians working in the light of Newton's *Opticks*. As a result, we can conclude that Boerhaave's Newtonianism consisted in the adoption of methodological procedures coming from the mathematical and the experimental traditions of Newtonian medicine as well as in the application of a Newtonian matter theory in which attractive forces were responsible of the internal functioning of the body.

Conclusion

As I pointed out in the beginning of this paper, Boerhaave's ideas on the ancillary role of chemistry for medicine played a fundamental role in Mutis's *General plan*, as his description of the faculty of chemistry (which should be attached to the faculty of medicine) evidences. According to Mutis:

> As the lectures on mathematics, physics and botany, this lecture (chemistry) does not limit its teachings to the physicians, for whom it is considered as an ancillary discipline of their main career. They are more general sciences in which young students from other careers can be trained according to their interests, looking for the public happiness. As regards chemistry, which is the subject we are dealing with in this moment, being its business to investigate the nature and properties of all the bodies, it sheds its lights upon all the sciences and arts that cannot have the progress we admire nowadays without it.[86]

Like Boerhaave, Mutis considered chemistry in a twofold way: on one hand, chemistry is a practical discipline for the physician who should study it, just like he studies mathematics or physics, namely, as an ancillary discipline. In this sense, chemistry is nothing but a discipline attached to the medical studies, useful for pharmacopeia. However, following Boerhaave's considerations, Mutis also adopted the idea that chemistry is a discipline that allows the physician to discover, explain and interact with the specific properties of the human body. On the other hand, in relation to this idea of the value of chemistry as a theoretical discipline, Mutis considered it as a theoretical discipline independent of others, the main purpose of which is "studying the nature and properties of all the bodies."

Mutis's acceptance of Boerhaave's consideration of the role of chemical analysis to account for physiological phenomena reveals that his enterprise of presenting the Newtonian approach to study natural phenomena in New Granada was more ambitious than it had been thought. Rather than being limited to the dissemination of Newton's physics from a merely theoretical point of view, in his lectures on mathematics, Mutis advocated for the application of its methodology and theoretical principles in different fields. The case of his use of it for designing the curriculum for medicine at the *Colegio del Rosario* depicts his commitment with his self-definition as a Newtonian.[87]

Mutis presented his study plan to Viceroy Mendinueta y Múzquiz, who accepted it in the same year, making it the foundation for the development of the curriculum of medicine at the *Colegio del Rosario*, designed by Miguel de Isla and Andrés Rosillo Meruelo — its director since 1802 — in 1804. In this sense, Mutis's plan was the first successful endeavour to organise and modernise the medical educational system in New Granada after the failed attempts in the 1770s, during the times of Moreno Escandón's reformism.[88] Nevertheless, the emergence of the revolutionary processes that concluded in the independence of New Granada from Spain between 1810 and 1819 limited the success in the implementation of Mutis's plan. Despite that the number of graduated physicians increased significantly — there were only two in the entire period before the re-inauguration of the faculty of medicine in 1805 —, almost all of them were forced to serve as military physicians in both the royalist and republican sides of the conflict. In point of fact, the faculty did not properly work during the entire revolutionary period (1810-1819).[89] This fact, which constitutes a source of difficulties from a historiographical point of view as it makes it almost impossible to trace the fate and works of the physicians educated under the aegis of the Mutisian reformism in New Granada, was fundamental for its endorsement by the medical faculties created in Colombia in the eve of the republican period. As the modernisation of the educational system was considered one of the causes of emergence of the revolutionary processes leading to Colombia's independence from Spain by its protagonists, Mutis's reformist ideas on education were identified as one of the causes of the independence itself.[90] In this sense, the General Plan was adopted by the faculty of medicine established in 1827 at the cloisters of the *Universidad Central*, the first public university of the Colombian republic period.

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[1] Studies on the multiple facets of the Botanical Expedition are in José Antonio Amaya, *Celestino Mutis y la Expedición Botánica* (Madrid: Debate, 1986); Daniela Bleichmar, *Visible Empire: Botanical Expeditions and Visual in the Hispanic Enlightenment* (London: University of Chicago Press, 2012); Mauricio Nieto Olarte, *Remedios para el Imperio: Historia Natural y la Apropiación del Nuevo Mundo* (Bogotá: Universidad de los Andes, 2006).

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[2] There are several studies concerning the economic purposes of the Botanical Expedition for Mutis and the Spanish Crown. See, for instance, Amaya, *Celestino Mutis*; Olga Restrepo Forero, "José Celestino Mutis: el Papel del Saber en el Nuevo Reino," *Annuario Colombiano de Historia Social y de la Cultura*, 18-19 (1998), 47-99; Antonio Lafuente & Leoncio López Ocón, "Scientific Traditions and Enlightenment Expeditions in Eighteenth-Century Hispanic America," in *Science in Latin America. A History*, ed. Juan José Saldaña (Austin: University of Texas Press, 2006), 123-150; Nieto Olarte, *Remedios para el Imperio*; Matthew James Crawford, *Empire's Experts: the Politics of Knowledge in Spain's Royal Monopoly of Quina (1751-1808)* (unpublished PhD thesis: University of San Diego, 2009); José Ramón Marcaida & Juan Pimentel, "Green Treasures and Paper Floras: the Business of Mutis in New Granada," *History of Science*, 52, 3 (2014), 277-296; Rocío Bruquetas, "The Search for the Perfect Color: Pigments, Tints, and Binders in the Scientific Expedition to the Americas," *Journal of Interdisciplinary History*, 45, 3 (2015), 367-388; Sergio Orozco-Echeverri & Sebastián Molina-Betancur, "José Celestino Mutis' Appropriation of Newton's Experimental Physics in New Granada (1761-1808)," *History of Science*, 57, 3 (2019), 291-323.

[3] A transcription of some of Mutis's lectures on mathematics is in José Celestino Mutis, *Pensamiento Científico y Filosófico de José Celestino Mutis*, ed. Guillermo Hernández de Alba (Bogotá: Fondo Cultural Cafetero, 1982), 43-68.

[4] *Cf.* Orozco-Echeverri & Molina-Betancur, *José Celestino Mutis' Appropriation*.

[5] The original version of Moreno Escandón's Plan is AGNC, Sección Colonia Colegios SC. 12,2, ff. 286r-309r. A copy of the manuscript is RJB III, 2, 4, 11 and a transcribed version is in Guillermo Hernández de Alba, *Documentos para la Historia de la Educación en Colombia* (Bogotá: Patronato Colombiano de Artes y Ciencias, Colegio Máximo de las Academias de Colombia, 1969).

[6] An account of the role of ecclesiastic orders in New Granada's educational system is in José Manuel Rivas Sacconi, *El Latín en Colombia: Bosquejo Histórico del Humanismo Colombiano* (Bogotá: Instituto Colombiano de Cultura, 1993), 46-65.

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[7] See Andrés Soriano Lleras, *La Medicina en el Nuevo Reino de Granada: Durante la Conquista y la Colonia* (Bogotá: Editorial Kelly, 1972); Emilio Quevedo & Camilo Duque, *Historia de la Cátedra de Medicina en el Colegio Mayor del Rosario durante la Colonia y la República 1653-1865* (Bogotá: Centro Editorial Universidad del Rosario, 2002); Pedro María Ibañez, *Memorias para la Historia de la Medicina en Santafé de Bogotá* (Bogotá: Fundación Editorial Epígrafe, 2006).

[8] For a general characterisation of the polemics concerning the reforms of New Granada's educational system in the 1770s, see Guillermo Hernández de Alba, "Proyecto del Fiscal Moreno y Escandón para la Erección de Universidad Pública en el Virreinato de la Nueva Granada, con Sede en la Ciudad de Santafé de Bogotá, año de 1768," *Thesaurus: Boletín del Instituto Caro y Cuervo,* 16, 2 (1961), 471-493; Diana Soto, *Mutis: Filósofo y Educador. Una Muestra de la Realidad Educativa Americana en el Siglo XVIII* (Tunja: Universidad Pedagógica y Tecnológica de Colombia, 2009).

[9] Details of this episode of the course of medicine at the *Colegio del Rosario* are in John F. Wilhite, *The Enlightenment and Education in New Granada, 1760-1830* (unpublished PhD thesis: The University of Tennessee, 1980). A historical reconstruction of the course of medicine at the *Colegio del Rosario* is in Quevedo & Duque, *Historia de la Cátedra de Medicina*.

[10] José Celestino Mutis, *Diario de Observaciones*, ed. Guillermo Hernández de Alba, (Bogotá: Editorial Minerva), 104.

[11] As Rivas Sacconi explains, because of the lack of books and the difficulty to purchase them, the professors were forced to dictate the content of their courses to his students. The manuscript copies of the textbooks were called *mamotretos*. José Manuel Rivas Sacconi, *El Latín en Colombia: Bosquejo Histórico del Humanismo Colombiano*, (Bogotá: Instituto Colombiano de Cultura), 64-65.

[12] Transcribed versions of these lectures are in Mutis, *Pensamiento Científico y Filosófico,* 33-68.

[13] Orozco-Echeverri & Molina-Betancur, *José Celestino Mutis' Appropriation*.

[14] RJB III, 2, 4, 11, f. 9r.

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[15] RJB III, 7, 1, 5, f. 282v

[16] A detailed study of 's Gravesande's considerations on theology and its relationship with physics is in Steffen Ducheyne, "'s Gravesande and the Relation between Physics and Theology," *European Journal of Science and Theology*, 9, 3 (2013), 107-117.

[17] RJB III, 7, 1, 5, f. 297r

[18] José Celestino Mutis, "Plan Provisional para la Enseñanza de las Matemáticas en el Colegio de Nuestra Señor del Rosario, Formado de Orden del Excelentísimo Señor Arzobispo Virrey, por D. José Celestino Mutis, Presbítero Catedrático Perpetuo de Matemáticas en Dicho Colegio, Director de la Real Expedición Botánica, su Primer Botánico y Astrónomo, Miembro de la Real Academia de Stockolmo, y Correspondiente del Real Jardín Botánico de Madrid," in *Documentos para la Historia de la Educación en Colombia. Vol. V*, ed. Guillermo Hernández de Alba (Bogotá: Editorial Kelly), 110-112.

[19] Both versions of the translation are in RJB III, 7, 1, 5, ff. 436r-458r and RJB III, 7, 1, 5, ff. 460v-522r.

[20] The manuscript is RJB III, 7, 1, 5, ff. 397r-416v.

[21] RJB III, 7, 1, 20, f. 1r. My emphasis.

[22] For the reception of Leibnizian calculus in England, see Charles Henry Edwards, *The Historical Development of Calculus* (New York: Springer 1994), 265-268; Niccolò Guicciardini, "Newton's Method and Leibniz's Calculus," in *A History of Analysis*, ed. H. N. Jahnke (Providence, RI: The American Mathematical Society, 2003), 73-105; Jason Bardi, *The Calculus Wars: Newton, Leibniz, and the Greatest Mathematical Clash of All Time* (New York: Basic Books, 2006), 169-242.

[23] Mutis's manuscript on conic sections is RJB III, 7, 1, 5, ff. 329r-330v. The manuscript on hyperbolas is RIJB III, 7, 1, 5, ff. 318r-320v. Interestingly, the folios before the section on hyperbolas deal with fluxions. It is likely that, in its original order, these folios were part of the manuscript on conic sections.

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[24] Both lectures have been transcribed in José Celestino Mutis, *Escritos Científicos de Don José Celestino Mutis*, ed. Guillermo Hernández de Alba (Bogotá: Instituto Colombiano de Cultura Hispánica, 1983), 69-91; 104-116.

[25] The debate between Mutis and the Dominicans as well as its political, social and cultural consequences has been studied in John Tate Lanning, "El Sistema de Copérnico en Bogotá," *Revista de Historia de América*, 18 (1944), 279–306; Diana Soto & Olegario Negrí Fajardo, "El Debate sobre el Sistema Copernicano en la Nueva Granada en el Siglo XVIII," *LLull*, 7 (1984), 53-75; Diana Soto, *La Reforma del Plan de Estudios del Fiscal Moreno y Escandón 1774-1779*, (Bogotá: Universidad del Rosario, 2004).

[26] José Celestino Mutis, *Escritos Científicos*, 33-62.

[27] Ibid., 34-35.

[28] Ibid., 35-36.

[29] Ibid., 36.

[30] In point of fact, the course of medicine at the *Colegio del Rosario* was only effectively inaugurated, after several attempts, in 1758 by José Vicente Román Cancino, who had studied Philosophy. His successor in the chair of medicine was his acolyte Juan Bautista de Vargas, to whom Mutis refers in his report, who had no medical training either. See, Quevedo & Duque, *Historia de la Cátedra de Medicina*, 20-33.

[31] Mutis, *Escritos Científicos*, 35.

[32] As request by Marquis of La Ensenada, Virgili created the *Reales Colegios de Cirugía* aiming to train surgeons for the Spanish Royal Navy, leading to a reformation of the role of surgery and medicine in the Spanish academic structure which began at Cadiz. Historical details on the creation of the *Colegio de Cirugía* of Cadiz and its relation to the Spanish Army are in Diego Ferrer, *Historia del Real Colegio de Cirugía de la Armada de Cadiz* (Cadiz: Universidad de Cadiz, 1983). Cadiz was also one of the most important centres of reception of Newton's physics in Spain during the 1750s. See Anthony Pagden, "The Reception of the 'New Philosophy' in Eighteenth-Century

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Spain," *Journal of the Warburg and Courtauld Institutes*, 51 (1988), 126–140; Antoni Malet, "Newton in the Iberian Peninsula", in *The Reception of Isaac Newton in Europe*, eds. H. Pulte & S. Mandelbrote (New York: Bloomsbury Academic, 2019).

[33] Mutis, *Escritos Científicos*, 64-67.

[34] Ibid., 66.

[35] In the context of a strong scholastic educational system in which the faculties of law and theology were dominant in the Spanish universities, the faculty of medicine had a less important social role. This was particular the case for the students and professors of surgery. The reconfiguration of their social role was only achieved in the mid eighteenth century, with the projects of modernisation that Pedro Virgili advanced, supported by the Spanish Crown. See, Juan J. Rodríguez Ballesteros, "La introducción de la física en los estudios médico-quirúrgicos y en la armada gaditana (1735-1845)," *Llull*, 27 (2004), 475–493; Juan Manuel Rueda Pérez, "Nacimiento de la cirugía española moderna en el siglo xviii," *Revista Hispanoamericana de Hernia*, 1, 3 (2013), 113–116.

[36] Mutis, *Escritos Científicos*,, 67.

[37] Ibid., 39-40.

[38] A brief characterisation of Mutis's inaugural lecture, entitled *Preliminary Speech Pronounced in the Opening of the Course of Mathematics*,' is in Orozco-Echeverri & Molina-Betancur, *José Celestino Mutis' Appropriation*.

[39] Mutis, *Pensamiento Científico y Filosófico*.

[40] Mutis, *Escritos Científicos*, 81-82.

[41] Ibid., 83.

[42] Ibid., 83.

[43] The category of Newtonianism has recently been subjected to intensive revisionism among Newton scholars. However, the appropriation of Newton's methodological and theoretical principles in several disciplines during the eighteenth century continues to be one of the central topics of these reconsidered conceptions of Newtonianism. See Anita Guerrini, *Newtonian Matter*

Theory, Chemistry, and Medicine, 1690-1713 (unpublished PhD dissertation: Indiana University, 1983); Margaret C. Jacob & Betty Jo Teeter Dobbs, *Newton and the Culture of Newtonianism* (New Jersey: Prometheus, 1995); Steffen Ducheyne & Jip Van Besouw, "Newton and the Dutch 'Newtonians': 1713-1750," in *The Oxford Handbook of Newton*, Eric Schliesser & C. Smeenk (Oxford: Oxford University Press, 2017).

[44] Pitcairne's works are published in Archibald Pitcairne, *The Whole Works of Dr. Archibald Pitcairne*, trans. G. Sewell & T. Desaguliers (London: E. Curll, J. Pemberton, and W. and J. Innys, 1727). Interesting studies of them can be found in Andrew Cunningham, "Sydenham Versus Newton: the Edinburgh Fever Dispute of the 1690s between Andrew Brown and Archibald Pitcairne," *Medical History. Supplement*, 1 (1981), 71-98; Guerrini, *Newtonian Matter Theory*, 56-145; Anita Guerrini, "The Tory Newtonians: Gregory, Pitcairne, and Their Circle," *Journal of British Studies*, 25, 3, (1986), 288-311; Anita Guerrini, "Archibald Pitcairne and Newtonian Medicine," *Medical History*, 31, 1, (1987), 70-83; John Friesen, "Archibald Pitcairne, David Gregory and the Scottish Origins of English Tory Newtonianism, 1688-1715," *History of Science*, 41, 2 (1987), 163-191.

[45] See Guerrini, *Archibald Pitcairne*, 70. A description of the meeting between Newton and Pitcairne is in H. W. Turnbull, *The Correspondence of Isaac Newton 1688-1694, Vol. III*. (New York: Cambridge University Press, 1961), 212-213.

[46] Pitcairne, *The Whole Works*, 7-8.

[47] Ibid., 9.

[48] In this point Pitcairne presents a characterisation of the advantages a mathematical approach to physiology provides by considering that it is reduced to identify the visible effects that certain interaction among powers can produce in the body. See, Ibid., 21-22.

[49] Guerrini, *Archibald Pitcairne*, 73. It is likely that she meant Book I.

[50] Despite the important role Pitcairne's lectures played in the emergence of a generation of Newtonian physicians, the fever dispute in Edinburgh during the 1690s was the main scenario

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where they discussed and presented their ideas. Initiated as a debate concerning the best therapies against continual fevers, it encompassed not only therapeutic issues but also methodological and disciplinary ones, which gave rise to the use of a Newtonian approach in medicine. A complete account of the fever dispute is in Cunningham, *Sydenham Versus Newton*.

[51] The characterisation of Cheyne's election of the geometrical method for presenting his physiological ideas is in his Preface. See, George Cheyne, *A New Theory of Continual Fevers* (Edinburgh: John Vallange and G. Strachan), Preface (note 56). The postulate and lemmata are in pp. 1-11.

[52] Ibid., 11.

[53] Ibid., 22.

[54] Ibid., 38.

[55] Guerrini, *The Tory Newtonians*.

[56] Cheyne, *A New Theory*, 37-78.

[57] Guerrini, *Newtonian Matter Theory*, 217; Theodore M. Brown, "From Mechanism to Vitalism in eighteenth-Century English Phisiology," *Journal of the History of Biology*, 7, 2(1974), 191; Christina M. Eagles, "David Gregory and Newtonian Science," *The British Journal for the History of Science*, 10, 3 (1977), 216-225.

[58] Keill's considerations on the articulation of mathematics and experiments for explaining physiological phenomena and diseases can be found in James Keill, *An Account of Animal Secretion, the Quantity of Blood in the Humane Body, and Muscular Motion* (London: George Strahan, 1708), VIII-IX.

[59] Ibid., 2.

[60] Ibid., 2.

[61] Keill explicitly refers to microscopic observations when he deals with the constitution of glands. See, Ibid., 82-84.

[62] Ibid., 7.

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[63] Ibid., 8.

[64] Such a characterisation is clear in the propositions accounting for the formation of substances to be secreted in the glands of the human body. See, Ibid., 9-23. An exemplary case of the kind of arguments that Keill used is in Prop. III, where he explains the variation in the force between particles depending on their mutual distances; thus concluding that it would be infinitely greater with their contact. See, Ibid., 13-16.

[65] For the influence of Boerhaave's works on medicine and chemistry in the eighteenth century, see Milton Kerker, "Herman Boerhaave and the Development of Penumatic Chemistry," *Isis*, 46, 1 (1955), 36-49; Rina Knoeff, *Herman Boerhaave, 1668-1738: Calvinist Chemist and Physician* (Amsterdam: Royal Netherlands Academy of Arts and Sciences, 2002); Rina Knoeff, "Chemistry, Mechanics and the Making of Anatomical Knowledge: Boerhaave vs Ruysch on the Nature of the Glands," *Ambix*, 53, 3 (2006), 201-249; John C. Powers, "Chemistry without Principles: Herman Boerhaave on Instrument and Elements," in *New Narratives in Eighteenth-Century Chemistry*, ed. L. M. Principe (Dordrecth: Springer, 2007), 45-62; Robert G. W. Anderson, "Boerhaave to Black: the Evolution of Chemistry Teaching," *Ambix*, 53, 3 (2010), 237-254; John C. Powers, *Inventing Chemistry: Herman Boerhaave and the Reform of the Chemical Arts* (Chicago: University of Chicago Press, 2016).

[66] Boerhaave's *Praelectiones academicae in proprias institutiones rei medicae* are popularly known as *Institutiones Medicae*. For this paper, I used the English edition published in London in 1751 by B Cowse and W. Innys.

[67] See, Herman Boerhaave, *Aphorisms: Concerning the Knowledge and Cure of Diseases*, trans. J. Delacoste (London: B. Cowse and W. Innys, 1715), 1-23; Herman Boerhaave, *Academical Lectures on the Theory of Physic* (London: W. Innys, 1751), 51-96.

[68] Boerhaave, *Academical Lectures*, 85.

[69] For Boerhaave's mechanical conception of the body, see Stanley W. Jackson, "Melancholia and Mechanical Explanation in Eighteenth-Century Medicine," *Journal of the History of Medicine and*

Allied Sciences, 38, 3 (1983), 298-319. A detailed explanation of physiological mechanics in the eighteenth century is in Brown, *From Mechanism to Vitalism*.

[70] Boerhaave, *Academical Lectures*, 64.

[71] See Boerhaave, *Aphorisms*, 4-5.

[72] See Ibid., 132-133. In this section, he also claims that the determination of the best method for curing a fever depends on the kind of substance that is producing the obstruction. See, Ibid., 134.

[73] Ibid., 133.

[74] Boerhaave, *Academical Lectures*, 46.

[75] Herman Boerhaave, *A New Method of Chemistry*, trans. Peter Shaw (London: T. and T. Longman, 1753), 65.

[76] See, Ibid., 1-5. Though Boerhaave points out the importance of chemistry as an independent discipline, in his historical analysis of the evolution of chemistry in *A new method of chemistry*, he also alludes to the role of chemistry in the medical field. See, Ibid., 35-60.

[77] Ibid., 173.

[78] Ibid., 172-173.

[79] Ibid., 65-66.

[80] Ibid., 174.

[81] Ibid., 247.

[82] Boerhaave, *Academical Lectures*, 89.

[83] Boerhaave, *A New Method*, 511.

[84] Knoeff argues that Boerhaave's advocacy of Newton's physics as a theoretical foundation for accounting for both physiological and natural phenomena was progressively vanished by his personal beliefs regarding the nature of God's providence. For Knoeff, while Newton postulated a direct action of God in nature, Boerhaave had a rather Calvinist position, in which God's action on nature was only performable through secondary causes. Thus, she claims that Boerhaave moved from Cartesianism to be a "doubtful Newtonian," adopting Newton's ideas on forces and praising

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his acceptance of chemistry as the best mean to investigate nature, but "being very careful in universally applying them to all natural phenomena." Knoeff, *Herman Boerhaave*, 119.

[85] Herman Boerhaave, *Sermo Academicus, de Comparando Certo in Physicis* (Lugduni Batavorum: Petrum Vander, 1715), 7-8.

[86] Mutis, *Escritos Científicos*, 271.

[87] Mutis's self-definition as a Newtonian has been studied in Orozco-Echeverri & Molina-Betancur, *José Celestino Mutis' Appropriation*.

[88] Details on the different study plans for the faculty of medicine in New Granada are in Emilio Quevedo, *Historia Social de las Ciencias en Colombia. Tomo VII. Medicina (1)*, (Bogotá: Colciencias, 1993).

[89] Emilio Quevedo, *Historia Social de las Ciencias en Colombia. Tomo VII. Medicina (2)*, (Bogotá: Colciencias, 1993), 55-56.

[90] Orozco-Echeverri and Molina-Betancur explain that this identification of Mutis's reformism, the modernisation of New Granada's educational system and the introduction of several enlightened ideas in New Granada is the result of an image created by the figures of the revolutionary processes leading to Colombia's independence. See, Orozco-Echeverri & Molina-Betancur, *José Celestino Mutis' Appropriation*.