DESCARTES'S TELEOMECHANICS IN MEDICAL CONTEXT:

Approaches to Integrating Mechanics and Teleology in Hieronymus Fabricius ab Aquapendente, William Harvey, and René Descartes

by

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In this dissertation, I examine the relation between mechanism and teleology in Descartes's physiology, placing his views in a wider medical and anatomical context. I show that in this context we find distinctively Galeno-Aristotelian approaches to integrating mechanics and teleology in the work of anatomists Hieronymus Fabricius ab Aquapendente and his more famous student, William Harvey. I provide an interpretation of teleology and mechanism in Descartes by exploring the historical and conceptual relationships between his approach and those exhibited by these anatomists.

First, I show that Fabricius and Harvey articulate creative, teleological, non-reductive approaches to mechanizing the animal precisely by developing Aristotelian and Galenic resources. They propose that mathematical mechanics, understood as an Aristotelian subordinate science, should be employed to articulate the way the functions of the locomotive organs explain (as final causes) certain features of their anatomy, rendering them hypothetically necessary. They articulate these explanations using the Galenic concepts *actio* and *usus*.

Employing the resources developed in my analysis of Fabricius and Harvey, I then provide a new interpretation of the relation of mechanism and teleology in Descartes and clarify its significance. Although he explicitly rejects final causes in natural philosophy, Descartes still appeals in physiology to apparently teleological concepts like *functio* and *usus*. By focusing on the medical context of these concepts, I show that Descartes intends to and primarily does employ these concepts in mechanical explanations. Descartes' explanations are meant to replace the metaphysically more extravagant but still material-efficient (not final-causal) explanations present in the medical tradition. I then argue that Descartes at times does in fact employ final-causal explanations similar to those in Fabricius's and Harvey's work. However, Descartes is hard-pressed to ground these explanations while still rejecting both divine purposes and non-mechanical principles in natural philosophy.

For CRD,

a rose to this thistle.

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PREFACE

I suppose this dissertation formally marks my scholarly coming of age. And as in one's upbringing, so in one's scholarly training a deep and—when enough goes right—happy debt to others is incurred. It is my pleasure here to acknowledge that debt.

My interest in philosophy, science, and their intertwined history first took shape during my undergraduate studies at the University of Notre Dame. There I found myself somehow a part of a talented, happy, and remarkably intense group of like-minded students with whom to live, study, and argue. I also benefited, in different ways from the generosity and pedagogical prowess of several professors—Neil Delaney, Fred Freddoso, Michael Loux, Al Plantinga, and Ken Sayre come especially to mind. And although I never took a course from him, it was the example of the sober, insightful, even wise scholarship of the late Ernan McMullin that crystalized my choice of specialization. I remember fondly a few kindly conversations with him more recently, when our paths crossed in the small (and sadly now a little smaller) world of history and philosophy of science. I also thank the Department of Physics and Astronomy at Eastern Michigan University who, while slightly puzzled by it all, welcomed a disciplinary interloper. I especially wish to thank Alexandra Oakes, Diane Jacobs, and Wade Shen for their support and encouragement while I was working on my M.S. there.

When I visited the Department of History and Philosophy of Science at the University of Pittsburgh as a prospective, my first impression was of a friendly, collegial, talented department—one highly conducive to the study of HPS. This is also my last (as it were)

impression. For this, I owe special thanks to a number of fellow graduate students. To Jonah Schupbach, Karen Zwier, and Benny Goldberg, as well as Bryan Roberts, Thomas Cunningham, and Katie Tabb I am in different ways and especially grateful; and also to Marcus Adams, Keith Bemer, Julia Bursten, Bihui Li, Elizabeth O'Neill, and Aleta Quinn. I wish also to thank Joann McIntyre and Rita Levine, administrators *extraordinaire*.

For the particular shape and dimensions of my research I am eager to thank the HPS faculty at Pittsburgh (they are not to be blamed for its quality). I thank Ted McGuire for encouragement, insight, and—with Barbara Tuchanska —for hospitality and a quiet place to work. I also thank Edouard Machery for his highly effective advising during comprehensives and again more recently. I thank Paolo Palmieri for first alerting me to Giuseppe Moletti and his unfinished dialogue on mechanics.

During my time at Pittsburgh, I benefited from several extra-curricular opportunities. I think of Dan Garber's and Roger Ariew's NEH summer seminar on Galileo, Descartes, and Hobbes in 2010. That three week gathering of early modern scholars was a pleasant affair, and I thank Dan (for this and all his other support and input), Roger, and all the participants for making it so. I especially think of Zvi Biener, Mary Domski, Patricia Easton, Geoff Gorham, Helen Hattab, and Marius Stan. I also had the opportunity to co-organize the *Medicine, Philosophy, and the 'Scientific Revolution' Initiative* in 2011-2012. With Charles Wolfe, Evan Ragland, Benny Goldberg, and Jim Lennox, I have had the pleasure of bringing together a wonderful group of early modern scholars working at the intersection of science, medicine, and philosophy. This together with a Helm Visiting Fellowship at the Lilly Library at Indiana University, Bloomington, introduced me to Nico Bertoloni Meli and a group of talented graduate students working in the area. I thank Nico for supporting my Helm application and for helpful and encouraging comments over the last few years, and Tawrin Baker, Ashley Inglehart, and Allen Shotwell for sharing their friendship and their scholarship with me. I thank the staff of the Lilly Library for access to their collection and Merilee Salmon and the Wesley C. Salmon fund for material support for my dissertation research. These and other opportunities have introduced me to a remarkable group of graduate students, as well as junior and senior faculty who work on early modern philosophy, science, and medicine. Among them, I owe special thanks for encouragement and insight to Dennis Des Chene and Karen Detlefsen.

I also benefited from (on again off again) participation in a lively Greek reading group—or was it a working group on Aristotle's natural philosophy?—attended by faculty and graduate students in the Pittsburgh area. In this context I am especially grateful to the late Allan Gotthelf, and to Ron Polanski, Topher Kurfess, and Nic Thorne (who also taught me Latin)—and, of course, to Jim Lennox.

Jim Lennox and Peter Machamer have been together an advisor greater than the sum of its parts. To each individually and to both together I say thank you. From seminars to office conversations, from written comment to liquid refreshment, from advice to threat—and with noteworthy patience—they have managed to get me through. I am deeply grateful.

An ivory tower does not a village make. I am happily indebted to a host of family, friends, and family friends who did make up a village (and a good one). I am grateful to them all, and particularly to my parents, who have supported, encouraged, and suffered me for so many years and who taught me how to live. And to my wife, who took over from them a number of years ago, I finally and most especially say thank you.

1.0 INTRODUCTION

The Honorable Robert Boyle singled out René Descartes as a paradigmatic champion of a new, promising—even 'excellent'—philosophy destined to scatter the obscurities of scholastic Aristotelianism. This new "corpuscularian" or "mechanical philosophy," said Boyle, posited one, uniform, catholic matter and explained natural phenomena only in those terms typically used to explain the workings of machines. However, this proponent of "big-tent" mechanism was disturbed by Descartes's rejection of final causes in natural philosophy. Descartes, unlike atheistic Epicureans, believed in a wise and beneficent divine creator but thought his purposes inscrutable and so irrelevant to physics. For this reason, Descartes says, final causes should be banished from natural philosophy.

In his *Disquisition about Final Causes* (1688), Boyle disagrees, arguing for a legitimate but limited place for final causes in a Christian natural philosophy. Boyle suggests that they will be particularly appropriate in the study of living things. Pierre Gassendi, too, questioned Descartes's rejection of final causes—particularly in the case of living things. In his *Objections*, Gassendi insists that the study of the parts of plants and animals (including man) can lead the physicist to knowledge of the ends for which these parts were created. These divine purposes, suggests Gassendi, are "on public display, as it were" and "can be discovered without much effort." In fact, precisely because of their accessibility, the discovery and study of the ends for which the parts were created are central to the "principle argument for establishing by the natural light the wisdom, providence and power of God, and indeed his existence."

> Leaving aside the entire world, the heavens and its other main parts, how or where will you be able to get any better evidence for the existence of such a God than from the use [*usu*] of the various parts in plants, animals, man and yourself (or your body), seeing that you bear the likeness of God? (AT VII 309, CSM II 215)

Gassendi suggests that the study of anatomy has, in fact, led to such knowledge:

> We know that certain great thinkers have been led by a study of anatomy not just to achieve a knowledge of God but also to sing thankful hymns to him for having organized all the parts and harmonized their uses in such a way as to deserve the highest praise for his care and providence. (AT VII 309-310, CSM II 215)

This is a clear reference to Galen, who calls the last book of *De usu partium* an *epode*.

> This book like a good epode sets forth these many and great advantages of the work I have now completed. By "epode" I do not mean the magician who uses enchantments; for we know that the melic poets, called lyric by some, have not only a strophe and an antistrophe but a third song as well, an epode which they used to chant standing before the altars and, as they say, singing hymns of praise to the gods. And so, likening this book to such an epode, I have given it that name.[1] (*De usu partium* XVII 3)

In alluding to anatomy and Galen's highly influential *De usu partium*, Gassendi reminds us that in the 17th century the most detailed and expert study of living things was found in medicine and the medical tradition. For Gassendi, Descartes's rejection of appeals to final causes and divine

[1] Galen suggests that one of the main advantages the study of the uses of the parts provides is a "perfect theology." Translations from Galen's *De usu partium* are from Margaret T. May's edition (Galen 1968).

ends is especially inappropriate when we turn to the study of the parts of animal (i.e., anatomy); and, for Gassendi, anatomy is most especially the business of Galen and the medical tradition.

In this dissertation, I take my cue from Gassendi and place Descartes's mechanization of living things and controversial rejection of final causes in their study in a medical and anatomical context. When Gassendi composed his *Objections*, nearly a century had passed since the publication of Andreas Vesalius's *De fabrica humani corporis* (1543), and anatomy was long-established as prominent, thriving discipline. In this context we find a very different, Galeno-Aristotelian approach to integrating mechanism and teleology in the work of anatomists Hieronymus Fabricius ab Aquapendente and his more famous student, William Harvey (the discoverer of the circulation of the blood).[2] I show that Fabricius and Harvey develop creative, teleological, and non-reductive approaches to mechanizing the animal precisely by developing Aristotelian and Galenic resources. In particular, they propose that mathematical mechanics, understood as an Aristotelian subordinate science, should be employed to articulate the way the function of the locomotive organs explains (as final cause) certain features of their anatomy, rendering those features hypothetically necessary. They articulate such final causal explanations using Galeno concepts of *actio* and *usus*.

Employing the resources developed in my analysis of Fabricius and Harvey, I then turn to the relation between mechanism and teleology in Descartes's physiology. Although he explicitly rejects final causes in natural philosophy, Descartes still appeals to apparently teleological concepts like *functio* and *usus*. By focusing on the medical context of these concepts and contrasting his approach to Fabricius' and Harvey's, I show that Descartes intends to and

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[2] When Gassendi penned his Objections it had also been more than ten years since William Harvey had published his *De motu cordis* (1628), and, as Descartes's exchange with Plempius, shows, for many it was a post-Harveian discipline.

primarily does employ these terms in mechanical explanations meant to replace the metaphysically more extravagant but still material-efficient (not final causal) explanations present in the medical tradition. I argue, further, that Descartes at times does in fact employ final causal explanations not unlike those characteristic of Fabricius' and Harvey's work and that he is hard-pressed to ground these explanations while still rejecting both divine purposes and non-mechanical principles in natural philosophy. By drawing attention to Fabricius' and Harvey's Galeno-Aristotelian integration of mechanics and teleology, I also undermine the sense of inevitability sometimes attaching to the anti-teleological and reductionist approach associated with Descartes.

1.1 DESCARTES AND MEDICINE

René Descartes's views on living things, health, and medicine have received increasing attention—so, too, has his relation to the institutions and theories of learned medicine of the 17th century.[3] Some have gone so far as to talk of Descartes's "Medical Philosophy."[4] There is ample evidence in his writings and correspondence that Descartes was preoccupied with (reforming) medicine, that he spent significant effort in the dissection of the organs of animals, and that he read widely in the medical literature.[5] Furthermore, some of Descartes's most significant early followers were doctors and professors of medicine—as were many of the Cartesians of the

[3] A number of authors have begun to focus on the medical context of Descartes's physiology: (e.g.) Lisa Shapiro (2003), Gideon Manning (2006) and (2012), and Thomas Steel Hall in his edition of Descartes's *Treatise on Man* (Descartes 2003). Dennis Des Chene (2001) suggests that more work is needed to explore the relevance of the medical tradition to understanding Descartes's treatment of living things.

[4] For example, Richard Carter's *Descartes's Medical Philosophy* (Carter 1983) and Vincent Aucante's more recent *La philosophie medicale de Descartes* (Aucante 2006).

[5] It is also possible that he undertook some formal training in medicine while at Poitiers, where he took his degree in law.

second half of the 17^{th} century. A historically sensitive account of Descartes's place in the intellectual landscape of the 17^{th} century must take all of this into account. Ignoring it puts us in danger of misunderstanding the nature and significance of Descartes's efforts.

Of course, partisans of focusing on Descartes's medical preoccupations can succumb to rhetorical excesses and produce their own distortions. It would, I think, be a mistake to call Descartes's philosophy a "medical philosophy," except in a very modest sense. Some have called Paracelsus's philosophy a "chemical philosophy." This, I take it, is meant to suggest something like the following: Paracelsus takes linguistic and conceptual resources developed in the context of alchemy and its traditions and privileges them, employing them as master metaphors or as ultimate principles in a total philosophy. Descartes's was not a medical philosophy in any analogous sense. It would be a mistake so to "medicalize" Descartes. His interest in medicine took a different shape. If we want to identify a source for his master metaphors and ultimate principles, I think we cannot do much better than to join Boyle in calling him a "mechanical philosopher." Figures like William Harvey or Jean Fernel (for example) are sometimes called "medical thinkers" in another sense. Here the idea is (roughly) that their primary social identities were recognizably medical and perhaps also that the genres of their publications were, too.[6] Descartes was not a "medical thinker" in this sense. If this is our concern, I suspect we would best call him a natural philosopher.[7] Still, Descartes was a *mechanical* and *natural* philosopher

[6] Actually, the question of the genre of Harvey's publications is a subtle one. I think it is best to identify them as works of *anatomy*. But the extent to which we should say that works of (early) seventeenth-century anatomy are *medical* is perhaps not entirely clear. And even less clear is whether Harvey thinks of anatomy as a medical discipline. As we will see, he understands anatomy to be primarily natural philosophical in character, but to have an intimate connection to medicine. At the same time, he well knows and appreciates the fact that the institutional home of anatomy is (in his time and for centuries before him) in the medical faculty of the university, that its practitioners are primarily physicians, that it is being taught primarily to future medical practitioners, and so on.

[7] The fruitfulness of this identification is amply exhibited by (e.g.) Daniel Garber's *Descartes's Metaphysical Physics* (Garber 1992) and Dennis Des Chene's *Physiologia* (Des Chene 1996), *Life's Form* (2000), and *Spirits & Clocks* (2001).See also the collection on Descartes's natural philosophy (Gaukroger, Schuster and Sutton 2000).

who had a deep, sustained interest in medicine—an interest that led him (at least) to read widely in the medical tradition, undertake dissections, and develop views on characteristically medical topics—including physiology, pathology, and therapeutics. In this sense, Descartes has a *medicine*. Furthermore, because Descartes understood his own views on these subjects to constitute a radical reform of medical theory, he gives some attention to emphasizing broad and fundamental differences between his approach and those of the medical writers. In this limited sense, then, Descartes also has a *philosophy* of medicine.[8] We are right, then, to attend to Descartes medical views and to his relation to 17th century medicine. We are also right to suspect that attending to the conceptual resources of 17th century medicine will shed light on various aspects of Descartes's thought.

1.2 DESCARTES, HARVEY, AND FABRICIUS

As I conceive it, much of the value of this study lies in highlighting the *conceptual* connections and disconnections between the very different approaches to mechanizing the animal found in Fabricius and Harvey, on the one hand, and Descartes, on the other. Still, it is appropriate to gesture briefly at some of the *historical* interactions between these three figures, at the beginning of this study.

We know that Descartes read Harvey's *De motu cordis* and felt compelled to reference and engage Harvey's views in his discussion of the heart and circulation in *Discourse* Part V, in

[8] However, it seems to me that this philosophy of medicine is more an application to medicine of a general theory of the sciences and of proper method in pursuing them, than it is a second order philosophical reflection on the theory and practice of medicine taken on its own terms.

his *Description of the Human Body*, and *The Passions of the Soul*.[9] And Harvey discusses Descartes's views, in turn, in his *Second Letter to Riolan*. We also have reason to believe Descartes read at least Fabricius's works on embryology; he mentions Fabricius explicitly in a 1646 letter to Mersenne.[10]

William Harvey's connection with Fabricius is much more substantial than these limited interactions. Harvey was taught by Fabricius at Padua, and Fabricius is one of the signatories of his medical degree. More importantly, though, is Harvey's interaction with Fabricius's publications. In the *Praefatio* of his 1651 publication on animal generation, William Harvey famously wrote "But in chief, of all the *Ancients*, I follow *Aristotle*; and of the later Writers, *Hieronymus Fabricius ab Aquapendente*. Him [i.e., Aristotle] as my *General*, and This [i.e., Fabricius] as my *Guide*."[11] This is not mere lip service; much of the rest of this work is structured around critically examining the relevant views of Aristotle and Fabricius in light of Harvey's own research. However much Harvey meant his comment to be a particular claim about his *Exercitationes de Generatione Animalium*, the point has wider validity. Harvey's earlier work also clearly shows the influence of a sustained engagement with the texts of Aristotle and his own teacher at Padua. The three (very different) main sources we have for Harvey's early anatomical research reflect a general, critical appropriation of Fabricius's methods and views. In *De motu cordis*, Fabricius's influence is apparent. Fabricius's work on the "valves" in the veins appears in Chapter 13 and plays a prominent role in Harvey's argument for the circulation of the blood. In addition, Harvey refers to Fabricius's work on the organs of

[9] And, of course, in his correspondence with Vopiscus Plempius.
[10] AT IV 555. See Annie Bitbol-Hespériès's discussion in her "Cartesian Physiology" (Bitbol-Hespériès 2000). There is, of course, no reason to suspect that Fabricius (who died in 1619) was aware of Descartes.
[11] "Prae caeteris autem, *Aristotelem* ex antiquis; ex recentioribus verò Hieronymum *Fabricium ab Aquapendente*, sequor; illum, tanquam *Ducem*; hunc, ut *Praemonstratorem*." *EGA* (1651 Amsterdam), p. 36. Translation taken from William Harvey, *Anatomical Exercitations concerning the Generation of Living Creatures* (London 1653), Preface.

respiration in the *Prooemium* and says in, Chapter 1, that part of his motivation for working on the heart was that Fabricius did not publish on it. Harvey also frequently refers to Fabricius's published views in his *Prelectiones Anatomiae Universalis* and even more frequently in his notes on muscle anatomy. Harvey's sustained, careful reading of Fabricius is also evident from his copy of the posthumous collection of some of Fabricius's works, *Opera Physica Anatomica* (1625). This copy is held by the Lilly Library at Indiana University, Bloomington. In it we see marginalia and underlining in Harvey's hand sprinkled throughout the two embryological texts included in the collection. (Figure 1) At places, we find underlining and marginalia in three distinct pens (but in one hand), suggesting that Harvey read and reread the work multiple times.

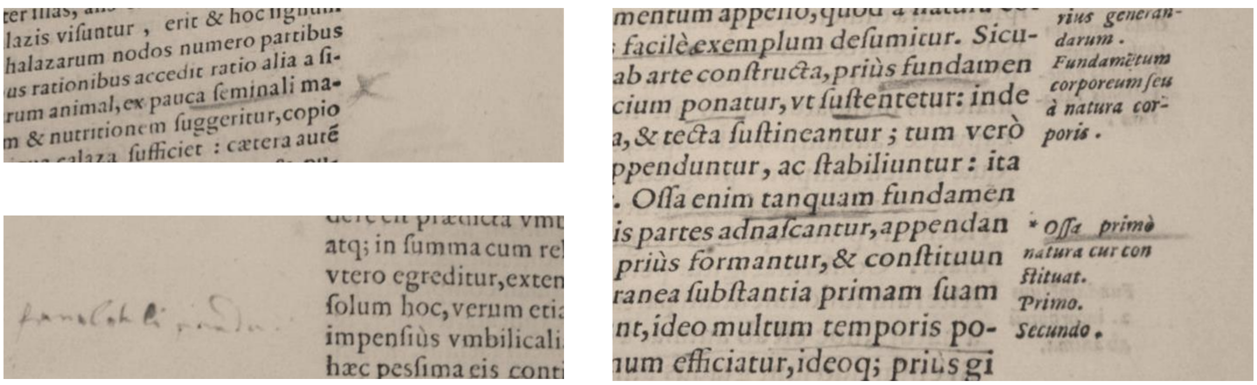

Figure 1. Examples of Harvey's marginalia and underlining in Fabricius, *Opera phyisca anatomica* (Padua 1625)

If we aim to understand Harvey's approach to anatomy, we must appreciate Fabricius's own project and Harvey's interaction with it.[12]

[12] Roger French (1994) and Andrew Cunningham (2006) both appreciate Fabricius's importance for understanding Harvey. Andrew Wear (1983), in his effort to place Harvey in a specifically anatomical and Galenic context, in contrast, chooses Andreas Laurentius as representative. This seems an odd choice, given the relative prominence in Harvey's work of references to Fabricius and scarcity of references to Laurentius. Perhaps under the influence of Cunningham's emphasis on the Aristotelian and natural philosophical aspects of Fabricius's anatomical project, Wear supposes that one has to look beyond Fabricius to find a distinct Galenic and anatomical influence on Harvey. This is unnecessary and unlikely. Fabricius is unquestionably an anatomist and deeply influenced by Galen. Harvey, too, bears an unmistakable Galenic mark, but there is no reason to think this reflects in some special way a non-Fabrician influence.

By tracing the role of mechanics, mechanism, and teleology in these three interconnected thinkers, this study makes (I hope) synergistic contributions to the history of philosophy, the history of science, and the history of medicine. To the history of medicine, I provide a careful, philosophically astute examination of Fabricius' philosophical anatomy—articulating the structure of its Galeno-Aristotelian teleological explanations and highlighting how Fabricius integrates mathematical mechanics into these explanations. This work on Fabricius, in turn, provides significant resources for examining William Harvey. My analysis of Harvey's anatomical project and his little known working notes on muscle anatomy and animal locomotion and of its relation to Fabricius's work sheds new light on the methods and explanatory aspirations reflected in Harvey's *De motu cordis*—often considered the important medical work of the 17th century.

Together, my work on Fabricius and Harvey contributes to the history of science, more generally, by adding to scholarship tracing the expanding importance of mathematical mechanics in the early 17th century—scholarship that has typically focused on the physical sciences, or, in medicine, on the later work of post-Cartesian thinkers. It also provides a striking example of the vitality and creativity of one strain of early modern Aristotelianism. Finally, by focusing on the medical tradition, I provide a fruitful contextualization of Descartes's physiology and a new interpretation of the place of teleology in his philosophy.

The multi-dimensional approach taken in this study is well-suited to the study of thinkers at a time when the already permeable disciplinary boundaries between philosophy, medicine, and the mathematical sciences were shifting significantly. Many early modern thinkers straddled disciplines, and developments in one often came via the importation of values and results from another. Although a welcome trend towards contextualist history of philosophy has greatly increased our understanding of the complexities the 17th century intellectual landscape, much work remains to be done, particularly in understanding developments in early modern medicine and their impact on this landscape. This study represents my first attempt to contribute to that work.

2.0 MECHANICS AND THE *QUAESTIONES MECHANICAE*

The seventeenth century is often said to be the century of the rise of mechanism. In order, however, to understand this claim it is important to distinguish at least two[13] different senses of 'mechanics'—both of which rose in prominence in the course of the 17th century: first, mathematical mechanics—particularly, as inspired by and given its orientation and place among the sciences (if not its most rigorous foundations and results[14]) by the Pseudo-Aristotelian *Quaestiones Mechanicae*; and second, micro-corpuscularian natural philosophies which came to be grouped together by Sir Robert Boyle and by many later historians under the head of the "mechanical philosophy." The first is relevant for our purposes because it is the kind of mechanics integrated into the anatomical projects of Fabricius and Harvey.[15] The second is relevant because Descartes's philosophy has been seen as a paradigmatic case of the mechanical philosophy, from the moment Boyle coined the term. In addition, Fabricius and (more so) Harvey are aware and critical of the rising prominence of such corpuscularian philosophies. Harvey seems to see them as instances of the kind of materialist theories that Aristotle and Galen

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[13] I return to these and several additional senses of "mechanics" below (4.4, p. 168ff).

[14] Another sense in which we might see a rise of mechanics in this period relates to the advances in mathematical mechanics tied to the rediscovery, mastery and expansion of resources from other ancient texts on mathematical mechanics—particularly those of Archimedes. I am not concerned here with these much studied conceptual developments and their relation to Galileo's work. My concern is only with the rise to prominence of mathematical mechanics understood as a subordinate science. In other words, I am interested in the way mechanics comes to be explicitly understood as a *science* of machines and not merely one of the "sellularian" arts (mentioned below).

[15] Both Fabricius and Harvey explicitly reference the *Quaestiones Mechanicae*.

rightly rejected.[16] Both of these senses of mechanics, in turn, must be distinguished from 'mechanics' in the sense of the mechanical or sellularian (manual) arts—the occupations not of philosophers but of (e.g.) the 'rude mechanicals' of Shakespeare's' *A Midsummer Night's Dream*. Keeping these three senses of mechanism distinct will greatly aid our ability to avoid confusion in our account of early 17th century approaches to 'mechanizing' the animal—and our account of their historical and conceptual interrelations.

In this chapter,[17] I provide a detailed account of mechanics in the first sense—*Quaestiones Mechanicae* inspired mathematical mechanics—in order, especially to distinguish it from the other senses of mechanics. I primarily examine the nature of mechanics (in this sense) as an Aristotelian subordinate mathematical science. To this end, I provide a general account of the Aristotelian idea of a subordinate science and trace how mechanics counted as one. This will include showing how the strain of mathematical mechanics inspired by the *QM* was grounded in circular motion around a center, typically the *hipomoclione*[18] or fulcrum of a lever. Secondarily, and more briefly, I examine the extent to which mechanics was conceived of as restricted to man-made artifacts at service of human interests.

This discussion will help us to understand the extent to which this tradition needed to be revised in order to justify the application of mechanics to animals (as opposed to human artifacts) and to their *natural* animal motion (progression). This issue is complicated by the fact that the Aristotelian tradition sees progression (a *natural* motion of the animal) to be the result of the pushing and pulling (and so in some sense *violent* motion) of its parts. In addition, we will

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[16] In the case of Aristotle, these were the philosophies of *phusikoi* like Empedocles and Democritus. For Galen, in addition to pre-Socratic materialism and their Hellenistic counterparts, the physiology of Erasistratus also exemplified this approach.
[17] Much of the material in this chapter appears in my recently published article on the subordinate sciences in Aristotle (Distelzweig 2012).
[18] As Fabricius and Harvey will transliterate the Greek.

see that the analysis of circular motion around a fixed fulcrum in *QM* will interact with the principles of animal motion expounded in Aristotle's *De incessu animalium* and *De motu animalium*.

The *QM* is constituted of a preface which discusses the scope and character of mechanics, and 35 separate questions or problems. The problems vary from questions regarding the balance, lever and pulley, to treatments of features of ships, forceps, nutcrackers, shore pebbles, projectiles and—interestingly—the act of standing up from a seated position (an animal motion). The preface delimits mechanics as the art that aids us in overcoming the difficulties associated with accomplishing tasks for our benefit, tasks that are *praeter naturam*, particularly in the sense that they involve moving greater weights with smaller forces. It also says mechanics shares something with both natural and mathematical theorizing. The "how" of mechanics is made clear by mathematics, while the "about which" or "with respect to what" is made clear by natural philosophy. This seems to mean that the objects and devices considered by mechanics are natural, that is, made of matter and having natural motions, but the causes of the motions involved in achieving our tasks are made clear by mathematical considerations. It is this characterization of mechanics as sharing in both natural and mathematical science that marks it off as an Aristotelian subordinate science and connects it with a number of passages in the Aristotelian corpus that treat these sciences.

In a number of places in the corpus Aristotle discusses the disciplines that came to be called the subordinate sciences: astronomy, harmonics, optics and mechanics. Aristotle comes to these disciplines as (to various degrees) already recognizable and developed sciences.[19] In

[19] Richard McKirahan (1978, 198) stresses this point.

Physics II.2 he calls them "the more natural branches of mathematics."[20] They are mathematical disciplines which treat, however, a particular domain of the natural world. Aristotle finds them of special interest for a number of reasons. First, their character, thinks Aristotle, provides strong evidence for his account of mathematics, particularly in contrast to that of the Platonists.[21] They are also of interest to Aristotle because they are existent disciplines which seem to straddle natural and mathematical science. As such, they require discussion in his general treatment of science.

Aristotle characterizes these sciences as being "under" (or "subordinate" to) other mathematical sciences, e.g. harmonics under arithmetic. As such, these subordinate sciences allow for exceptions to certain general restrictions on demonstrative science and introduce a disciplinary divide between knowledge of the facts exhibited in their natural domain, and the proper demonstrative knowledge of the reason why these facts hold.[22] In sections 2.2 and 2.3, I argue that for Aristotle:

1. The subordinate sciences pick out their proper subject by a double *qua*-operator, one natural and one mathematical (e.g., optics treats its objects *qua* sight, *qua* line).
2. The resulting subordination relation is best compared neither to species-genus nor matter-form relations, but to that of subject to (proper) attribute.
3. These sciences consider only the mathematical attributes exhibited by their natural domains.

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[20] Physics II.2 194a7-9; here he actually refers only to the first three. (All quotations are taken from *The Complete Works of Aristotle*, edited by Jonathan Barnes (Aristotle, The Complete Works of Aristotle 1984) except those from *Posterior Analytics* which are taken from Jonathan Barnes's Clarendon Edition (Aristotle 2002). I have adapted the translation in a few places, as noted.)
[21] See *Physics* II.2 and *Metaphysics* XIII.3.
[22] See *Posterior Analytics* I.7,9,13.

4. They provide demonstrations of the majority of these attributes from more fundamental and explanatory mathematical attributes proper to their natural domains.

I will draw on Aristotle's methodological discussions of these sciences found especially in *Posterior Analytics* I, but also in *Physics* II.2 and in his discussion of mathematics in the *Metaphysics*. I will also draw on Aristotle use of optics to explain features of the rainbow in *Meteorology* III. I will then point out, in section 2.4, how this account sheds light on Aristotle's practice in *De Caelo*. There he undertakes a *natural* investigation of the heavens distinct from but closely related to astronomical (and so *mathematical*) investigations of the same. This will provide a helpful example with which to compare mechanics as it relates to natural philosophical discussions of motion, including animal motion (section 2.5). First (in section 2.1), I must briefly treat Aristotle's account of mathematics and demonstrative science, in general.

2.1 MATHEMATICS AND DEMONSTRATIVE SCIENCE IN ARISTOTLE

To understand Aristotle's philosophy of mathematics, it is worthwhile to sketch what he takes to be its two primary competitors: the Platonic and Pythagorean accounts. The Platonic account, Aristotle suggests, understands the objects of mathematics to be separately existing objects distinct from the natural, sensible phenomena. These ideal objects (the so-called intermediates) have only those features described and demonstrated in mathematics. Aristotle suggests that this view is motivated by a concern to ensure that mathematics is true. The line treated by geometry is a length without breadth; no natural bodies are lengths without breadth; so geometric lines must be ideal objects. If such ideal objects did not exist, geometry would be false.[23]

The Pythagoreans, in contrast, are characterized by Aristotle as believing that mathematical objects (particularly number) do exist in the natural world; in fact, the *elements* of the natural world are mathematical. Aristotle suggests that the motivation behind this view is largely derived from an appreciation that numerical (and other mathematical) attributes are exhibited by natural things; the musical scale and the heavens are two prominent examples.[24] Aristotle thinks neither view is correct, though both highlight important features of mathematics to be accounted for: mathematics seems to treat idealized objects with only certain attributes, and natural objects exhibit these attributes. Aristotle's treatment of mathematics reflects his general view of the structure of demonstrative science while focusing on accounting for these two important features.

Aristotle accounts for these features by employing what Jonathan Lear (1982) has called a "*qua*-operator" or "predicate filter." Roughly, this *qua*-operator is used to distinguish an extensional consideration of a domain from an intensional one. For example, the extension of the term "man" can be thought of as the set of all particular human beings. These human beings display a host of disparate attributes; they have various complexions and kinds of knowledge, some are male and some female, some healthy and some sick, etc. If we consider men simply as an extensional set of individuals, the host of attributes encountered is beyond comprehension. However, for Aristotle, this is not how we come to scientific understanding of the world. We do not simply latch onto a set of particulars. We always consider individuals with respect to having some particular character. We may consider the set of men as things that can be healthy or sick,

[23] See, e.g., *Metaphysics* XIV.3 1090a35-b1.
[24] See, e.g., *Metaphysics* XIV.3 1090a20-1090a30.

as being men, or as being solids. In each case, we consider only those attributes that have a special connection to them having the character under consideration.[25]

In mathematics, as in all sciences, our knowledge of a domain is rooted in understanding the necessary causal connections between objects being of a certain kind and their various attributes. Only a finite set of attributes will have such strong connections to things in virtue of being of a certain kind. Only these attributes are considered by a scientist who takes that kind of thing as his object:

> And it is true to say of the other sciences too, without qualification, that they deal with such and such a subject—not with what is accidental to it (e.g. not with the white, if the white thing is healthy, and the science has the healthy as its subject), but with that which is the subject of each science—with the healthy if it treats its object *qua* healthy, with man if *qua* man. (*Metaphysics* XIII.3 1077b34-1078a2)

The science of the healthy considers man, but it provides understanding only of those attributes of man which are causally connected to health. It does not provide understanding of the hair color or knowledge of various men, nor (Aristotle's example) the whiteness of a man—these are accidentally connected to man being healthy. However, this does not imply that the science of the healthy requires the existence of men who have *only* those attributes with which it is concerned; nor does saying there are healthy things imply that there are entities with only those attributes—there are no such bizarre entities.

The mathematical sciences, like all sciences, treat their subjects *qua* having a particular character. Geometry treats of things *qua* magnitude, in one, two or three dimensions, providing understanding of those attributes of objects which are causally connected to them and each other

[25] Aristotle characterizes this connection especially in *Posterior Analytics* I.2.

because they have magnitude. Arithmetic treats its objects as being indivisible unities and collections of indivisible unities; it only provides understanding of those attributes which are causally connected to the objects inasmuch as they are such collections. This is analogous to the way medicine provides understanding only of the attributes of objects so connected to health.

Now these three "pockets" of interconnected attributes (geometric, arithmetic, and medical) display a certain mutual independence. Regardless of whether the object is the kind of thing that can be healthy, inasmuch as it *is* the kind of thing that has *magnitude*, geometry provides understanding of its geometric attributes. Thus, we can treat each of them separately and generally, ignoring other disconnected attributes. In fact, this is the *appropriate* way to come to scientific understanding.

> Each question will be best investigated in this way—by supposing separate what is not separate, as the arithmetician and the geometer do. For a man *qua* man is one indivisible thing; and the arithmetician supposed one indivisible thing, and then considered whether any attribute belongs to a man *qua* indivisible. But the geometer treats him neither *qua* man nor *qua* indivisible, but as a solid. For evidently the properties which would have belonged to him even if perchance he had not been indivisible, can belong to him apart from these attributes. Thus, then, geometers speak correctly; they talk about existing things, and their subjects do exist. (*Metaphysics* XIII.3 1078a22-30)

Mathematics is not problematic in the way it treats its objects with reference only to certain interconnected features; it is actually a clear example of a method common to all the sciences.

Geometers suppose purely geometric entities and arithmeticians purely numerical ones; this just means they treat things only inasmuch as they exhibit geometric or arithmetic attributes.[26]

Before turning to the subordinate sciences, it will be necessary to examine in more detail one more implication of Aristotle's conception of science: scientific demonstrations must be at the right level of generality. If we have a demonstration that establishes that isosceles triangles[27] have interior angles equal to two right angles, we do not have proper demonstrative knowledge. This is because isosceles triangles are not the proper subject of the attribute established. *All* triangles have their angles equal to two right angles, and it is *qua triangle*, not *qua* isosceles, that triangles have the feature. It is not until we understand that they have this feature *qua* triangle, having a demonstration of the feature from the definition of triangle and appropriate geometric principles, that we have a genuine demonstration. Similarly, if we have a demonstration that all *bronze* triangles have the feature, we would not have proper knowledge. However, if we wish to understand the *ductility* of the bronze triangles, we will need to understand that the ductility holds in virtue of the cause of that ductility. Thus, we do not understand it properly if we take into account its triangularity. *All* bronze is ductile, not just bronze *triangles*. Indeed, our understanding will not be proper unless we understand the ductility in terms of the subject's being (e.g.) metal. From this understanding we can establish that bronze has ductility by noting it is a metal. Similarly, we can establish that isosceles triangles have interior angles equal two right angles by noting they are triangles.[28] This way of establishing truths that are a part of genuinely

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[26]Here I follow James Lennox (1986, 36-37)—who also employs Lear's analysis in his account of subordinate science—in departing from Lear (1982) who takes this to mean they posit "useful fictions." For different views, see the interpretations of Edward Hussey (1991a) who understands this in terms of "representative objects," and Mueller (1979) who wishes to see more of a distinction between the "*qua*" language and "separate" language.

[27] This example is used by Aristotle in *Posterior Analytics* I.4 and 5.

[28] Lennox (1987) has highlighted this kind of "demonstration" and distinguished it clearly from universal demonstrations (at the appropriate level of generality). The first he calls A-type demonstration and the second B-

demonstrated truths is noted by Aristotle.[29] However, the reason why isosceles triangles have such interior angles, and bronze has ductility, is at the level of triangle and metal, respectively.

We can now turn to the more natural of mathematical sciences. We will see that because these sciences treat the mathematical attributes of natural domains, they sit at the intersection of other sciences and so exhibit certain unique features.

2.2 THE MORE NATURAL OF THE MATHEMATICAL SCIENCES

Aristotle thinks the subordinate sciences are *mathematical* sciences that stand in a special relation to certain natural domains. Before exploring Aristotle's understanding of its repercussions, I will first establish that Aristotle did in fact understand them to be mathematical. This is worthwhile because there has been some confusion on this point.[30] Astronomy is the easiest of the subordinate sciences to establish as mathematical. In addition to *Physics* II.2, Aristotle counts it a mathematical science in numerous places in the *Metaphysics*. For example, in his discussion of the nature of a putative universal science of being *qua* being, Aristotle refers to astronomy as one of the mathematical sciences, together with geometry and universal mathematics.

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type. He makes this distinction in order to stress Aristotle's insistence on explanations at the appropriate level of generality.

[29] See *Posterior Analytics* II.3 91a1-6.

[30] For instance, in his commentary Barnes claims Aristotle thinks these are the more mathematical of the *natural* sciences (Aristotle 2002, 159). Similarly, Ross in his commentary on the *Physics* (Aristotle 1960) claims that, in contrast to the view common to Aristotle's contemporaries, Aristotle insists that they are branches of natural science. Interestingly, the Latin version of the *Physics* used by Aquinas and others mistranslates the key *Physics* II.2 passage, rendering it as "the sciences which are more physical than mathematical." See Aquinas's commentary on the *Physics* , Book II, Lecture 3 (Thomas Aquinas, Commentary on Aristotle's Physics 1963). Though this mistranslation forces Aquinas to identify a way in which the subordinate sciences are more physical than mathematical, he still insists that astronomy is a part of mathematics. Mueller (2006) and W. R. Laird (1983, 6-7) discuss this issue.

> One might indeed raise the question whether first philosophy is universal, or deals with one genus, i.e. some one kind of being; for not even the mathematical sciences are all alike in this respect,—geometry and astronomy deal with a certain particular kind of thing, while universal mathematics applies alike to all.[31] (*Metaphysics* VI.1 1026a24-27)

Furthermore, in *De Caelo* II.10 and 14 Aristotle refers to those who participate in and contribute to astronomy as "mathematicians."[32] In his aporetic remarks regarding the objects of the mathematical sciences in *Metaphysics* III.2, Aristotle discusses astronomy, optics and harmonics, precisely because they are examples of mathematical sciences.[33] Finally, several passages in *Posterior Analytics* refer to these along with mechanics as mathematical sciences.[34]

Though mathematical, the subordinate sciences are not like geometry and arithmetic, because these more natural of the mathematical sciences have as their subjects particular natural domains. If they were not about these natural domains, they would not be the sciences that they are.[35] The aporetic passage in *Metaphysics* III.2 mentioned above argues against the Platonic account of mathematical intermediates by insisting that astronomy, optics and harmonics have as their subjects the sensible heavens, sight and voice.

> [S]o that since astronomy is one of these mathematical sciences there will also be a heaven besides the sensible heaven, and a sun and a moon (and so with the other

[31] See also *Metaphysics* I.8 989b30-34 and XII.8 1073b2-7. Although there are interpretive questions on the point, Aristotle may mean by universal mathematics (e.g.) a science that treats number and continuous quantity in common—or he may simply mean the mathematics of continuous quantity, in general (as opposed to treating only lines).

[32] See *De Caelo* II.10 291a29-291b10; II.14 297a2-6 and 98a15-20. I return to these below.

[33] See *Metaphysics* III.2 997b14-24; see also the cognate passage at *Metaphysics* XIII.2 1077a1-8. I return to this passage below.

[34] Perhaps the clearest is I.14 79a18-20 (optics). However, I.13 78b35-79a3 (optics and harmonics) and 79a10-16 (optics) both imply that these are mathematical and sciences. Mechanics is treated as similar to optics, harmonics and astronomy at *Posterior Analytics* I.13 78b35-79a3 and *Metaphysics* XIII.3 1078a16.

[35] For an interesting comparison, see Socrates' discussion of "true astronomy" (which seems not to be about the sensible heavens) in *Republic* VII 528e-530d (especially 530c-"we will let be the things in the heavens, if we are to have a part in the true science of astronomy…" (Translation is from *The Collected Dialogues of Plato* edited by E. Hamilton and H. Cairns (Plato 1996)).

heavenly bodies) besides the sensible ones. Yet how are we to believe these things? It is not reasonable even to suppose these bodies immovable, but to suppose their moving is quite impossible. And similarly with the things of which optics and mathematical harmonics treat. For these also cannot exist apart from the sensible things, for the same reasons. For if there are sensible things and sensations intermediate between Form and individual, evidently there will also be animals intermediate between animals-in-themselves and the perishable animals.[36] (*Metaphysics* III.2 997b14-24)

Aristotle's argument here seems to work as follows:

(1) Astronomy, harmonics and optics are mathematical sciences.

(2) If the objects of mathematical sciences are Platonic intermediates, then the objects of these sciences are Platonic intermediates.

(3) That the objects of these sciences are Platonic intermediates is reducible to absurdity; their objects must be the concrete sensible heavens, sight and voice.

(4) Therefore, mathematical objects are not Platonic intermediates.

Physics II.2 can be understood to be making a similar point. Finally, in *Posterior Analytics* I.27, in a discussion of what makes a science more or less accurate, Aristotle says that harmonics, unlike arithmetic, is "said of an underlying subject." (*Posterior Analytics* I.27 87a33) That is, harmonics is about voice. All these sciences, then, are mathematical and yet pick out a particular natural domain.

The subordinate sciences lie at the intersection of the mathematical and the physical. The subjects of astronomy and the other sciences under consideration are picked out in terms of natural differentiae—imperishable bodies up there, perhaps; the spatial phenomena of sight; or

[36]See also the cognate passage at *Metaphysics* XIII.2 1077a1-8.

the pitch, melody and articulation in sound.[37] At the same time they consider only the *mathematical* attributes exhibited by the natural domain so delimited. Aristotle articulates this peculiar fact about these sciences in two reciprocal ways. In *Physics* II.2 he characterizes optics as the "converse of geometry":

> These are in a way the converse of geometry. While geometry investigates natural lines but not *qua* natural, optics investigates mathematical lines, but *qua* natural, not *qua* mathematical. (*Physics* II.2 194a9-11)

These sciences, that is, study the mathematical attributes that are *per se* connected with line or number, but not in a general and abstract manner, not *qua* mathematical, but rather inasmuch as they are attributes of the natural domain of the heavens, sight and voice.

In *Metaphysics* XIII.3 Aristotle says that these sciences are more precise than others because they consider only certain features of their objects.

> The same account may be given of harmonics and optics; for neither considers its objects *qua* sight or *qua* voice, but *qua* lines and numbers; but the latter are attributes proper to the former. And mechanics too proceeds in the same way. (*Metaphysics* XIII.3 1078a13-16)

These sciences do *not* consider sight and voice simply *qua* sight and voice. Such a consideration would require a treatment of the faculties of vision and hearing, the causes of sight and voice, their medium, etc. Optics and harmonics treat their subjects only inasmuch as they exhibit mathematical attributes, that is, *qua* line and number.[38] Astronomy also considers its subject in

[37] For this characterization of "voice" (φωνὴ) see *De Anima* II.8 420b5-8.
[38] Julia Annas suggests Aristotle is here saying that we must "abstract from the individual deviations of actual objects," and then presents a problem for this account (Annas 1976, 150). However, there is no indication in this text that Aristotle thinks that, e.g., the relevant optical phenomena are only imperfectly linear. In fact, Aristotle's

this restricted way: it does not treat the heavens in their complete natural context, not *qua* natural bodies, but only in terms of magnitude and simple motion.

> Thus a science which abstracts from the magnitude of things is more precise than one which takes it into account; and a science is most precise if it abstracts from movement, but if it takes account of movement, it is most precise if it deals with the primary movement, for this is the simplest; and of this again uniform movement is the simplest form.[39] (*Metaphysics* XIII.3 1078a10-13)

Astronomy is the most precise[40] of the sciences considering motion because it considers its objects as magnitudes and according to "the primary movement" only—that is, local motion only (which is the primary form of change) and not all local motion but the primary local motion—the uniform circular movement of primary body (i.e., of the heavens).

These sciences treat their domain under a double *qua*-operator. Harmonics treats its subject *qua* voice, *qua* number; optics treats its subject *qua* sight, *qua* line; astronomy *qua* the heavens, *qua* magnitude-and-primary-motion.[41] This double aspect of the subjects of these sciences is what allows Aristotle to say that they treat mathematical objects *qua* natural (*Physics* II.2) and that they treat natural objects *qua* mathematical (*Metaphysics* XIII.3). It also leads Aristotle to speak of them as sciences "under" geometry or arithmetic. Finally, this double aspect is responsible for two interrelated features of these sciences. They allow kind-crossing in demonstrations. They also introduce a disciplinary division between the fact and the reason why.

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understanding of the subordinate sciences lends further support to Lear's (1982) argument, against Annas, that Aristotle thought mathematical attributes are (sometimes) perfectly exemplified in nature.

[39] Although astronomy is not explicitly mentioned, I take Aristotle here to rank arithmetic, geometry and astronomy. See Ross's commentary on the *Metaphysics* on this point (Aristotle 1997, 417).

[40] For this notion of precision, see *Posterior Analytics* I.27 87a34-37.

[41] In his commentary, Simplicius provides a similar characterization, saying it treats the heavens "as the sort of things that are shaped and moving bodies." (Simplicius 1997, 46)

It is appropriate to turn our attention to these points and Aristotle's discussion of them in *Posterior Analytics*.

2.3 SUBORDINATE SCIENCES AND THEIR PECULIARITIES

Aristotle characterizes these sciences as being related to another mathematical science as one under the other (θάτερον ὑπὸ θάτερον)—for example, optics is under geometry. This language is found in several key passages in *Posterior Analytics*.[42] It is worthwhile to clarify just what the subordination relation between these sciences is for Aristotle. As discussed above, geometry and arithmetic have as their subject magnitude and number, considered in abstraction from any particular natural bodies. The subject of the subordinate mathematical sciences is not so independent of an underlying subject. These sciences pick out their object with a double *qua*-operator. The result is a kind of subset of the higher science's domain. This may suggest that the subject of the lower science is related to the higher as species to genus.[43] However, this subset is not distinguished according to the differentiae of the higher mathematical science, but rather of natural science. In contrast, planar geometry is a subset that *is* delimited according to mathematical differentiae, and so can be thought of as a *species* of geometry. Because the genus

[42] Specifically, *Posterior Analytics* I. 7 75b14-17; I.9 76a-16; I.13 79a10-17, 78b36-38.

[43] McKirahan so characterizes it: "The relation between quantity in general and spatial magnitude is the same as the relation between spatial magnitude and the subject genus of optics" (1992, 76). R. J. Hankinson also fails to clearly distinguish between species-genus and subject-attribute relations, blurring the relationship between universal mathematics and geometry on the one hand, and geometry and optics on the other (Hankinson, Aristotle on Kind Crossing 2005, 43-47). The species-genus interpretation was also present in some medieval commentaries (Laird 1983). In his commentary on the *Posterior Analytics,* Barnes considers the possibility that the relation is species to genus; he rejects it, saying only that it would "trivialize the notion of a subordinate science" (Aristotle 2002, 160). Here, following Aquinas (Thomas Aquinas 2007) in his commentary on the *Posterior Analytics* (Book 1, Lecture 25), I provide reasons to reject the species-genus interpretation more specific than Barnes's offhand remark. However, below I will also reject *Aquinas's* matter-form interpretation.

of optics has been delimited via natural attributes, all the mathematical differentiae of geometry are present in optics (one could think of planar optics as treating only optical situations involving two dimensions). The subordinate sciences are not related to the higher sciences as species to genus.

The relation of one under the other is most helpfully compared to that of subject to attribute. Aristotle stresses that a difference between the two sciences is that unlike the higher science, the lower *is* "said of an underlying subject."[44] Now this cannot mean that voice and sight, or the heavens are said of an underlying subject. They are not *said of* a subject; they *are* the underlying subject.[45] Aristotle means rather that the mathematical attributes are said of an underlying subject—voice, sight or the heavens. The interconnected mathematical attributes constituting the kind or subject of the higher science become the attributes predicated of the subject of the lower science. In this way the sciences are one under the other. It should be noted that this interpretation is different from that found in Aquinas's commentary on the *Posterior Analytics* (Thomas Aquinas 2007). Aquinas interprets the relation as one of matter to form.[46] The advantage of speaking of subject and attribute instead of matter and form is that it keeps the discussion independent of Aristotle's account of matter and form, potentiality and actuality, change, etc.—all of which are noticeably absent from *Posterior Analytics*. "Underlying subject" (ὑποκειμένου) unlike "matter" (ὕλη) is a part of the vocabulary of *Posterior Analytics.*[47]

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[44] For the higher science, see *Posterior Analytics* I.13 79a7-10. For the lower, see *Posterior Analytics* I.27 87a32-34.
[45] As James Lennox has pointed out to me, this interpretation requires taking Aristotle to be using "underlying subject" in an extended sense. Sight and voice are *not* underlying subjects in the primary sense of not being in another subject. That is, unlike animals, they do not exist independently. I think Aristotle's statement in the *Metaphysics* that line and number are proper attributes of sight and voice (*Metaphysics* XIII.3 1078a13-16) provides support for my interpretation.
[46] In his commentary, Ross suggests something similar (Aristotle 1965, 63).
[47] "Form" (εἶδος) does appear in *Posterior Analytics* at 79a6-9. However, there "form" is not related to "matter," potentiality, etc. It is connected only with not being said of an underlying subject: "For mathematics is concerned with forms (εἴδη): its objects are not said of any underlying subject (ὑποκειμένου)." Lennox (2008) argues that in

Let us examine, now, the two further features of the subordinate sciences: (1) they allow for demonstrations from the higher mathematical science to transfer to them; (2) they introduce a disciplinary divergence of the fact and the reason why.

The first of these features is discussed by Aristotle in *Posterior Analytics* I.7, 9 and 12. It is presented as an exception to a general principle in his account of the sciences. Because sciences display the kind of independence emphasized above and consist of necessary predications at the right level of generality, Aristotle argues, demonstrations, in general, cannot transfer from one science to another. This is because only terms in one kind can be predicated of each other in this way. If a demonstration included terms belonging to different kinds, at least one of the predications in the demonstration would not be the appropriate kind of predication: "For the extremes and the middle terms must come from the same kind, since if they do not hold in themselves, they will be incidentals." (*Posterior Analytics* I.7 75b11-12) Aristotle puts this point another way by saying that the demonstrations (like the sciences of which they are a part) include "the kind with which the demonstrations are concerned." (*Posterior Analytics* I.7 75b7) For this reason, "you cannot prove anything by crossing from another kind—e.g. something geometrical by arithmetic." (*Posterior Analytics* I.7 75a38-39)

Aristotle gives several examples of failed or inappropriate attempts to prove something in one science by the principles of another—that is, failed attempts at "kind crossing." One cannot:

(1) Prove by geometry that "there is a single science of contraries."

(2) Prove by geometry "that two cubes make a cube."

(3) Prove by geometry "anything that holds of lines not as lines and as depending on the principles proper to them—e.g. whether straight lines are the most beautiful of lines, or

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Physics II.2 Aristotle is developing just what "form" is in the context of natural science—something very different from "form" as understood here.

whether they are contrarily related to curved lines; for these things hold of lines not in virtue of their proper kind but rather in virtue of something common."

(4) Prove the squaring of the circle in the way Bryson did. "Such arguments prove in virtue of a common feature which will also hold of something else; and so the arguments also attach to other items which are not of a kind with them. Hence you do not understand the item as such but only incidentally—otherwise the demonstration would not attach to another kind as well."[48]

All of these fail to accomplish their goal. The second is an attempt to prove a theorem in arithmetic—that the product of two cubes numbers is itself a cube number (Heath 1949, 46). The first and third are examples of attempting to prove by geometry certain truths that involve a different kind of principle—metaphysical or aesthetic—and that hold of a much wider set of objects, considering them in a very different way. The last example is difficult to evaluate because we know very little about Bryson's proof.[49] Suffice it to note that Aristotle's concern here is similar to that expressed in (3): that it used common principles. This suggests that it depended on principles that were at least as general as universal mathematics. If this is so, he proved something of a much wider scope that is true of the circle not because it is a circle, but only incidentally—if he proved anything at all. The subordinate sciences, however, are presented as an exception to this prohibition.

> But a demonstration does not attach to another kind—except that, as I have said, geometrical demonstrations attach to mechanical or optical demonstrations, and arithmetical demonstrations to harmonical. (*Posterior Analytics* I.9, 76a22-25)

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[48] For the first three examples see *Posterior Analytics* I.7 75b13-21; for the fourth, see *Posterior Analytics* I.9 75b40-76a4.

[49] Heath discusses the evidence regarding Bryson's proof (Heath 1949, 47-50).

This exception is closely connected to the sciences being related as one under another. In I.7 he identifies the exceptions as precisely those so related.

> Nor can one prove by any other science what pertains to a different one, except as are so related to one another that the one falls under the other—e.g. the optical facts with respect to geometry, and the harmonical facts with respect to arithmetic.[50] (*Posterior Analytics* I. 7: 75b14-17)

He also characterizes these cases as ones in which the kinds of the two sciences are the same in some respect (*Posterior Analytics* I.7 75b9-10) and their principles share a common feature (*Posterior Analytics* I.9 76a8-16).

This suggests the following picture. The subjects of the higher mathematical science and the lower are different in kind. However, they are similar in some respect—they have a common feature. That the kinds are different can be understood from our discussion of the fact that the subordinate sciences are said of an underlying subject; that is, they have natural bodies or processes as their subject. In contrast, the kind of the higher mathematical sciences is not the sensible heavens, nor sight, nor voice. Its kind is magnitude treated as a "form"—i.e., as not said of some underlying subject. However, these two kinds are clearly the same in some respect. Both geometrical objects (the principles of geometry) and optical processes (the principles of optics) exhibit magnitude. Because they both treat magnitude (one *simpliciter* and as a "form", one as exhibited by sight) the interconnections between terms that constitute the demonstrations in the higher science can be transferred to the objects of the lower.

However, this transference is only legitimate because of the relation between these two sciences and reflects the final peculiarity of the subordinate sciences mentioned by Aristotle: the

[50] Translation adapted. Barnes (Aristotle 2002) translates τὰ ὀπτικὰ and τὰ ἁρμονικὰ as "optics" and "harmonics"; but these are neuter plurals and so likely refer to the facts proved, not the sciences themselves.

disciplinary divergence of the fact (τὸ ὅτι) and the reason why (τὸ διότι). This becomes clear by looking more carefully at the I.9 comparison of this legitimate transfer and Bryson's illicit proof. As mentioned above, Bryson's proof is rejected because it invoked principles broader than geometry, it proved according to some "common feature." However, this seems to be just what Aristotle allows in his treatment of the subordinate sciences:

> Otherwise, it will be like proving something in harmonics by arithmetic. Things of this sort [facts in harmonics] are indeed proved in the same way [as Bryson's proof—that is, according to something common and applicable to another kind], but there is a difference: the fact [the conclusion] is of one science (for the underlying kind [the subject of the conclusion] is different), while the reason [the middle term] is of the higher science which is concerned with the attributes which hold of it [the middle term] in itself. Hence from this consideration too it is clear that you cannot demonstrate anything simpliciter except from its own principles. But the principles of these sciences have a common feature.[51] (*Posterior Analytics* I.9 76a5-16)

The difference Aristotle notes between Bryson's proof and those in harmonics is that in the latter the fact belongs to one science while the reason why belongs to the higher science. This, presumably, is not so in Bryson's case. The fact and the reason why of the squaring of the circle, Aristotle seems to suggest, belong to geometry. Thus, the reason why must be demonstrated within geometry, not in terms of some higher common feature. This is the difference between the two cases.

Aristotle elaborates on this disciplinary divergence of the fact and the reason why in I.13. Here he makes it clear that the facts of harmonics and the other subordinate sciences are

[51] The words in brackets are my interpretive clarifications.

established by observation and that the fact is treated by the lower science and the reason why by the higher.

> Here it is for the observers to know the fact and for the mathematical scientists to know the reason why. The latter possess demonstrations which give the explanations, and often they do not know the fact—just as people who study universals often do not know some of the particulars through lack of observation. (*Posterior Analytics* I.13 79a1-79a7)

The scientist who takes optics or harmonics as an area of study establishes through sense that the phenomena exhibit a wide range of mathematical attributes.[52] The geometer and arithmetician do not know that the optical and harmonical phenomena exhibit these particular attributes (at least not *qua* geometer or arithmetician): the facts belong to the lower science. However, when these observers turn from establishing these facts to seeking an explanation, they find that the mathematical attributes exhibited are interrelated in mathematical ways. Certain of the discovered mathematical features explain other of their mathematical features. To understand these causal relations between the various mathematical attributes displayed, they must turn to mathematics.

Since the causal relations to be explained hold between *mathematical* attributes; it is to be expected that these relations will be explained mathematically. The demonstrations connecting these attributes will be the demonstrations of geometry or arithmetic, the "higher science which is concerned with the attributes which hold of it [the mathematical attribute exhibited by the natural domain] in itself." (*Posterior Analytics* I.9 76a12-13) This is because the explanatory connections between the attributes do not depend on them being predicated of (e.g.) voice or sight: the reason why of these attributes belongs to the higher science. Thus, with respect to these

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[52] See, also, *Prior Analytics*. I.30 46a17-21; *Parts of Animals* I.1 639b7-10.

explanatory connections, the attributes can be treated in abstraction from the underlying subject (as "forms"). In this way, the subordinate sciences "make use of forms" though their subject differs in essence (*Posterior Analytics* I.13 79a7), i.e., the underlying kind is different (*Posterior Analytics* I.9 76a12) from those of geometry and arithmetic.

A brief description of an example will make this clear. In *Meteorology* III Aristotle provides an explanation of certain meteorological phenomena that are all reflections: halos, mock suns, rods and rainbows. He provides the most involved treatment of rainbows. Various aspects of the rainbow are explained in various ways. When he seeks to give the reason why the rainbow always has the shape of a segment of a circle, never greater than a semi-circle, his treatment takes a decidedly geometric turn, providing a careful geometric proof.[53] The proof starts with the eye, sun and clouds standing in a certain geometric configuration, and certain geometrically expressed principles governing sight (i.e., principles of geometric optics), and concludes that the resulting rainbow will be circular and will always be cut by the horizon such that at most half of it will be visible. It is carried out using only mathematical terms—lines, segments, angles, ratios, etc.—and without any mention of the natural underlying subject of these terms. It makes use of forms. However, at the conclusion of the proof the lines and points are identified with the natural underlying subjects. Thus, certain mathematical attributes known to be exhibited by a natural phenomenon are shown to be causally derived from certain other mathematical attributes also known to be exhibited by the phenomenon.[54] It should be noted that the demonstration of this feature of the rainbow will only be at the correct level of generality if taken as a purely geometric one. It is not simply in virtue of being a rainbow that the rainbow

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[53] Heath provides an analysis of the proof (Heath 1949, 191-190).
[54] I treat this as an example of optics, though Aristotle would see it as from the science of the rainbow. (See *Posterior Analytics* I.13: 79a10-13.) However, the point made is independent of this fact. Lennox (1986) provides a characterization of the relationship between optics and the science of the rainbow.

displays the demonstrated feature; rather it is in virtue of displaying the particular geometric arrangement from which the demonstration begins. Regardless of whether this geometric arrangement holds because of meteorological and optical principles, such an arrangement will result in the magnitude in question having the geometric attribute in question. Thus, the "reason why" belongs to the higher science.

However, in the case of the subordinate sciences, that the natural domain of concern displays these fundamental explanatory mathematical attributes is not incidental. These fundamental mathematical attributes (e.g., the configuration of the earth, sun and clouds) are not merely incidental to the subject (the earth, sun, and clouds) and so are not eliminated from consideration by the natural *qua*-operator. This Aristotle stresses in various ways; he says: the *principles* of the subordinate sciences share a common feature with those of the higher mathematical science (*Posterior Analytics* I.9 76a15); the *kind* of the two sciences is the same in some respect (*Posterior Analytics* I.7 75b9-10); line and number are *proper* to sight and voice (*Metaphysics* XIII.3 1078a13-16). Optics and the other subordinate sciences have a unity and scope not exhibited, for example, by the study of the healthy *qua* geometric. Such an accidental intersection of the mathematical and physical would not yield a science. No geometric attributes are proper to the principles of health. The circularity of some particular wound, for example, is an accidental attribute of the wound, the result of happenstance, and not *because* it is a wound.[55]

This consideration requires a refinement of the nature of the relation between the higher and the lower science: it is one of *proper* attribute to subject. Because the fundamental mathematical attributes of the phenomena which operate as principles for the subordinate science are proper attributes, either they are immediately predicable of the natural domain (and so

[55] This is why, for Aristotle, medicine is not under geometry, despite the possibility that geometry could be involved in some reasoning about wounds. See *Posterior Analytics* I.13 79a14-17.

indemonstrable first principles for natural science), or they are demonstrated to hold of the subject non-mathematically. For demonstrations, being explanatory and causal, cannot be reciprocal.[56] Interestingly, in *De Caelo* Aristotle provides demonstrations of certain rather fundamental mathematical features of the astronomical domain.[57] In the next section I will briefly examine these demonstrations and how they reflect Aristotle's understanding of the relationship between astronomy, a mathematical discipline, and natural science.

2.4 *DE CAELO* AND ASTRONOMY

In the *De Caelo* Aristotle treats the number, magnitude and locomotion of the simple bodies constituting the cosmos.[58] The *De Caelo* has a close relationship to mathematics, in general, and astronomy, in particular.[59] Nonetheless, *De Caelo* is a treatise in natural science, not astronomy.[60] In its opening passages, Aristotle clearly implies that he is undertaking a study in natural science:

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[56] This point is made in *Posterior Analytics* I.3.
[57] He also considers the possibility that one of these may simply be an immediate predication; see *De Caelo* II.5: 287b26.
[58] Leo Elders gives a related characterization of the focus of *De Caelo* (Elders 1965, 43).
[59] The close relationship to mathematics, in general, can be seen in, e.g., his discussion of why there are only three dimensions in bodies (268a6-268b5) and in the noteworthy inclusion of "magnitudes" as among the things natural science considers (268a1-5).
[60] Contra Barnes who, in his commentary on the *Posterior Analytics* (Aristotle 2002) seems to imply that *De Caelo* is a treatise on astronomy ("Astronomy, too, is one of the more mathematical of the sciences…Aristotle wrote a treatise on this, too." p. 159.) Similarly, in and earlier paper (Barnes 1975) he says *De Caelo* is "mathematical in the broad sense" (p.76)—the broader sense being, presumably, that of the subordinate sciences.

> The science which has to do with nature clearly concerns itself for the most part with bodies and magnitudes and their properties and movements, but also with the principles of this sort of substance, as many as they may be.[61] (*De Caelo* I.1, 268a1-4)

When Aristotle refers to astronomers' findings, he treats them as confirming evidence brought in from another discipline.[62] Furthermore, throughout the work Aristotle's arguments depend on natural principles and concepts.[63] This is so even when discussing the shapes, sizes and arrangements of the cosmos—i.e., even when demonstrating certain mathematical attributes of the heavens (the domain also treated by astronomy).

In *De Caelo*, Aristotle provides a demonstration of the spherical shape and immobility and centrality of the earth (our home) from natural causes—the nature of earth (the element).[64] He also provides demonstrations regarding why the heavens are spherical,[65] why they move with uniform circular motion, each in one direction, [66] why there is more than one such locomotion;[67] why the "stars" are spherical (which for Aristotle includes the fixed stars, the planets, the sun and the moon),[68] why the rates of revolution of the heavenly spheres vary,[69] and why the stars and planets are distributed in certain ways.[70] All of these (sometimes explicitly tentative[71]) demonstrations are non-mathematical, and from broadly natural principles. These demonstrated attributes can then serve as the fundamental explanatory mathematical attributes by which the

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[61] See, also, *De Caelo* III.1, 298a26-b1.
[62] E.g., *De Caelo* II.10, 11, 14.
[63] Discussions like Elders's (Elders 1965, 43-46), I think, mischaracterize the place of mathematics in the *De Caelo*.
[64] See *De Caelo* II.14.
[65] See *De Caelo* II.4.
[66] For circular motion, see *De Caelo* I.2-4; for uniformity, see II.6; for in one direction, II.5.
[67] Why there must be at least two, see *De Caelo* II.3.
[68] See *De Caelo* II.11.
[69] See *De Caelo* II.10.
[70] See *De Caelo* II.10.
[71] See, especially, *De Caelo* II.5; on the tentative nature of these demonstrations, one thinks of *Parts of Animals* I.5 644b23-645a7.

astronomer demonstrates other derivative mathematical attributes. Because *De Caelo* is a work not of astronomy but of natural science, it includes the (non-mathematical) demonstrations of these fundamental mathematical attributes, but does not demonstrate *from* them—such additional demonstrations are mathematical and belong to astronomy.[72]

Let me illustrate this by looking briefly at Aristotle's treatment of the spherical shape of the stars in *De Caelo* II.11. Here is the chapter in full.

> With regard to the shape of each star, the most reasonable view is that they are spherical. It has been shown that it is not in their nature to move themselves, and, since nature does nothing without reason or in vain, clearly she will have given things which possess no movement a shape particularly unadapted to movement. Such a shape is the sphere, since it possesses no instrument of movement. Clearly then their mass will have the form of a sphere.
>
> Again, what holds of one holds of all, and the evidence of our own eyes shows us that the moon is spherical. For how else should the moon as it waxes and wanes show for the most part a crescent-shaped or gibbous figure, and only at one moment a half moon? And astronomical arguments give further confirmation; for no other hypothesis accounts for the crescent shape of the sun's eclipses. One, then, of the heavenly bodies being spherical, clearly the rest will be spherical also.

Here we have a typical example of the interaction of natural science and astronomy in *De Caelo*. Both astronomy and natural science treat of the shape of the stars. However, the natural scientific

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[72] Lennox (2008) makes this point with reference to the sphericity of the earth. This point is missed by discussions like S. Leggett's in his translation of Books I and II of Aristotle's *De Caelo* (Aristotle 1995, 27-28), which focus not on what the astronomer does that the natural scientist does not, but only on what the natural scientist does that the astronomer does not.

treatment is given in the first part of the passage. Aristotle provides a demonstration of the spherical shape of the stars from natural principles:

(1) That the stars do not move themselves, but are carried by the heavenly spheres (already established in II.8);

(2) The general principle that nature does nothing in vain;[73]

(3) The claim that the sphere possesses no instrument of movement;

In the second half of the passage, Aristotle argues for the same view on the principle that if one of the heavenly bodies (the moon) is spherical, so too must be the others. In showing that the moon is spherical he references astronomical arguments from the character of solar eclipses. The astronomer, through careful observation arrives at the conclusion that the moon is spherical from the crescent shape of a solar eclipse. Such an argument is only a proof of the fact that the moon is spherical. The moon is *not* spherical because solar eclipses are crescent. The reason why it is spherical is given by natural science as in the first part of the passage. The astronomer can, however, give the reason why of the crescent shape of the solar eclipses (one mathematical attribute) in terms of the spherical shape of the moon and the spatial configurations of the earth, moon and sun (other more fundamental mathematical attributes). Solar eclipses are crescent because the moon is spherical. This, the natural scientist leaves to the astronomer. This pattern is also present in the astronomical treatment of the phases of the moon. The astronomer can establish only the fact that the moon is spherical, but can give the reason why the moon shows phases.[74]

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[73] For a nice discussion of the role of this and other teleological principles in the *De Caelo*, see Mariska Leunissen's "Why Stars have no Feet: Explanation and Teleology in Aristotle's Cosmology" (Leunissen 2009). She focuses on the more complex treatment in *De Caelo* II.8.

[74] Aristotle uses precisely this example in *Posterior Analytics* I.13 78b4-12 to illustrate the difference between the fact and the reason why.

This pattern of interaction between the natural scientific and astronomical treatments of the features of the heavens informs, more or less explicitly, the other instances listed above. The astronomer, through careful observation, comes to knowledge that many mathematical attributes are displayed by the heavens. These are explanatorily related to one another in such a way that astronomical science can give mathematical demonstrations of some such attributes in terms of other more fundamental ones. However, of these most fundamental attributes, mathematical astronomy can only give proofs of the fact. Proper demonstration of these fundamental mathematical attributes (if they are not ultimate principles, and so are to be demonstrated at all) will be given by another non-mathematical science.

It is sometimes claimed that Aristotle's natural science is a purely qualitative one and that Aristotle saw no place for mathematics in understanding the observable world. One must, however, distinguish the claim that Aristotelian natural science is not mathematical from the claim that Aristotle thinks mathematics has no role in providing genuine scientific understanding of features of the sensible world. Regardless of whether the former claim is true, it is clear that the latter is not. This point is obscured by the tendency to focus on comparing the mathematical and natural treatments of such fundamental mathematical attributes as the sphericity of the earth or the heavenly bodies. Though, in such cases, the natural science gives the reason why, in the case of the vast majority of the mathematical features exhibited by the heavens mathematics gives the reason why. The same will be true, presumably in the realm of the other more natural of the mathematical sciences: optics, harmonics and, most important for our purposes, mechanics. For Aristotle, then, there are many features of the natural world for whose proper demonstration we must turn to mathematics.[75]

2.5 16TH CENTURY MECHANICS AS A SUBORDINATE SCIENCE

With this general account of Aristotle's approach to the subordinate sciences, we can turn specifically to mechanics and to the pseudo-Aristotelian *Quaestoines Mechanicae* as it was understood around the end of the 16th century. In his study of the scope of Renaissance mechanics, W. R. Laird has argued that

> [o]ne of the effects of the reintroduction of the *Mechanical Problems* in the sixteenth century…was to elevate mechanics to the status of a theoretical, intermediate science and to apply to it the theory of subalternation elaborated in the Middle Ages and still actively discussed in the sixteenth century. (Laird 1986, 47)

Laird traces the influence of the preface of the *QM* in 16th and early 17th century texts. His analysis suggests that even among authors who were more sympathetic to Archimedean approaches to the foundations of mechanics (e.g., Bernardino Baldi) conceiving of the scope of mechanics in broadly Aristotelian terms as a subordinate or intermediate science was commonplace.[76] As mentioned above, this view of mechanics was rooted in the preface of the *QM*, which states that mechanics has something in common both with natural and mathematical

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[75] Aristotle may even have thought that new subordinate sciences could be needed; indeed, he may have taken steps toward developing some. So J. Jope (1972) understands Aristotle's treatment of motion in *Physics* VI (See also Hussey's (1991b) discussion). The introduction of mathematical figures in certain passages in *De Motu* and *De Incessu* are also suggestive.

[76] See Laird 1986, 56-57.

theorizing.[77] The 'how' pertains to mathematics while the 'about' or 'concerning what' is manifest to natural philosophy.[78]

That mechanics "proceeds in the same way"[79] as astronomy, optics and the other subordinates sciences is reflected in the *Quaestiones Mechanicae*. In the preface it is explained that

> [t]he original cause of all such phenomena [such as when the lesser weight moves the greater] is the circle. It is quite natural [*eulogos*] that this is so; for there is nothing strange in a lesser marvel being caused by a greater marvel, and it is a very great marvel that contraries should be present together, and the circle is made up of contraries… (847b16-20)

It is also explained that

> [t]he phenomena observed in the balance can be referred to the circle, and those observed in the lever to the balance; while practically all the other phenomena of mechanical motion are connected with the lever. (848a11-15)

According to the preface, then, the explanations of almost all mechanical phenomena will be traced back to the lever, balance, and ultimately to the circle (or circular motion) and its properties. In this way, mechanical phenomena will be demonstrated (mathematically) from

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[77] 847a24-26

[78] 847a27-28. Henri de Monantheuil in his 1599 translation and commentary renders this line, "Etenim quod ipsum quomodo ad mathematica pertineat: ipsum vero circa quod, ad Physica, manifestum est." (Monantheuil 1599, 12). The most popular and widely reproduced Latin translation of the *QM* was Niccolo Leonico Tomeo's, which first appeared in his 1525 *Opuscula* (published again 1530). Leonico leaves this line out of his translation (Leonico Tomeo 1530, 22). Leonico Tome's translation is also reproduced in the Venice Junta edition of 1552 (the relevant text is can be found on 54 *recto*) in volume 7 of the Venice Junta edition (Aristotle 1552). In margin notes in the manuscript of the text of the *QM* that formed the basis of his translation, Leonico suggests that 847a27-8 is a scholium since it is not in some manuscripts. Joyce van Leeuwen (Leeuven 2012) for a brief discussion of this manuscript and its relationship to Leonico's translation. Thanks also to Joyce van Leeuwen for informing me (personal communication) of the margin note in the manuscript. For a general introduction to Renaissance translations and editions, see Rose and Drake 1971.

[79] As Aristotle says at *Metaphysics* XIII.3 1078a13-16

more fundamental mathematical facts concerning the circle. For the author of *QM*, the most important feature of circular motion for the explanation of mechanical phenomena is the fact that "no two points on one and the same radius travel with the same rapidity, but of two points that which is further from the fixed centre travels more quickly…." (848a15-18) The most important (and perhaps puzzling) aspect of this feature of circular motion, the author clarifies, is that this more rapid movement of points further from the center occurs when and even though the points are under the influence of the same force. This differential response to force of bodies exhibiting circular motion is what, ultimately, will explain mechanical effects.

In a recent analysis of the *QM*, Mark Schiefsky (2009) traces the explanatory structure of the *QM*, showing the extent to which the 35 problems do indeed provide explanations by reference to the fundamental properties of circular motion. He concludes that in at least 18 of the problems this explanatory structure is explicit; of the remaining 17 only seven do not seem to have any connection to circular motion and its properties. In the explanations that do fit neatly into the structure, Shiefsky points out, the explanations are provided by

> identifying correspondences between the device or situation in question and the lever, balance, or circle. Each of these three conceptual schemata or models has a fixed number of components or 'slots' designated by a standard terminology… While the terminology for the slots is quite consistent, each slot can be filled by different objects depending on the particular situation. (Schiefsky 2009, 50-51)

For the circle these 'slots' are the center and radii (of different lengths); for the balance they include the beam and the cord from which it is suspended; the slots for the lever are the fulcrum, the weight to be moved, the mover, and the lever itself. One explains a mechanical phenomenon, then, by identifying in the situation under consideration what fills each 'slot' and then providing in terms of that identification the reason for the phenomenon.[80]

Guiseppe Moletti (1531-1588) was professor of mathematics at Padua from 1577 until his death in 1588. He lectured on mechanics at Padua in 1581-82 and 1585-86.[81] These lectures—and indeed his whole tenure at Padua—overlapped with Fabricius' long tenure there (1565-1613). Although I am not able to document any evidence of specific interactions, it is not unlikely that the two were well aware of each other and interacted. This is especially likely, given that Moletti was also a physician and may well have taught or practiced medicine privately while at Padua or during his earlier time in Venice from 1556-70. For this reason his approach to mechanics is of particular relevance.

In his account of the scope of renaissance mechanics, Laird characterizes Moletti's account of the scope of mechanics. For Moletti,

> [t]he subject of mechanics … is not simply machines, but rather sensible quantity mobile in circular motion, or machines whose form or principle is circular motion or compounded from it. The properties of mechanics are the powers and virtues of such machines for lifting and drawing weights and for throwing projectiles. (Laird 1986, 61)

This characterization of the subject (the kind of the science) and the properties (to be demonstrated) reflects Moletti's view that mechanics is a subordinate science whose subject is picked out using what I have called a double *qua*-operator. It also reflects the primacy of the circle in the explanatory structure of mechanics. According to Laird, Moletti uses the scholastic

[80] This is not unlike the way that identifications work in the discussion of the rainbow in *Meteorology* III discussed above.

[81] For an introduction to Moletti's life and work, see the introduction to Laird's edition of Molleti's unfinished dialogue on mechanics (Laird, The Unfinished Mechanics of Giuseppe Moletti 2000).

language of “contraction” to describe how mechanics treats a natural or sensible subject mathematically.

> One science is subalternated to another, [Moletti] asserts, when each considers the same subject but in a different way, in that the first adds an accidental difference to this subject. Optics, for example, adds the physical quality visible to line, the subject of geometry; …. In the case of mechanics, the added accident, according to Moletti, is circular motion. For like other intermediate sciences (and Moletti uses the term *scientiae mediae*), namely, harmonics, optics, and astronomy, mechanics applies mathematical arguments and demonstrations to sensible things and concerns sensible matter and motion, whereas pure mathematics concerns only abstract quantity. It is this purely abstract quantity that the intermediate sciences "contract" or apply to sensible matter, making what Moletti calls "sensible quantity" (*quantum sensibile*). (Laird 1986, 61)

For Moletti, mechanics considers a limited and mathematically articulable set of properties of sensible objects: those for which the ‘how’ is made clear by mathematical demonstrations grounded ultimately in the circle.

Moletti’s account of the scope of mechanics also reflects the influence of the preface of *QM* in another important way. Recall that the preface identifies mechanics as that part of art by which we accomplish things that are *praeter naturam* and that are for (varying) human benefit. As an example of overcoming nature by producing something *praeter naturam*, the author suggest cases in which a large weight is moved by something having little power to move (*momentum*). Thus mechanics, even more explicitly than other subordinate sciences,[82] had a

[82] Mechanics connection to human benefit, though more pronounced, is not perhaps unique among the subordinate science in this regard. After all, both harmonics and optics were especially preoccupied with explaining phenomena

close connection to art, human artifice and human ends. One could say that, although mechanics was a science and not an art, still it was the science *of an art* (or perhaps better, of the *products* of this art). It provided causal, scientific understanding of human technology and of how, by means of it, we achieve things *praeter naturam*.

> As to whether mechanics is an art or a science, Moletti decides in favor of the latter …. For Moletti, sciences differ from arts both in their subjects and in their ends: the subjects of sciences are necessary and eternal, while those of arts are subject to our will; and the end of sciences is knowledge of causes and the truth, while the end of arts is productive work. He argues that because the principles and causes of machines are necessary and eternal and in no way subject to our will, mechanics is a science, not an art. (Laird 1986, 61)

For Moletti, then, the science of mechanics studies machines, but terminates not in the production of any artifice, but in an understanding of causes and principle of their operation. These principles, says Moletti, are themselves eternal and necessary truths. Mechanics explains how we accomplish things that are *praeter naturam*, things that typically involve the components of machines undergoing violent motion (i.e., motion caused by something external), and that involve smaller forces moving larger weights. However, it does so by identifying necessary and eternal principles responsible for the *praeter naturam*. The motions of mechanics, then, are *praeter naturam* in the sense that the motions are outside the nature of the moved component (having their source in another component) and involve the components being arranged in ways that take advantage of the *nature* of circular motion[83] in order that the mover can have a smaller

produced by human artifice (musical instruments and mirrors, for example) and having special significance to human goals.

[83] Schiefsky (2009) stresses that mechanics depends on the *nature* of the circle.

force of motion than the component that it moves. Mechanics studies motions brought about in one part by the artificial arrangement of the mover and moved part.

As Laird has pointed out in several places (2000, 2008), this understanding of mechanics allows Moletti to see a very close connection between mechanics and the natural movement of animals. In both his lecture notes and his unfinished dialogue on mechanics Moletti connects mechanics and the way animals move themselves. In the earlier unfinished dialogue, near the beginning of the second day, Moletti's characters discuss how locomotion depends on there being an unmoved point providing a source of resistance for the mover. Moletti connects this principle, drawn explicitly from Aristotle's analysis of animal motion in *De motu animalium* and *De incessu animalium*, to the fixed point (the center of the circle or fulcrum of the lever) in mechanics. (Laird 2000, 137) This connection is undoubtedly encouraged by the prominent role that circular motion (around a joint) plays in Aristotle's analysis of animal locomotion, and the way the joint is both center of the circular motion and the location of the internal fixed point of resistance required for animal locomotion. As Laird (2008) points out, Leonico's very popular translation of the *QM* was first published in 1525 (and again in 1530) in a volume that also included his paraphrases of the *De motu animalium* and *De incessu animalium*. Laird suggests this accident of publishing may well help explain Moletti's familiarity with the animal works, and so his making a connection between the two.

Moletti closes this discussion of animal locomotion with the following exchange between his two interlocutors:

> AN. …But tell me, do you think that the flight of birds and the swimming of fish pertain to mechanics?

PR. In fact the mechanic, as I shall later show you, has from their movement grasped many most useful things. (Laird 2000, 137)

Although, Moletti never returns to the subject in the unfinished dialogue, in his later lecture notes on mechanics he expands on this idea. Moletti insists that "Certainly in all the works of nature mechanical art is present …."[84] Indeed, "if this science of mechanics were not in natural things, humans would not have discovered his art…."[85] Humans discovered the lever, he suggest, by observing those things that are present in his own body, "for when we move our arms to lift a weight, such motion is the motion of a lever. And also by his horns, the bull showed us the invention of the lever. … And in one word, I would say animals have taught us the mechanical art by their motions as well as their instruments and organs."[86]

Besides suggesting that humans learned mechanical principles from nature, Moletti suggests also that nature and human mechanics have a similar means-ends structure.. By the science of mechanics we understand how to accomplish by artifice the various things that benefits us. Nature knows how to arrange means to achieve her various ends. Nature, he says, operates from knowledge of the end and, indeed, knows at one and the same time both the end and the means conducive to the end, while humans must first grasp an end and then search (sometimes unsuccessfully) for the means.[87]

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[84] "Est igitur omnino in operibus quidem naturae ars mechanica…" The translation is my own. The Latin is as reported by Laird (2008, 178 n. 16).

[85] "Si igitur haec scientia mechanica non fuisset in naturalibus rebus, homo non adinvenisset suam artem…." The translation is my own. The Latin is as reported by Laird (2008, 178 n. 15).

[86] "Praeteria homo observans ea quae inseipso reperiuntur adinvenit vectum, nam dum movemus brachium ad elevandum pondus, talis motus est vectis motio. Taurus etiam cornibus docuit adinventionem vectis. … Et ut uno verbo dicam animalia suis motibus suisque instrumentis et organis docent nos artem mechanicam." The translation is my own. The Latin is as reported by Laird (2008, 178 n. 15).

[87] "Natura quidem ex cognitione finis operatur, … nam natura simul et semel cognoscit finem, et media quae ad finem conducunt. … Now vero quamvis cognoscimus finem saepe tamen caremus mediis quae nos ducere ad finem possunt, quapropter non semper finem consequi possumus." As reported by Laird (2008, 178 n. 16).

2.6 CONCLUSION

Moletti's example shows us just how far, by the end of the 16th century, an Aristotelian mathematical practitioner of mechanics can extend the relevance of mechanics to the study of living things. While for Moletti, mechanics, strictly speaking, is a subordinate science that provides causal explanations of human artifacts, still its principles are necessary, eternal, and govern the operation of natural things—especially living things. Furthermore, they determine the means to nature's ends. While for Moletti this fact is reflected primarily in the way humans *learn* mechanics from nature, it will take only a small step to instead employ mechanics to *understand* nature. Anatomist Hieronymus Fabricius ab Aquapendente—and William Harvey after him—take just this step. They integrate mathematical mechanics in a non-reductive way into the teleological explanations of animal anatomy that characterize their Galeno-Aristotelian anatomical projects.

3.0 FABRICIUS'S GALENO-ARISTOTELIAN TELEOMECHANICS OF MUSCLE

Hieronymus Fabricius ab Aquapendente (Girolamo Farici, 1533?–1619) has attracted the attention of historians of science as an important contributor to Renaissance anatomy. For example, Andrew Cunningham (1985)[88] has done much to help us understand Fabricius's approach to anatomical research (what Cunningham calls his "Aristotle Project").[89] More recently, Cynthia Klestinec (2011) has provided an insightful discussion of Fabricius's career, focusing on pedagogy, private and public anatomical venues, and the experience of his students at Padua.[90] In addition, because of his use of mathematical mechanics in his work on muscle anatomy, Fabricius has received attention from Ugo Baldini, in his study (Baldini 1997) of treatments of animal motion prior to Giovanni Borelli's 1680/1681 *De motu locali animalium*. Julian Jaynes also briefly discusses Fabricius and his use of mechanics in an article on the problem of animal motion in the 17th century (Jaynes 1970). However, general treatments like Cunningham's give little attention specifically to Fabricius's work on muscle anatomy and his use of mechanics there, and neither Jaynes nor Baldini locates Fabricius's work on these topics

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[88] See, also, his later treatment of Fabricius in his book length study of Renaissance anatomy (1997).

[89] Howard Adelmann (1942, 3-35) provides a general introduction to Fabricius's life, career, and publications in his edition of Fabricius's 'embryological' treatises. See also Maurizio Rippa Bonati's bibliographical essay (Rippa Bonati 2004). For a helpful, more general discussion of humanistic medicine at Padua, including anatomy, see Jerome Bylebyl, "The School of Padua: humanistic medicine in the sixteenth century" (J. Bylebyl 1979).

[90] For a discussion of Fabricius's approach in relation to that of his most famous student, William Harvey, see Roger French, *William Harvey's Natural Philosophy*, chapters 2 and 3, especially p. 64–68 (French 1994); Andrew Cunningham's, "Fabrici and Harvey" (Cunningham 2006); and Peter Distelzweig, "*Meam de motu & usu cordis, & ciruitu sanguinis sententiam:* Teleology in William Harvey's *De Motu Cordis*" (Distelzweig forthcoming).

within his larger anatomical project. The result is a misunderstanding of Fabricius's use of mechanics by Baldini and Jaynes, on the one hand, and an impoverished understanding of the extent of Fabricius's creative development and extension of Aristotelian and Galenic resources, on the other.

In this chapter, I argue that Fabricius attempts to integrate mathematical mechanics into teleological explanations of muscle anatomy characteristic of his general anatomical project. These explanations are structured by a Galenic distinction between the composition of a part, its action (*actio*), and its use (*utilitas*), and by an Aristotelian emphasis on providing systematic final causal explanations of the presence and variation in anatomical detail of related parts across species. This analysis of Fabricius's use of mechanics stands in contrast to that suggested by Jaynes and Baldini. Both scholars suggest that Fabricius provides an explanation of animal locomotion in terms of a descriptive mechanics of the animal. My analysis shows that Fabricius is providing explanations of the *parts* of animals, not of their *locomotion*. The principles of mechanics, I argue, play the role in Fabricius's project that matter theory generally does: They undergird the necessity of certain anatomical features of a part, given their function (what Aristotle calls "hypothetical necessity." Finally, I argue that Fabricius's mechanics is Aristotelian: the pseudo-Aristotelian[91] *Quaestiones Mechanicae* serve as his primary reference point, and he thinks of mechanics as an Aristotelian subordinate mathematical science that (a) identifies quantitative, causally interrelated features present in the natural world, but (b) treats them as only a small subset of the features of natural things. His is a non-reductionist application of mechanics to nature. Fabricius's Galeno-Aristotelian "teleomechanics" provides an important

[91] Fabricius attributes the work to Aristotle.

example of the vibrancy and creativity of late Aristotelianisms in a medical context.[92] It challenges and complicates standard accounts of a 17th-century triumph of mechanics *over* Aristotelianism.

In Section 3.1, I briefly illustrate the presence of mechanics in Fabricius's work (focusing especially on the final section of his *De musculis* on the *utilitates* of muscles), and characterize the work on Fabricius done by Jaynes and Baldini. Here it will be seen that neither have adequately located the work in Fabricius's larger project. In Section 3.2, I step back and provide a general characterization of Fabricius anatomical project. I focus especially on characterizing Fabricius's efforts to provide systematic teleological explanations of features of the parts of animals, both similarities and variations among related parts, emphasizing its Galenic and Aristotelian aspects. My account of Fabricius's anatomical project seeks to synthesize and adjudicate between the work on Fabricius done by Cunningham, which stresses the Aristotelian character of Fabricius's project, and that of Nancy Siraisi (2004), which emphasizes Galenic aspects of Fabricius's work and is critical of Cunningham's account. In Section 3.3, I return to Fabricius's use of mechanics in his work on muscles, and, in light of this understanding of his anatomical project, I provide a more accurate characterization of Fabricius's use of mechanics. I conclude by highlighting how Fabricius's 'mechanizing' of the animal is Aristotelian.

[92] In this way it complements the scholarship on Renaissance and early modern Aristotelianisms of, e.g., Charles Schmitt (1983) and Christia Mercer (1993).

3.1 FABRICIUS'S MECHANICS OF ANIMAL MOTION?

Fabricius's use of mechanics is most conspicuous in his discussion of the *utilitates*[93] of muscles. It is here that we encounter Fabricius employing a number of more and less abstract diagrams in his analysis of muscles in terms of levers (Figure 2 and Figure 3). Here Fabricius refers to the *Quaestiones Mechanicae*, distinguishes between the views of Galen and those of "mathematicians or practitioners of mechanics," and contrasts "natural" and "mathematical or mechanical" causes of anatomical facts.[94]

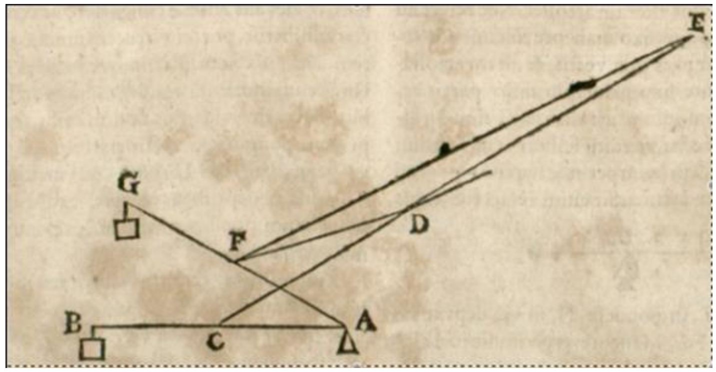

Figure 2. Fabricius, *Opera omnia anatomica & physiologica* **(1687)**, 420.

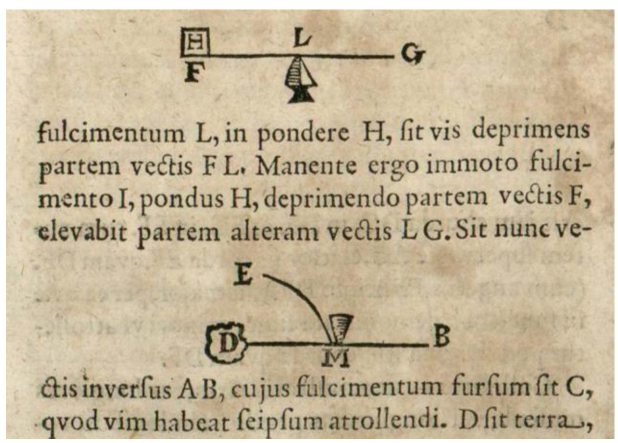

Figure 3. Fabricius, *Opera omnia anatomica & physiologica* **(1687)**, 419.

In his sweeping article on animate motion in the 17th century, Julian Jaynes begins with a brief treatment of Fabricius, focusing on his efforts in *De motu locali animalium, secundum totum* to connect different kinds of animal progression with differences in the animals' environments. Jaynes says, ". . . Fabricius separated out the biological problems of

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[93] I explain Fabricius's use of this Galenic term below.

[94] For example, "*An ergo de vecte bene resondet Arist. q. 3. Mechanica*?" in Hieronymus Fabricius ab Aquapendente, *Opera omnia anatomica & physiologica* (Fabricius ab Aquapendente, Opera omnia anatomica & physiologica 1687, 419); and "*juxta Aristotelem in Q. 29. Mechanica*," (420). All references to Fabricius's work are to this edition, unless noted. All translations are mine, unless noted. For the contrast between Galen and the mathematicians and between natural and mathematical cum mechanical causes, see 416–417.

animal motion. He failed to find a solution, but succeeded in correlating animal motion with environment in a remarkably prescient way." (Jaynes 1970, 232) Of Fabricius's use of mechanics, Jaynes says only that "[n]ot having the advantage of Galileo's *Della Scienza Mecanica* which did not appear until 1634, Fabricius's mechanics of these motions only began what Borelli was to complete at the end of the century." (221) Jaynes characterizes these later efforts of Borelli as in part solving "much of the problem Fabricius and the Aristotelian writings had opened. . . . Borelli showed the bones to be true levers, that the length of the limb, the distance to the muscle, or differences in the center of articulation all influence the force necessary to make the movement." (223) Jaynes suggests that Borelli provides a particular kind of explanation of animal motion "found in the descriptive mechanics of the organism treated as a physical system." (233) In Jaynes's story, Fabricius is a "proto-Borelli," attempting to explain animal motion by providing a descriptive mechanics of the animal.

Fabricius's use of mechanics receives more detailed consideration from Ugo Baldini, who traces the origin of discussions of animal motion in the 17th century to two Aristotelian texts:

> [Aristotle] provided a phenomenology of animal motions in the opuscule which Greek tradition entitled περί πορείας ξώων and Middle Ages *De animalium incessu* (*De animalium progressu, De animalium gressu*). Then he provided a sort of psychophysiology of spontaneous motions in the περί ξώων χινήσεως [*sic*] (*De motione animalium* or *De motu animalium*). The two works are largely unrelated: the first is mostly descriptive; the second lacks any mechanical character, and almost nowhere refers to motions or single structures producing them. (Baldini 1997, 194)

Baldini is concerned about tracing how certain features of Aristotle's accounts in *De motu animalium* and *De incessu animalium* fare in each thinker he examines. He is also concerned with comparing each thinker's efforts to Borelli's. Baldini distinguishes a number of different facets of 17th-century analyses of animal motion and places Fabricius at the beginning of his account of one of them: efforts to analyze movements of parts of the body in terms of levers. He is preoccupied with the extent to which Fabricius treats the limbs as levers and how much of the analysis to be found in Borelli's later work is already present in Fabricius.[95] Thus Baldini also treats Fabricius as a "proto-Borelli" and (at least implicitly) shares the view that Fabricius's use of mechanics is at the service of providing explanations of animal motions by analyzing anatomical structures in mechanical terms.

If one is preoccupied with the development of mathematical mechanics and the rise of the mechanical philosophy—and iatromechanism, in particular—it is perhaps natural to assimilate Fabricius's use of mechanics to a familiar picture of a 17th-century triumph of mechanism over Aristotelianism and its faculties and final causes. However, there is reason to be suspicious of this assimilation. Jaynes and Baldini both fail to locate Fabricius's use of mechanics in his larger anatomical project. Indeed, Jaynes is almost completely silent on Fabricius's intellectual context—save connecting his work with Galileo's in a vague and speculative way (Jaynes 1970, 220). Although Baldini has improved the interpretation by connecting Fabricius's work to Aristotle's treatises on animal locomotion, he mischaracterizes the project of the *De incessu animalium* in an important way. Although this short treatise does provide a description of the limbs and motions involved in progression, its project is not descriptive but explanatory.

[95] For example, in his summary remarks closing his section on Fabricius, Baldini writes, "A long distance has been travelled from Aristotle's model, but an equally long one still separated Fabrici [Fabricius] from Borelli's approach" (Baldini 1997, 208)

Aristotle is providing final causal explanations of the presence of locomotive organs and their variations. This fact, reflected throughout the short work, is clear enough from its opening lines:

> We have now to consider the parts which are useful to animals for movement in place; first, why each part is such as it is and to what end they possess them; and second, the differences between these parts both in one and the same creature, and again by comparison of the parts of creatures of different species with one another.[96] (*De incessu animalium* 1 704a4-8)

After providing a list of features of the locomotive parts (and related facts about how they move) Aristotle concludes, "[w]e have to examine the reasons for all these facts, and others cognate to them; that the facts are such is clear from our natural history, we have now to ask reasons for the facts." (704b8–11) Aristotle's project is not descriptive but explanatory and provides (teleological) explanations of animal *parts*, not animal *motions*. Might not Fabricius's texts, a part of what Cunningham has called Fabricius's "Aristotle project," share similar goals?

Another reason to wonder whether Baldini succeeds in carving Fabricius's work at the joints is the difficulty with which he connects the structure of Fabricius's texts to his own categorization of the topics and issues under consideration:

> Firstly [Fabricius] resolved the Aristotelian duality of dynamical and phenomenological into more specialized subjects. Physiological themes he mostly studied in *De musculis*; anatomical ones partly in the same work, partly in *De ossium articulis*; biomechanical aspects mainly in the third part of *De musculis*; phenomenology of animal motion in *De motu locali animalium secundum totum*. (205)

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[96] Unless noted, translations of Aristotle are taken from Jonathan Barnes, ed., *The Complete Works of Aristotle* (Aristotle 1984).

Clearly, Baldini's conceptualization of the topics covered differs from the understanding shaping Fabricius's publications. This same point is reflected also in Baldini's silence regarding the near ubiquitous division of Fabricius's works into three sections, the first on structure or fabric of a part, the second on its action, and the third on its *utilitates*.[97] Baldini does not consider or explain why Fabricius's prominent use of mechanics appears in the section on the *utilitates* of muscle and not in the sections on its *fabrica* or *actio*. A satisfactory interpretation should explain this fact and place Fabricius's use of mechanics in the context of his work on muscles and his general anatomical project.

3.2 FABRICIUS'S PHILOSOPHICAL AND EXACT ANATOMY

In his work on Fabricius, Andrew Cunningham (1985)[98] has emphasized especially the influence of Aristotle's animal books, even calling Fabricius's anatomical research his "Aristotle Project." However, in a recent paper, Nancy Siraisi (2004) has insisted on the Galenic character of Fabricius's project, emphasizing especially his near ubiquitous use of Galen's distinction between action and use. In what follows I will provide my own characterization of Fabricius's project that recognizes, with Siraisi, its Galenic aspects, while insisting, with Cunningham, that Fabricius's project has important, particularly Aristotelian preoccupations.

In what follows I will draw attention to four points regarding Fabricius's work: (1) his approach to anatomical research is "system-based"; (2) his work is consistently structured by a Galenic distinction between the structure or make up of a part, its *actio*, and its *utilitates*; (3) it

[97] I return to this tripartite structure later.
[98] See also his later treatment of Fabricius's project (Cunningham 1997).

aims to provide Aristotelian final causal explanations of the anatomical features of the parts by reference to the action of that part; (4) it is marked by an Aristotelian preoccupation with explaining similarities and variation exhibited by related parts both in the same species and across species.[99]

3.2.1 Studying Functional Organ Systems

First, then, to Fabricius's focus on studying and publishing works on connected systems of organs. He did not publish a universal anatomy like Vesalius's *De Humani Corporis Fabrica* (Vesalius 1543) or Laurentius's *Historia Anitomica Humani Corporis* (Laurentius 1600). Rather, he published smaller works focused on particular physiological systems; each work focused on groups of parts at the service of some particular animal function.[100] An examination of Fabricius's publications makes this clear.[101] (See Figure 4, the *Syllabus Tractatuum* of the posthumous *Opera Omnia* of 1687.) For example, Fabricius published works like *De locutione & ejus instrumentis* and *De respiratione & ejus instrumentis*, which explicitly pick out the parts to be studied as those that are the instruments of certain activities. In addition, works like *De larynge, vocis instrumento*; *De oculo, visus organo*; and *De aure, auditus organo* also identify the anatomical parts to be studied precisely in terms of the function they serve. Similarly, Fabricius published *De gula*; *De ventriculo*; *De omento*; *De varietate ventriculorum*; *De*

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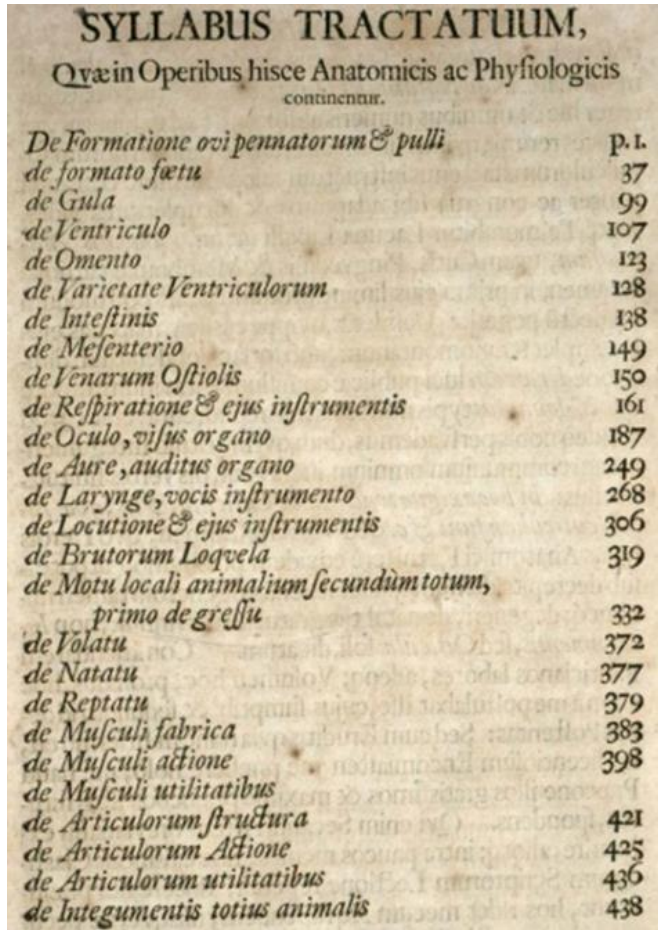
[99] This aspect of Aristotle's project is clearly articulated in the opening passage from the *De incessu animalium* discussed above (p. 11).
[100] That said, Fabricius did intend all the works to be seen as part of one project. He suggests that students could eventually bind all the individual tracts together. See the dedication to *De venarum ostiolis* (Fabricius ab Aquapendente 1603). A translation can be found in K. J. Franklin, trans., *De Venarum Ostiolis 1603 of Hieronymus Fabricius of Aquapendente (1533?–1619)* (Fabricius ab Aquapendente 1933).
[101] For a list and timeline of Fabricius's publications see (Rippa Bonati 2004).

intestinis; and *De mesenterio* (listed separately in Figure 4) together in one volume. The opening lines of this text exhibit Fabricius's system-based approach:

> We now treat the stomach, and we will join with it also those things which are connected and go with it—that is, the intestines and the esophagus—and, for the same reason, the mesentery, the bowels, and the muscles of the anus and of the abdomen, as much as these all are parts that, as a kind of chain, at the same time are conjoined and are aided by one another's roles. (99)



SYLLABUS TRACTATUUM,

Quæ in Operibus hisce Anatomicis ac Phyſiologicis continentur.

Figure 4. Fabricius, *Opera omnia anatomica & physiologica* (1687), *Syllabus Tractatuum.*

Here we see that the motivation for grouping the discussion of organs together is their connection and mutual interdependence. They all form one system—they are the organs that are at the service of extracting nutriment from food. This leads Fabricius to treat in one work organs that otherwise might not be treated together. For example, if the treatment was guided instead by the "three bellies" the throat and the muscles of the anus and abdomen would likely not be treated in connection with the rest.

3.2.2 Fabricius's Galenic *Actio* and *Utilitas*

The second feature of Fabricius's project is that it is structured by a Galenic distinction between the description of a part (what Fabricius variously refers to as *structura*, *fabrica*, *compositio*, *historia*, *anatome*, *dissectio*[102]), the action (*actio*) of a part, and the *utilitates* of a part. This feature can also be exhibited by the *Syllabus Tractatuum*. We see, in the case of his work on muscles and on the joints, the editor has listed separately Fabricius's works treating these three topics: *De musculi fabrica*, *De musculi actione*, *De musculi utilitatibus*; *De articulorum structura*, *De articulorum actione*, *De articulorum utilitatibus*. This structure, though listed by the editor only in these two cases, is actually present in virtually all of Fabricius's works.[103] Indeed, Fabricius frequently discusses this "tripartite" structure at the beginning of his works. For example, in the opening of *De oculo, visus organo*, Fabricius says:

> This disputation of ours will be tripartite. For first we will make clear the fabric and structure of the entire eye. Then we will examine the action of the eye—that is, vision itself. Finally, we will contemplate the *utilitates* of both the whole eye and the individual parts of this same eye. And all of these things we will hunt through dissection. For dissection (if one judges correctly) has this use, (1) to manifest those things that belong to

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[102] It can be noted that these terms seem to be of two kinds. Some refer to the thing studied (*fabrica*, *structura*, *dispositio*), the other to the way of studying it (*historia, anatome*, *dissectio*). Fabricius, however, does not seem to make much of such a distinction. See for example, the passage from the *De oculo, visus organo* quoted just below. There he lists as coordinate both *structura* and *historia*. Similarly, in the passage opening his work on the digestive system also quoted below, he coordinates *historia*, *structura* and *anatome*. Similarly, in opening his work on muscles he says "Primum igitur a musculi fabrica, seu historia, seu dissection, seu structura, seu compositione exordium sumemus, utputa quae ex Galeno, & actionem ostendit, & usus quoque detegit, uti audietis." (383) Here he treats all of these (save *anatome*) as equivalent. In the dedication to *De voce* Fabricius discusses a distinction between *dissectio* (as the actual act of dissection) and *historia* (the exposition of the features of the parts made clear by *dissectio*). Such a distinction, he says, is legitimate, but for his purposes, and following Galen, he will include *dissectio* in *historia* (Fabricius ab Aquapendente 1600).

[103] *De venarum ostiolis* and *De motu locali animalium secundum totum* are notable exceptions—though the former is implicitly structured by the distinction.

the eyes, that is structure, *historia*; (2) to lead to the notice of the action and faculty; (3) and finally to uncover and reveal the *utilitates* of the eye.[104] (187)

As this quotation suggest, Fabricius thinks that it will often (if not always[105]) be dissection itself that will allow one to find both the action and the *utilitates* of the parts of the body. Anatomical dissection is not at the service only of discovering and describing structure, but is ultimately at service of philosophical knowledge of the parts, knowledge rooted in causes. I will turn to this again below.

Indeed, Fabricius understands this distinction to mark his habitual and constant approach, at least when undertaking philosophical or exact anatomy, as opposed to "popular" anatomy:

> Therefore we devote this treatise to the stomach, intestines, throat, bowels and the muscles of the anus and abdomen--however we are pursuing these things πρὸς δ' ἀκρίβειαν and not πρὸς τὴν ὄψιν (as Aristotle uses these terms in *On Respiration*), that is, exactly and most thoroughly and not for the eyes only and in as I might say popular anatomy. [106] And for this reason we will explore as we usually do three things concerning

[104] Tripartita erit nostra haec disputatio. Primo enim totius ocluli fabricam structuramque patefaciemus. Deinde agemus de oculi actione, hoc est de visione ipsa. Postremo tum oculi in universum, tum singularum ipsius oculi partium utilitates contemplabimur. Haec autem omnia fere per dissectionem venabimur. Dissectio enim (si quis recte aestimet) eum habet usum, ut tum ea, quae oculis insunt, hoc est structuram & historiam, manifestet: tum in actionis facultatisue notitiam deducat: tum denique oculi utilitates aperiat atque declaret.

[105] It should be noted that Fabricius is not always so certain of the ability of dissection to provide us the knowledge we are after. For example, he opens his discussion of the action of the larynx: "The *historia* of the larynx being set aside, we proceed to the second part of this work, which searches for the action of the larynx. This is neither self-evident, as is the case with sight for the eyes, or grasping for the hands; nor is it made conspicuous by its completed work, as is the case with chylification (digestion) and the stomach; nor again is it manifested by some motion, as contraction is for muscles, or erection for the penis, rather in this case it is revealed through reliable authorities. For Galen everywhere reports that voice is the action of the larynx and the larynx is the instrument of voice." (281) (Expedita Laryngis historia, ad secundum tractationem accedimus, qua Laryngis actionem perquirit. Hac neque per se nota est, ut oculorum visio, aut manus apprehension: neque etiam ex opere facto innotescit, ut ventriculi chylificatio: neque per motum aliquem manifestatur, ut musculorum contraction, penis erectio, sed per probatos auctores elucescit. Etenim Galenus passim Laryngis actionem vocem esse, & vocis intrumentium Laryngem pronunciat…)

[106] Fabricius repeats this phrase (taken from Aristotle's *On youth, old age, life, death, and respiration* 22) a little later in this text. Before beginning his detailed treatment of the organs to be considered there, starting with the throat, Fabricius first provides a rough [*rudis*] sketch of the all these organs and their interconnection. Along the

each organ: *historia* or structure or anatomy; then the action of the organ; and third its *utilitates*.[107] (99)

This threefold distinction has its roots in Galen. Galen distinguishes between the action (*energeia*) of a part and its usefulness (*chreia*) in the "*epode*" (i.e., Book 17) of the *De usu partium*. There he writes,

> Now the action [*energeia*] of a part differs from its usefulness [*chreias*], as I have said before, because action is active motion and usefulness is the same as what is commonly called utility [*euchrestia*]. I have said that action is *active* motion because many motions occur passively and those which happen to bodies when other bodies move them are even called passive. Thus the bones in the limbs have a motion produced by the muscles that are in the limbs and move the bones now outward, now inward at their articulations. With respect to the first principle of motion, which is the authoritative part of the soul, the muscles play the role of instrument, but with respect to the bone moved by them they play both this role and that of the efficient also.[108] (*De usu partium* 17.1)

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way he correlates their Latin and Greek names and discusses some etymology. This quick sketch is meant to provide something of a reference point for the more detailed work to follow. He concludes it writing, "These things then being brought πρὸς τὴν ὄψιν, that is, brought at once into view … now we should undertake the more copious and exact treatment of the individual organs…" (His veluit πρὸς τὴν ὄψιν, hoc est, in conspectum quondam … adductis, jam tractationem singulorum uberiorem & exactoriem aggrediamur…") (99). This suggests that the distinction is between a popular anatomy in which the organs are provided a summary treatment and exact anatomy, in which the individual organs are treated in depth and with an emphasis on full understanding. Harvey makes a similar distinction between *curiosa* and popular anatomy in his lecture notes. I discuss this when I turn to Harvey below.

[107] Agimus nunc de ventriculo, cui etiam quae ei adjuncta & adnata sunt conjungemus, videlicet instestina, & Gulam demum: eodem monimne mesenterium, omentum, ani musculos, & abdonmins, tanquam partes quae, ceu catena, simul inexae sunt, & mutuis invicem juvantur officiis. Igitur de Ventriculo, Intestinis, Gula, omento, & ani atque abdominsi musculis tractationem insitituimus: de quibus quidem a nobis disserendum est πρὸς δ' ἀκρίβειαν non autem πρὸς τὴν ὄψιν, ut Aristotelis lib. de resp. verbis utar: hoc est exacte ac diligentissime, non ad oculum tantum, & populari (ut sic dixerim) Anatome. Ideoque ex nostro more tria de unoquoque organo explorabimus, videlicet historiam, seu structuram, seu anatomen; deinceps actionem organi: tertio loco utilitates.

[108] This and all the passages from *De usu partium* are taken from Margaret T. May's translation (Galen, On the usefulness of the parts of the body 1968).

In order to clarify what his notion of action (active motion) involves, it is useful to have Galen's well-known discussion of the distinction between action (*energeia*) and work (*ergon*) in *De naturalibus facultatibus*:

> The discussion which follows we shall devote entirely, as we originally proposed, to an enquiry into the number and character of the *faculties* of Nature, and what is the work [*ergon*] which each naturally produces. Now, of course, I mean by a work [*ergon*] that which has already come into existence and has been completed by the *activity* [*energeias*] of these faculties—for example, blood, flesh, or nerve. And *activity* [*energeian*] is the name I give to the active change or *motion*, and the *cause* of this I call a *faculty*. Thus, when food turns into blood, the motion of the food is passive, and that of the vein active. Similarly, when the limbs have their position altered, it is the muscle which produces, and the bones which undergo motion. In these cases I call the motion of the vein and of the muscle an activity, and that of the food and the bones a symptom or affection, since the first group undergoes alteration and the second group is merely transported. One might, therefore, also speak of the activity [*energeia*] as a work [*ergon*] of Nature—for example, digestion, absorption, blood-production; one could not, however, in every case call the work [*ergon*] an activity [*energeia*]; thus flesh is a work [*ergon*] of Nature, but it is, of course, not an activity [*energeia*]. It is, therefore, clear that one of these terms is used in two senses, but not the other.[109] (*De naturalibus facultatibus* I.2)

For Galen the action of a part must not be some passively caused motion in the part; an action is a motion for which the part is responsible. This restriction on what can count as the action of a part is reflected, for example, in Fabricius's discussion of the throat in *De gulae actione*. There,

[109] The translation is Arthur Brock's from the Loeb edition (Galen 1916).

after setting aside the "private" actions that the throat exhibits which benefit the throat, and which all parts have (ability to attract nutrition, etc.), Fabricius asks if the throat has a "public action," one which it provides to the whole, as the eye does vision. He suggests that there is reason to think that it does not. For Aristotle, notes Fabricius, says the throat is a path and passage-way only (*via* and *meatus*), but "to be a path and passage-way is not to do [*agere*] something, but insofar as it is passable and is a long hollow, it makes available a path to nutriment. But action is an active motion, produced by the part itself, says Galen. Therefore being a path is not an action or a doing, but is a use [*usus*] only…." (101) Thus, if the throat is a passage way only, then it has no public action, because it would do nothing. [110]

It should also be stressed that "motion," and so "action," in Galen and Fabricius's sense, is much broader than locomotion, but can include alteration and change in size. In Fabricius, for example, among the private actions of the throat dismissed from consideration in his section *De gulae actione* is the assimilation of blood in the process of nourishing itself. (101) Further, as Galen's example of the action of the veins in producing blood suggests, action can refer to something that, presumably, does not involve any change in the acting part, but only the exercising of a faculty to change another part. Regardless of whether the part being studied undergoes any clear case of change itself in performing its action, it is clear that the action of a part must be something the part does. Sometimes this action, which can itself be called a work (*ergon*), will terminate in the production of something. For example, the action of the veins (sanguinification) will produce blood; this product is called a work in a narrower sense. The term *ergon*, suggests Galen, has a broader and narrower sense. It can refer, in its broader sense, to an activity or a product. In its narrower sense, it refers only to the product. Both sanguinification

[110] Fabricius, in the end, does think the throat has an active role to play in moving the food down to the stomach.

and blood may be called an *ergon* of nature in the broader sense. However, only the product (blood) is called an *ergon* in the narrower sense. *Energeia*, for Galen, refers only to the activity.

It should also be noted that the action of a part does not refer to simply anything the part happens to do; it does not refer to any and every motion produced by the part. To be an action of a part, the active motion must be functional; it must contribute to the life of the animal—either to life itself, or to some living activities of the animal, like walking or self-nourishing. Although an action must contribute to the life of the animal, we must not confuse that contribution with the action itself. Galen distinguishes between a part's action and the usefulness of that action:

> Hence the usefulness of first importance to animals is that which is derived from actions and the second is that from the parts; for there is no part which we desire for its own sake, and a part deprived of its action would be so superfluous that we should cut it off rather than wish to keep it. (*De usu partium* 17.1)

The usefulness of an action is, roughly, the action's contribution to the life of the animal. For example, in his *De usu respirationis*, Galen asks what the use of breathing is. He first notes:

> That it is not a trifling use is clear from our inability to survive for even the shortest time after it has stopped. Hence also it is obvious that its importance is not for any particular and partial activity, but for life itself. For just as our walking is impaired in so far as we are deprived of the means of walking, and our seeing, if we lose the wherewithal for seeing, so, if what is necessary for life is cut off, we die.[111] (*De usu respirationis* 1)

Eventually, Galen will argue that the usefulness of respiration is the maintaining of the innate heat (in the heart, especially, but also in the brain) by fanning and cooling and the removal of waste products from the process of combustion of blood in the heart. This is the contribution the

[111] Translation is from the edition of Galen's texts on respiration and the arteries edited by D. J. Furley and J. S. Wilkie (Furley and Wilkie 1984, 81).

action of respiration makes to the life of the animal. However, it is not the action of respiration itself.

Although Galen's distinction between the action and the usefulness of the action is present in the passage quoted above, the central distinction he is drawing there is between the usefulness of actions and usefulness of parts. It is to this latter notion that we must turn now. In Fabricius's tripartite treatises the final part is devoted to discussion of the *utilitates* of *parts*, not those of the *actions* of those parts. That he makes this distinction can be seen, for instance, by noting that he has separate discussions of each. For example, his discussion of the *utilitates* of the action of muscle is in *De musculi actione*, while his discussion of the *utilitates* of the muscles themselves constitutes the whole of the *De musculi utilitatibus*. The discussion of the usefulness of the *action* of the muscles is the final section of *De musculi actione*:

> The third and final part of this second section [*De musculi actione*] remains; it takes on the *utilitates* of the action of muscle. For the first part seeks the action of muscle and the second the particular instrument of that action, while the third seeks to what the action of muscle is useful [*utilis*].[112] (408)

Fabricius says that the muscle's action (contraction or tension) has a general usefulness, as it produces motion, and by motion the soul or animal accomplishes all that it does. He then goes on to discuss some of the most "admirable and frequent" things accomplished through the contraction and tension of muscles, looking both at simple and immediate consequences of contraction and tension (like the shortening of the muscle, the thickening and hardening of it) and posterior actions accomplished by means of these, like moving our eyes, or expelling urine.

[112] Superest nunc hujus secundae tractationis tertia & ultima pars, quae utilitates actionis musculi persequitur. Etenim prima musculi actionem: Secunda, praecipuum instrumentum actionis indagat: Tertia, ad quod utilis action musculi sit, inquirit.

This is a discussion of the *utilitates* of the *action* of the muscle. The *utilitates* of the muscle itself belongs not to *De musculi actione*, but rather to its own section, *De musculi utilitatibus*.

The study of the usefulness of *parts* is for Fabricius, like Galen, in the first instance, a study of the suitability of the part to its action.[113] Indeed, this is why Galen says that knowledge of usefulness requires first knowledge of the action of a part. Discussing the usefulness of the hand, and using this discussion as an illustrative example of how to study usefulness, Galen says,

> Such are the characteristics of the bones in the fingers. Next I shall discuss the properties of their other parts, that is, when I have first reminded you that, as I have shown, it is impossible to determine correctly the usefulness of a part before its action is known. It is evident, and we all agree without needing to demonstrate it, that the action of the hand is grasping, but there is no agreement at all on the actions of the veins, arteries, nerves, muscles, and tendons; the actions of these parts are not self-evident and hence do need further discussion. This, however, is not the proper time to inquire into them, for I propose to speak not of actions, but of usefulness. Accordingly, for the success of my discourse it will be necessary both now and in all the rest of this work to use as fundamental principles the conclusion I have reached through proofs set forth in my other writings. (*De usu partium* I.1)

These conclusions have to do with what the activities of various parts are, including those of nerves, veins, and muscles. In order to understand how a part is fitted to its action, one must of course know what that action is. It is only possible to understand the *chreia* of the hand, if it is

[113] In this regard I follow May's analysis (Galen, On the usefulness of the parts of the body 1968, 9).For other treatments, see the discussion in Wilkie and Furley (Furley and Wilkie 1984, 58-69) and in R. J. Hankinson's (1989). I agree with Hankinson that *chreia* is not always best translated "usefulness" in Galen's texts; however, I think that with attention to the distinction between the *chreia* of parts and that of actions, and the possibility of more and less technical uses of the term, much of the diversity of uses in Galen appear coherent. Regardless, in his introductory discussion of the general approach to studying the *chreia* of parts (using the hand as example) opening book 1, it seems clear that what he is seeking to isolate is indeed the fittedness of parts to their actions.

already known that its action is grasping. There is another way in which, for Galen and for Fabricius, we must know the actions of parts in order to study usefulness. This has to do with parts made of parts. Indeed, Galen's immediate point in the discussion just quoted is that we must know the actions of the nerves, veins, arteries, muscles, etc., in order to understand the usefulness of the *hand*. For in order to known how it is fitted to its action of grasping we must know that the muscles contract, that the nerves distribute sensation and motion to the parts, etc. Only with this knowledge in place can we see how these parts in the hand render the hand fitted to grasping.

In Book I, noting his disagreement with Plato and Aristotle on the usefulness of the fingernails, Galen pauses to sketch his method for studying usefulness: "I sought first to discover a standard for judging this difference of opinion and then to devise one universal method which will enable us to find the usefulness of each part and its attributes." (*De usu partium* I.7) The method Galen describes lies behind much of Fabricius's approach. Galen takes as the starting point of his discussion a Hippocratic saying, "Taken as a whole, all the parts in sympathy, but taken severally, the parts in each part cooperate for its effect." (*De usu partium* I.7) Galen interprets this saying:

> All the parts of the body are in sympathy with one another, that is to say, all cooperate in producing one effect. The large parts, main division of the whole animal, such as the hands, feet, eyes, and tongue, were formed for the sake of the actions of the animal as a whole and all cooperate in performing them. But the smaller parts, the components of the parts I have mentioned, have reference to the work of the whole instrument. (*De usu partium* I.7)

Galen sees the body as an instrument of the soul, and the soul as having a particular character. This character is responsible for the body having the particular structure that it does.[114] For the character is to be expressed in appropriate actions of the animal. These actions in turn are carried out by the parts, which contribute in various ways to the actions. The parts contribute to the actions of the animal as a whole by means of their actions.[115] In addition, these parts will often be themselves composed of smaller parts. These smaller parts will all contribute by means of their actions to the exercise of the larger part's action, and so on.

The study of the usefulness of a part, then, will start from its contribution to the living activities of the animal as whole, this often being the action of the part. It will then systematically examine how the part carries out this action. This will involve first identifying the particular sub-part that is particularly responsible for the action. Fabricius sees this as an important part of the study of the parts, and devotes attention to it regularly. He states the principle in general terms at the beginning of his treatment of the action of the parts of the fetus in his *De format foetu*:

> For the *utilitates* of an organ always have reference to its action, and depend upon the action which proceeds from a homogeneous part of it. For this reason, in every organ there is always provided one part from which the action proceeds, while the other parts of the organ are related to the action as useful assistants.[116] (79)

Fabricius articulates and applies this Galenic idea in the second part of *De musculi actione*:

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[114] See his discussion of this point earlier in Book I, where he says, "The usefulness of all [the parts] is related to the soul." (Galen, On the usefulness of the parts of the body 1968, 61-67).

[115] Not always. Sometimes the parts will contribute not by their action but by some other feature not properly speaking an action. Galen gives the example of bone contributing by its hardness.

[116] Etenim utilitates semper ad actionem referuntur, eamque respiciunt, quae a similari parte prodit: propter quam causam in quoquo organo perpetuo datur una pars, quae est praecipuum instrumentum actionis, ut puta a qua action proficiscitur, aliae vero ad ispam, ut ministrae & utiles referuntur. Translation is adapted from Adelmann's (Adelmann 1942).

> Indeed since it is Galen's view that in all organs that consist of many subparts, one of them will be present, to which, more than the others, the action of the whole organ is joined, and which is thus judged the author and prime cause of that same action—as in the eye the crystalline humor is judged the principal author of vision, in the liver, the flesh of the liver, in the penis, the dark, loose flesh, in the larynx, the *glottis*, in the heart, the substance of the heart, in the head, the *cerebrum*, and thus in the others. Therefore, in this way we must seek in the muscle the part, by which, principally, the contraction is performed.[117] (403)

This is the "particular instrument" of the muscle's action mentioned above (p.64) in Fabricius's introduction to his discussion of the usefulness of the action of muscles. The study of the usefulness of a part will also involve systematically examining how all the features of the part as a whole, and those of the sub-parts, contribute to the part's function. The kinds of contributions the features and sub-parts make includes making the exercise of the action possible at all or making it better or easier; the contribution may also involve protecting the part as a whole or some other sub-part:

> The eye, for example, is the instrument of sight, composed of many parts which all cooperate in one work, vision; it has some parts by means of which we see, others without which sight would be impossible, others for the sake of better vision, and still others to protect all these. (*De usu partium* I.8)

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[117] Veruntamen quoniam est Galeni sententia, quod in omni organo, quod ex multis constat particulis, una tamen prae caeteris in eo consistit, cui potissimum action totius organi commissa est, quae proinde censetur autor, & prima causa ipsius actionis; ut in oculo crystalinus visionies praecipuus autor censentur; in jecore, care jecoris; in pene caro laxa, nigraque; in larynge glottis; in corde substantia cordis, in capite cerebrum; & sic de aliis. Propterea ejusmodi pars, a qua potissimum contraction celebrator in musculo inquirenda est.

Galen provides a list of all the kinds of features one should consider in each part and its sub-parts:

> However, in order that the discourse may proceed systematically, let us enumerate all the inherent attributes of bodies. The first and most important of these is temperament (the mixtures), since it is temperament that is responsible for the characteristic essence of the parts. … The parts, then, possess these qualities by virtue of their essence, and their odors, flavors, colors, hardness, and softness follow of necessity. There are necessarily other contingent attributes also, namely, position, size, contexture, and conformation. (*De usu partium* I.9)

This list of features of the parts to be studied will often be found structuring Fabricius's discussions of parts, both in the sections providing the *historia* of a part and that discussing their *utilitates*.[118] For example, his discussion of the *utilitates* of muscle opens by delineating his project, which will involve considering muscles as wholes, all of the parts of muscles, and in each case looking at temperament, the necessary consequents (Galen's odors, flavors, colors hardness, and softness which "follow of necessity", and the accidents (Galen's contingent attributes):

> In this third part of the treatise the aim is to explicate the aptitude of both the parts of and the whole muscle, and then also the *utilitates* working together for the complete discharge of the action of the muscle that are produced and result from the aptitude. This aptitude is

[118] Cunningham's (1985, 212) attempt to see Fabrcius's categorization of features to study in terms of Aristotle's *Categories* is mistaken. Fabricius's takes these headings from Galen. They may have been mediated also by Mondino's list, which Mondino, in turn, takes from John of Alexandria. See Roger French's discussion of anatomical *accessus* (French 1979). (It is worth noting that French there connects John of Alexandria's list directly to Aristotle's *Categories*. However, given that John of Alexandria is commenting on Galen it seems more likely that he is drawing directly from Galen.)

acquired from those things present in muscles, and consists in the temperament, consequences and accidents [of the muscle and its parts].[119] (409)

Thus, Fabricius follows Galen's approach to studying the usefulness of the parts remarkably closely, and Galen's summary of his method could well serve as a summary of much of Fabricius's.

> Accordingly, whenever one wishes to examine carefully the usefulness of everything appertaining to an instrument, let him first inquire to what its action is due, and he will find that in most cases the action is derived from the characteristic substance but sometimes from one of the secondary attributes, such as color in the case of the eyes. Next let him investigate the usefulness of each of the other parts [of the instrument] to see whether it is serviceable because of its action or because of some attribute resulting from temperament, as bone is serviceable on account of its hardness. After this, he should examine each contingent attribute of the whole instrument and of its parts. These attributes, as I said a little earlier, are position, size, contexture, and form. (*De usu partium* I.9)

3.2.3 *Historia*, Teleology, and Aristotelian Comparative Anatomy

Although the list of features found here in Galen clearly guides Fabricius's discussion of parts, when we turn to look in more detail at Fabricius's *historia* of parts, we find another major influence: Aristotle. We see that the scope of Fabricius's project includes all animals. Though

[119] In hac tertia tractionis parte intentio est aptitudinem explicare, & partium, & totius musculi: tum vero etiam, quae ex ea producuntur, & resultant utilitates ad musculi actionem persolvendam conspirantes. Quae sane aptitudo ab iis, quae insunt, desumitur & in temperamento, consequentibus, & accidentibus consistit.

Galen of course discusses animal anatomy and makes comparisons between humans and other animals, and indeed thinks the same distinctions between part, action and usefulness apply to animals, his focus is unambiguously on the human case, and his is a medical project. But when we turn to Fabricius, we see animal anatomy appearing for its own sake, and with many of the comparative and causal preoccupations found in Aristotle's animal books. When studying a particular part, Fabricius wants to delineate carefully what animals have this part and how the part varies from species to species. With this in place, he seeks to provide final causal explanations for the presence, absence, and systematic variation of the part under consideration in terms of the variations in the action of that part and in the context of the part.[120] I will turn to this pattern of final causal explanation in a moment. First, a few words about his work on *historia* and an example are in order.

After giving a general orientation to all the organs he will treat in his work on the digestive system, Fabricius begins with the throat. He first tackles certain linguistic ambiguities to clarify exactly what he will be discussing, providing in conclusion an articulation of what he means by the throat, and sets out the first issue to be treated in his *historia*:

> The throat then begins from the mouth and the innermost jaws, and is stretched downward through the neck and chest, connected by the binding of fibers to the spine and windpipe, and, piercing the diaphragm, is bored through into the stomach and ends. Before I speak of its variation and differentia, first comes investigating whether all animals have a throat?[121] (100)

[120] I.e., variations in the habits, environment, and general body structure characteristic of different animals.

[121] Gula igitur ab ore incipit, & faucibus imis, deorsumque per collum ac thoracem porrigitur, spinae arteriaeque nexu fibrarum continua, & diaphragma perforans in ventriculum pertunditur & finit. De cujus varietate & differentiis ante quam dico, subit primum inquirere, num Omnia animalia gulam habeant?

The first issue Fabricius raises, then, is precisely what animals have the organ under consideration. After referring to apparently contradictory passages in Aristotle, he concludes that the organ is not necessary and is not present in all animals, but only in those that breathe air:

> Thus, it should be concluded that the throat is not necessary *simpliciter*, since it is not present in all. For it would be in all if it was of a necessary nature, as Aristotle said speaking of the testicles. But the throat is present only in those animals that have a neck, and those have a neck which have a *guttur* and windpipe [rough artery], and of course those have a *guttur* and windpipe which have voice; and they have voice which have respiration; and those which have respiration, have lungs and a chest [*thorax*].[122] (100)

He then goes on to suggest that it is necessary that these parts (the lung and chest) have a higher position and the stomach a lower one, and this requires a space to intervene between the mouth and the stomach, "and because of this space the throat is provided."[123] (100) Thus, insects and fish and all non-breathing animals have effectively no throat. But in breathing animals the throat is necessary.

Having thus delineated what animals have a throat and tracing down the cause of them having a throat, Fabricius turns to a discussion of how the throat varies from animal to animal. He considers variations in substance (for example, birds having more sinewy or membranous throats, others like man and cattle having fleshier ones), length (which, perhaps obviously, correlates with length of neck), and thickness, and situation, particularly in relation to the windpipe and spine. He discusses the relation between the size of the throat and the size of the

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[122] Itaque concludendum est, Gulam simpliciter necessariam non esse, cum omnibus non insit. Omnibus enem esset, si necessitates ratio haberetur, dicebat Aristot. loquens de testibus, se iis tantum gula inest, quibus collum: collum autem, quibus guttur, & aspera arteria; guttur vero & aspera arteria, quibus vox; vox autem, quibus respiratio, quibus autem respiratio, iis & pulmones & thorax insunt.
[123] "…& propter hoc spatium gula comparata est."

opening to the stomach, taking the latter to be more fundamental. After this he discusses the structure of the walls of the throat and muscles associated with it.

This preoccupation with identifying what animals have an organ, and how this correlates with other organs or features of the animal (e.g., with being live-bearing or having lungs), along with identifying systematic patterns of variation, also correlated with either kinds of animals (birds, cattle, etc.) or variations in other parts (e.g., the size of the stomach or the length of the neck), reflects an Aristotelian influence. First, Fabricius is here concerned with animal anatomy for its own sake, not simply as a stand in for or contrast with human anatomy. In this, he is more Aristotelian than Galenic. Second, and more importantly, Fabricius in seeking the kinds of correlations he does in his *historia*, is modeling this concern for animal anatomy after Aristotle's own approach in *History of Animals* and *Parts of Animals*, texts which Fabricius frequently references.[124]

James Lennox and Allan Gotthelf have done much to illuminate the methodological significance of the comparative aspects of Aristotle's zoology, connecting them with Aristotle's theory of scientific explanation in *Posterior Analytics*.[125] Recall from the last chapter that in the *Posterior Analytics* Aristotle insists that proper scientific explanations must occur at what Lennox calls "the correct level of generality"; in such explanations, the subject, attribute, and cause will be appropriately related both extensively and intensively. Lennox and Gotthelf have shown in some detail how this requirement shapes both Aristotle's explanations in *Parts of Animals* and his reports in *History of Animals*. Fabricius embraces this aspect of Aristotle's

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[124] Fabricius discussion of the necessity of the necessity or not of the throat and its variation depends heavily on Aristotle's discussion of the same in *Parts of Animals* III.3 664a13-34 and *History of Animals* I.16 495a19-23. In this dependence on Aristotle's animal works it is no exception.

[125] James Lennox, *Aristotle's Philosophy of Biology* (Lennox 2001), especially chapters 1 and 2; Allan Gotthelf, *Teleology, First Principles, and Scientific Method in Aristotle's Biology* (Gotthelf 2012), especially chapters 9 and 12.

project, and it similarly shapes his published works. When studying a particular part, Fabricius tries to carefully delineate which animals do and do not have the part and how the part varies from species to species. Furthermore, Fabricius follows Aristotle in articulating these correlations in terms of shared and varying attributes (e.g., four-legged, blooded, or respiring). With these correlations in place, Fabricius seeks teleological explanations for the presence, absence, and systematic variation of the part under consideration. These explanations make reference to the action of that part, the usefulness of that action, and variations in the life and other features of the animals (i.e., by reference to those shared and varying features, in terms of which the patterns of presence and variation were articulated). In our example, Fabricius identifies the general final cause of the presence of throats in animals (the presence of lungs and a chest), and other more specific causes for the differences exhibited by throats in different kinds of animals. This preoccupation with providing explanations, however, takes us beyond Fabricius's *historia* to his discussion of the *utilitates* of parts. As he says before commencing his discussion of the fabric and structure of the throat,

> …nor should you expect, listeners, the causes or that for the sake of which the throat is thus constructed, while we set forth the fabric of the throat; for that pertains to the study of use and will be set forth in the third chapter.[126] (100)

As this quotation suggests, Fabricius associates causal explanations of the features of parts with the discussion of *utilitates*, and by cause he means final cause, that for the sake of which. To this understanding of the teleological explanation of animal parts, I turn now. Here, too, we see Aristotelian influence.

[126] …neque epectetis, auditors, dum gulae fabricam explicamus, causas, seu cujus gratia ita gula facta sit: haec enim ad usus pertinent, & in tertio capite explicabuntur.

Fabricius, in his work on the *utilitates* of parts, is providing Aristotelian teleological explanations of the parts. For he identifies the final cause of the *utilitates* of the parts to be the actions of those parts:

> The third part being that part, which pursues the *utilitates* (both already and commonly known ones, and those proposed by me) which always look toward and contemplate the action of the larynx (that is, voice) and are directed to that action as towards an end.[127] (290)

In order to understand Fabricius's approach, it will be valuable to examine briefly Aristotle on explanations of parts. This approach takes as a starting point the claim that the soul is the final cause of the body. In *De Anima* II.4 Aristotle says that the soul is cause in several senses. It is the cause as essence of the body, and it is also the cause as source of motion of the vital activity of animals (animal locomotion, as well as the change involved in sensation and growth. In addition, says Aristotle, it is the end or final cause of the body:

> And it is clear that the soul is cause also as that for the sake of which. For just as the intellect acts for the sake of something, in the same way also does nature, and this something is its end. Of this sort is the soul in animals in accordance with nature; for all natural bodies are instruments for soul, and just as it is with those of animals so it is with those of plants also, showing that they exist for the sake of soul.[128] (*De anima* II.4 415b15-20)

That the body is for the sake of the soul, then, is connected to the various parts of the body being instruments of the soul. The soul is, for Aristotle, (the ground of) the unified set of faculties or

[127] Tertiam partem eam esse, quae utilitates persequitur, tum totius, tum partium organi, jam & vulgo notum, & a me propositum est, quae sane utilitates perpetuo laryngis actionem, hoc est, vocem respiciunt, & contemplantur, in eamque tanquam in finem diriguntur.
[128] Translation is from D. W. Hamlyn's Clarendon edition (Aristotle 1993)

abilities whose exercise is the activities of living, like self-nourishment, reproduction, sensing, desiring, moving and knowing. The parts of the bodies are the various instruments by which these activities are carried out, and the body as a whole is the instrument by which the complex characteristic life of a particular animal is carried out:

> Since every instrument is for the sake of something, and each of the parts of the body is for the sake of something, and what they are for the sake of is a certain action, it is apparent that the entire body too has been constituted for the sake of a certain complete action. For sawing is not for the sake of the saw, but the saw for the sake of sawing; for sawing is a certain use. So the body too is in a way for the sake of the soul, and the parts are for the sake of the functions in relation to which each of them has naturally developed.[129] (*Parts of Animals* I.5 645b15-20)

Because the body is for the sake of the soul and its activity, and the parts for the sake of subordinate actions, the features of the body and of its parts are explained and indeed rendered more or less necessary with reference to the life of the animal and the various activities composing it.

Aristotle discusses this kind of necessity, which he calls hypothetical necessity,[130] in *Physics* II.[131] There, having insisted against materialist predecessors on the importance of formal and final causes, he turns to the question of the nature of necessity present in nature, in light of

[129] This and all translations from *Parts of Animals* is from Lennox's Clarendon edition (Aristotle, Parts of Animals 2001).
[130] For an account of Aristotle on "hypothetical necessity," see John Cooper, "Hypothetical necessity and natural teleology" (Cooper 1987).
[131] See also *Parts of Animals* I.1 639a22-640a9 and I.3 642a1-642b4.

his claim that nature acts for an end. For, he wants to insist, there is a kind of necessity even here—indeed, for there to be a *science* of nature there had better be:[132]

> Similarly in all other things which involve that for the sake of which: the product cannot come to be without things which have a necessary nature, but it is not due to these (except as its material); it comes to be for an end. For instance, why is a saw such as it is? To effect so-and-so and for the sake of so-and-so. This end, however, cannot be realized unless the saw is made of iron. It is, therefore, necessary for it to be of iron, if we are to have a saw and perform the operation of sawing. What is necessary then, is necessary on a hypothesis, not as an end. (*Physics* II.9 200a7-14)

Given, then, that there is an animal of a certain character, it will of necessity have certain parts with certain features, just as given that there is a saw (a real saw, capable of sawing), it will have certain kind of teeth and be made of a certain material.

For example, in the early chapters of *Parts of Animals* II, Aristotle begins by discussing the levels of composition involved in animals: the composition out of elements, out of homogeneous parts like flesh, bone and blood, and the composition out of heterogeneous parts like hands. Having distinguished these, he then considers the relationship between, in particular, homogeneous and heterogeneous parts. Here we see him arguing that such a hypothetical necessity holds between a heterogeneous part, like a hand, and the various homogeneous parts out of which it is composed. This hypothetical necessity is grounded in the fact that the homogeneous parts are for the sake of the heterogeneous parts and that these parts, in turn, are instruments of the soul:

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[132] Lennox (1994) provides an exploration of this issue and others arising from trying to understand how Aristotle's biology exhibits Aristotle's general philosophy of science.

> Thus animals have been constituted from both of these parts, but the uniform parts are for the sake of the non-uniform; for of the latter there are functions and actions, e.g. of eye, nostril, and the entire face, of finger, hand, and the entire arm. And since the actions and movements present both in animals as a whole and in their non-uniform parts are complex, it is necessary for their components to have distinct potentials; for softness is useful for some things, hardness for others; certain things must have elasticity, other flexibility. Thus while in uniform parts such potentials are distributed part by part (one of them is soft while another is hard, one moist, another dry, one pliant, another brittle), in the non-uniform parts they are distributed to many and are conjoined with each other; for a different potential is useful to the hand for pressing and for grasping; Accordingly, the instrumental parts have been constituted from bones, sinews, flesh, and other such parts, *not* the latter from the former. As being for the sake of something, then—on account of *this* cause—these parts are related in the way stated … . (*Parts of Animals* II.1 646b10-26)

So the complexity of the action or function of a part will determine and be explanatory of its structure and make-up. For this structure and make-up is for the sake of the functioning whole.

Fabricius understands his treatment of *utilitates* to be a way of articulating this Aristotelian project of tracing the hypothetical necessity of anatomical features given the hierarchical structure of animal activities, terminating ultimately in the activity of the body as a whole—what Aristotle calls "a certain complete action" in *Parts of Animals* I.5 quoted above (p.76). In the opening of his treatment of the action and *utilitates* of the parts of the fetus in *De format foetu*, Fabricius interprets Galen's insistence on the centrality of action in understanding anatomy in Aristotelian terms (using the eye as his example).

> For example, the eye is an organ whose action is vision, which is carried out principally in the crystalline [humor]…But if you should inquire further into the *utilitas*, not of the parts of the eye, but of the whole organ and its action, that is, for instance, if you should inquire what vision is useful, I should answer that it is useful for some other action, for example, that of the brain, because through vision images are presented to the chief perceptive faculties, imagination, reason, and memory, so that they may discern from these images what is true or false, beneficial or harmful, for the purpose of pursuing the one, and avoiding and fleeing the other. This, finally, is an action which is useful to life itself, that is, to a still more comprehensive action, as Aristotle says.[133] (79)

Fabricius does so with an eye to explaining the systematic variations he traces in his *historia*. In this he is following Aristotle, who stresses that we should be attentive to what features are present in what groups of animals.

> Therefore one should first discuss the actions—those common to all, those according to kind, and those according to form. I call 'common' those that belong to all the animals, and 'according to kind' those whose differences from each other we see in degree; for example, I speak of bird 'according to kind', but I speak of mankind, and everything without any difference according to its general account, 'according to form.' (*Parts of Animals* I.5 645b21-27)

Aristotle wants then to provide causal explanations of these features at the right level of generality:

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[133] Verbi gratia coculus est organum, cuius actio visio est; quae in cristallino potissimum clebratur, … Quod si non amplius de oculi partibus sed de toto orgaono, & eius actione inquiras utiltatem, ut puta cui scilicet visio sit utilis; respondere est, alicui alteri actioni, ut puta cerebri, quia per visionem principibus facultatibus cognoscentibu, idest imagination, rationi, & memoriae species offeruntur: ut inde, quod verum est, & falsum, salutare, ac perniciosum discernant, ad alterum assequendum, alterum vero vitandum, & fugiendum: quod tandem ispi vitae, ut puta actioni pleniori, ut dicit Aristoteles est utile. Translation is adapted from Adelmann's (Adelmann 1942).

> [W]e must attempt to state the causes both of the common and of the distinctive attributes, beginning first, as we have determined, with those that are first. (*Parts of Animals* I.5 646a1-3)

Aristotle, for example, provides a very abstract explanation for why *all* animals have homogeneous parts in *PA* II.1:

> Since it is impossible to be an animal without perception, on this account too it would seem necessary for animals to have some uniform parts; for perception is in these, while actions are present through the mediation of the non-uniform parts. (*Parts of Animals* II.1 647a 22-25)

That is, because all animals have sensation, and because sensation requires homogeneous parts, all animals will have homogeneous parts. This is a final causal explanation of a feature common to all animals, with reference to a cause present in all animals—organs of sensation. This general approach to explaining parts and functions and the variation they exhibit from animal to animal is articulated explicitly in Aristotle's work specifically on the motive organs--*De incessu animalium* (quoted above, p. 54).

As I suggested in my discussion of his *historia* of the throat, Fabricius is interested precisely in understanding what animals have a part, and why. He is also interested in understanding the variety and differences in throats displayed by different species; he wants to provide explanations of these differences. In both cases, the explanations, for Fabricius, will be final causal, teleological explanations, in which, typically, the identified action of a part will be the final cause for the sake of which the part is and has the features and subparts it does.

These explanations are revealed in his discussions of the *utilitates* of the parts; for there he shows how the parts are fitted to their action, and how their variations are fitted to variation either in the action or the context of that action. By identifying the usefulness of variation, that is by identifying how the various features and parts of an organ contribute to the action of that part, Fabricius is providing final causal explanations of those features and parts. Furthermore, for Fabricius, the actions of the parts, as we have seen, have their own usefulness. They contribute to some life activity or other—that is, they are at the service of some part of the soul:

> The action of muscle, then, is contraction or tension, which the muscle carries out, not for its own sake, but for the sake of some good—that is, in order to carry out the offices of the principle part of the soul—that is, in order by sense to discriminate and by motion to undertake and do everything.[134] (408)

It will be in reference to the varying *utilitates* of an action of one kind of part in its various instances that this difference in action and context will be articulated.

Although this has been implicit in much of the discussion above, it should be stressed explicitly that for Fabricius, as for Aristotle and Galen, to identify the contribution a part or its features makes to the actions of the animal—and ultimately to its life—is to identify a *causal* factor, the final cause, *responsible* for the presence of that part or feature. Fabricius is not simply interested in understanding *how* animals carry out the various activities, he is interested in determining *why* the parts and activities are present as they are. Furthermore, Fabricius is not interested only in understanding *how* the various activities animals exhibit do in fact contribute to the preservation of the animal, but in explaining *why* those activities are present. Fabricius aims to determine what is responsible for the presence of the parts and activities, and, following Aristotle and Galen, he believes that the fact that they contribute in the specific ways that they do

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[134] Musdculi igitur action, contraction seu tension est, quam musculus exequetur, non propter seipsum solum, sed alicujus boni gratia, quod est, ut animae principalis partis munera exequatur, quae sunt, ut sensu quidem cognoscat, motu vero cuncta moliatur, & faciat.

to the preservation of the animal and its characteristic life (the *actio plenior* of *Parts of Animals* I.5) is precisely what is responsible for their presence.

Comparison to analyses of "function" in contemporary philosophy of biology can help make the import of this point clear. Two main approaches to "function" have provided the framework and starting point for much recent work on "function." These are the etiological analysis of function (so-called Wright-functions) and the systems analysis of function (so-called Cummins-functions). In his important articulation of a systems analysis of function (Cummins 1975), Robert Cummins argues that to identify the function of a component of some larger system is to identify the exercise of a simpler capacity of that component, which exercise is referenced in a function-analytical explanation of a more complex capacity of the larger system. A function-analytical explanation, in turn, is one that explains such a complex capacity by showing how the spatiotemporally structured exercise of simpler capacities of components of that system bring about or constitute the exercise of the complex capacity. The 'function' of a component is the contribution it makes in that explanation. In his analysis, Cummins insists that assigning a function to a component does not imply that the component is there *because* of that function. That is, he rejects Larry Wright's etiological analysis of "function," according to which a function ascription is explanatory (Wright 1976). For Wright, to identify the function of a component is to provide an (elliptical) explanation of its presence. Such explanations, according to Wright, have a distinctive feature: they provide consequence-etiologies. The function is an effect or consequence of the component that is responsible for the presence (appears in the etiology) of that part.

Fabricius's teleology is an etiological teleology and not merely a systems teleology. Fabricius's anatomical study does, of course, involve coming to understand *how* the animal works, how its various activities get carried out by the exercise of the capacities of the component parts. For Fabricius, the anatomist will be able to provide a function-analytical explanation of animal activities, but that is not the ultimate goal. The anatomist's research terminates, instead, in an etiological explanation of the presence of those component parts, their activities and their variations. The etiology is a final causal etiology. The idea that the contributions parts and activities make to the preservation of the animal and its characteristic life is responsible for the presence of those parts and activities—that is, the idea that final causes are causally relevant to the presence of those part and activities—reflects a view of nature (and its Author) as purposeful. Although the extent to which Fabricius embraces a Platonic or Aristotelian view of the purposive character of nature is not always clear, it *is* clear that for Fabricius, nature acts for ends, and, so, those ends causally determine the presence of the parts.[135]

Fabricius, in his anatomical research and writing, studies physiological systems united by serving one common activity or function. He structures his work according to a Galenic distinction between a part, its action, and its *utilitates*. In his first section, he provides descriptions of the part, often paying attention to the range of animals in which the part is found, and the systematic variations in that part from species to species. In the second section, he discusses the action of the part. With these in place, he can go on to his discussion of the *utilitates* of the part in the third section, where he makes plain the final causal explanations for the presence of the parts, its features, and their variations, in terms of the identified action (as

[135] The lack of clarity is due in part to the fact that Fabricius borrows language freely from Plato, Aristotle, and Galen (he speaks of nature acting for the sake of something; he speaks of the Craftsman's purposes, etc.), but he does not explicitly clarify how he thinks this language fits together. For my purposes, I do not need to attempt to resolve these ambiguities. It is enough to establish that Fabricius aims at final causal explanations of the parts, and so exhibits an etiological rather than systems teleology. Lennox (1985) has an interesting discussion of teleology in Plato (with some comparison to Aristotle's teleology.

final cause) of that part and the variation in that action and its context from instance to instance (as variation in that final cause). This is the essential structure of Fabricius's philosophical anatomy. With this in place, we can examine more fruitfully the presence of mathematical mechanics in *De musculi utilitatibus*.

3.3 FABRICIUS'S TELEOMECHANICS OF MUSCLE

As has been noted above, Fabricius published his works on muscles and joints together. The opening sentences provide the rationale we would expect from Fabricius, for he identifies them as the principle and proximate instruments of a particular animal function:

> We will now treat first the fabric of the muscles, and then also the joints of the bones. These are the principle and proximate instruments of the locomotion of the animal, and locomotion is judged the most perfect action of the animal….[136] (383)

His work on muscles and bones is an example of his systems-based approach to anatomical research. He understands the muscles and to a lesser extent the joints of the bones to be the instruments of all locomotion—not only of animals progression, but also of all the motions of the parts involved in activities as various as eating, looking and expelling excrement. Besides being system-based, his works on muscles and joints are also structured by his standard distinction between the description of the part and its variation, the treatment of its action, and the discussion of its *utilitates*.

[136] Agemus nunc primo de musculi fabrica: inde etiam de ossium dearticulationibus: Quae praecipua ac proxima instrumenta sunt motus animalis localis: qui perfectissima animalis action…

After introducing the work on muscles and joints as a whole, stressing the ubiquity of motion in the life of animals, Fabricius begins his work on muscles:

> First then we will take our beginning from the fabric, *historia*, dissection, structure or composition of the muscle, as it is from Galen, and make clear its action and disclose each *usus*.[137] (383)

It is in the final section on the *utilitates* of muscles that Fabricius makes the most conspicuous use of mathematical mechanics. First, in the section on the fabric of the muscles he discusses the subparts of the muscles, like flesh, membranes, arteries, veins, nerves, tendons, and the constitution of muscle especially out of flesh and *nervaceum corpus*. He then discusses variation in these parts as they constitute different muscles. He finally turns to features belonging to muscles as a whole instruments:

> Because the fabric of the muscle is constructed from similar [i.e., homeomerous] parts, the muscle is constituted an organ[138] which requires a certain magnitude, shape, position, number, connection, insertion, and other differentia of an organ and dissimilar body, the treatment of which is presently laid out. [139] (393)

Here Fabricius discusses the important variations exhibited by muscles in shape, dimensions, number, and in the nature of the origin and end of the muscles, as well as of the tendons. This leads eventually to a discussion of the presence or absence of muscles (or something analogous) and their major variations in all animals, divided into four categories or grades. It is in discussing

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[137] Primum igitur a musculi fabrica, seu historia, seu dissection, seu structura, seu compositione exordium sumemus, utputa quae ex Galeno, & actionem ostendit, & usus quoque detegit, uti audietis.

[138] An organ, unlike a similar part, has a particular shape, size, structure, position, etc. proper to it. The distinction is between, e.g., the liver and blood. To be a liver, a part must have a particular shape, etc. In contrast, blood does not require any particular shape or size.

[139] Extructa musculi ex partibus similaribus fabrica, jam musculus organum factum est, quod exposcit certam magnitudinem conformationem, positionem numerum, connexionem, insertionem, & reliquas organi, & dissimilaris corporis differentias, quas modo persequi propositum est.

the usefulness of muscles with respect to these properties of muscles as wholes that Fabricius will introduce mechanical considerations in to his discussion in *De musculi utilitatibus*.

Before Fabricius turns to exhibit such teleological explanations of the presence and variation of muscles across animal kinds, he first identifies and discusses the action of the muscle. Besides the correlations articulated in the *historia* section, the action of the part features centrally in these explanations. Fabricius identifies the action of muscle as contraction or tension, and he identifies what he calls the "*nervaceum corpus*" (i.e., the fibers, not the flesh) as the principal part responsible for this action. He also discusses how this contraction contributes to the life of the animal (i.e., he discusses the *utilitates* of the *action*). Here he stresses the wide variety of activities to which muscle contributes by its contraction, including, for example, progression, eating, looking, and holding and expelling waste. Ultimately, suggests Fabricius, all of these activities are, in one way or another, at the service of pursuing what is beneficial and avoiding what is harmful.

This variety of ways in which individual muscles contribute to the life of the animal by their contractions grounds the teleological explanations of the variety found in muscles in the final section, *De musculi utilitatibus*. Here Fabricius discusses the subparts and features of the muscle, following the same general order of exposition he used in the section on the *historia* of the muscle. He begins with the way the various subparts of muscles (i.e., veins, arteries, flesh, nerves, and tendons) render them fitted to its identified action—that is, he traces the *utilitates* of the components of muscles. He then turns to consider the *utilitates* of muscles as wholes:

> Having explained the *utilitates* of the parts of muscle, it remains to explain the *utilitates* of those features that belong to the whole muscle. Now position,

magnitude, connection, figure, number, and insertion do so belong; from all of these as from proper sources *utilitates* are acquired.[140] (414)

It is here that Fabricius introduces mechanical principles. What role do these principles play in the discussion of the *utilitates* of muscles? These principles, I suggest, are primarily used to articulate the hypothetical necessity according to which certain features of the muscles are required, given the role the muscle's action plays in the life of the animal.

In order to see this, and to see how it is simply one instance of a general approach in which material considerations are invoked to articulate the hypothetical necessity of features of parts, I first look at his discussion of the *utilitates* of the veins in muscles. I then compare this to his discussion of *utilitates* of the insertion points of muscles, where mechanical principles are invoked. The discussion of the veins is brief and can be quoted in full:

> Now it is said that the veins and arteries (especially the veins) come together in the fabric of the muscle so that the muscles, like a plant, may be nourished and continue living. Now this is especially so for muscle, as much as it receives and demands much larger veins and arteries than the other parts of the body. For where a greater portion of fleshy, hot, loose and soft substance is lost, it was appropriate that abundant blood be available and large veins lead for the purpose of restoring [that portion]. But if one of the parts of muscle is observed to be fleshier, or another dedicated to more frequent motion, then for this same reason also more frequent and larger veins will be provided to them.[141] (409)

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[140] Expositis utilitatibus partium musculi, supersunt utilitates eorum, quae toti musculo accidunt exponendae. Accidunt autem Positio, Magnitudo, connexio, figura, numerus, insertio; a quibus omnibus tamquam a propriis fontibus utilitates desumuntur.

[141] Jam dictum est venas & arterias, maxime autem venas, concurrere ad musculi fabricam, ut tanquam planta, musculus tum nutriatur, tum in vita parmaneat. Veruntamen illud primatim musculus nanciscitur, quod venas &

The veins, in general, distribute nourishment to the parts of the animal. In explaining their presence as components of muscle, Fabricius identifies the way this renders the muscle fitted to its action. The veins provide the necessary nutriment for keeping the muscle alive. That the muscle receives in general larger and more veins than other organs is explained with reference to muscles being especially prone to losing a "greater portion of fleshy, hot, loose and soft substance," and so in greater need of nourishment. The muscles tend to lose such material for two reasons, it seems. First, they are often very fleshy; second, when contracting they tend to lose material. This also explains the variety in the size and number of veins leading to different muscles. The more flesh in the muscle and the more frequently it is used (the more frequently it performs its action), the larger and more numerous the veins.

How frequently a muscle will contract is connected, in turn, to what contribution it makes to the life of the animal. As his discussion of the *utilitates* of flesh in muscle makes clear, for Fabricius, flesh contributes in various ways to the strength and facility with which a muscle contracts and to the protection of the muscle's principal part. Muscles vary in their need for this strength, facility, and protection depending on the role they play in the life of the animal. So, like the variation in the size and number of veins leading to muscles, the variation in fleshiness of muscles will be explained with reference to the activities to which the muscles' contractions contribute. In both cases, the role the muscle plays explains and renders necessary certain features of the muscle. This hypothetical necessity is grounded in material considerations like the behavior of fleshy, hot, loose, and soft material in the circumstances of contraction. Given these

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arterias longe majores admittit, & expetit, quam caeterae coporis partes: sicut enim ex carnosa substantia, calida, laxa, & molli, major portio defluit, ita copiosum sanguinem suppeditare, & grandes venas deducere ad eam resarciendam oportebat. Quod si ex musculi partibus alia carnosior, alia vel motui frequentiori dicata observetur, huic quoque propter eandem rationem venae frequentiores, & majores obtigere.

features of the material and behavior involved, a certain fleshiness and provision of veins is rendered necessary, given the role of a particular muscle.

This same structure will be present in the consideration of the *utilitates* of the features of the muscles as wholes. One of these features is the insertion point of the muscle in the bone it moves. Fabricius says muscles have varied insertion points:

> For some are inserted into the beginning of the moving bone, others beyond, that is, either up to the middle, nearly into the middle, or beyond the middle. For the muscles which bend the second and third joints of the digits, likewise those of the elbow and of many others are inserted into the beginning of the bone to be moved. The deltoid muscle is inserted into the middle; the muscle drawing the arm to chest into short of the middle; the internal muscle of the femur, beyond the middle of the moving bone.[142] (416)

After characterizing the variation under consideration, he goes on to identify how these variations fit the various muscles to their particular actions.

> The *utilitas* of these variations is as follows: whenever nature sets up simply to move a bone, she always makes the insertion and the end of the muscles towards the beginning of the moving bone, as is the case in most muscles. Whereas if beyond the motion of the bone to be moved, nature also requires a strong motion, then she establishes the insertion beyond the beginning of the bone to be moved:

[142] Nam alius in principium ossis movendi inseritur, alius ultra, hoc est, vel ad medium, vel prope medium, vel ultra medium. Nam musculi secundum, & tertium articulum digitorum flecentes, item cubiti, & aliorum complurium, ad principium ossis movendi. Musculus vero delthois ad medium; musculus adducens brachium ad pectus, citra medium; musculus internus femoris, ultra medium os movendum inseritur.

> and the further from the beginning the insertion is, the stronger the motion following.[143] (416)

The variation in needed strength of the motion of the moved bone explains the variation in the insertion point. Fabricius traces this need for strength in the motion, in turn, to the role that motion plays in the life of the animal:

> At this point it is appropriate finally to understand that [among] strong motions, some are going to be strong from themselves and through the proper nature of the action of the member (as are the first and second muscles flexing the digits of the hand); others are going to be strong for another reason, evidently on account of the weight of the bone or the member to be moved (for example, such are the muscles of the femur, the humerus, and the shoulders); finally others are going to be strong because of each cause. For example, such are the muscles of the elbow and knee; for by the elbow large and heavy bodies are lifted and raised; in addition, the remainder of the arm is raised and carried—and similarly with the knee.[144] (416)

The strength of the motion is required because the muscle moves a larger part of the body in addition to the bone it moves directly, or because the bodily motion itself must be strong, or for both reasons. Thus, the role the action of the muscle plays in the animal explains and renders the strength of the motion produced by the muscle necessary or best. This needed strength of motion,

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[143] Utilitas autem hujus verietatis est; ut quotiescunque natura simpliciter os movere statuit, perpetuo ad principium ossis movendi insertionem, & finem musculi faciat, uti contingit in plerisque musculis. Quod si paeter motum ossis movendi, robur quoque motus natura exposcit, tunc ultra principium ossis movendi insertionem molitur: & quo longius a principio insertio sit, eo robustior succedit motus.

[144] Quo loco illud scire postremo convenit, quod robusti motus, alii ex se, & per propriam naturam actionis membri futuri sunt robusti, ut sunt primi & secundi musculi digitos manus flecentes: alii futuri sunt robusti ratione alterius, videlicet ponderis ossis, seu membri movendi, ut sunt musculi femoris, humeri, scapularum: alii denique futuri sunt robusti, propter utramque causam, ut sunt musculi cubiti genu. Nam cubito magna, & ponderosa copora sublevantur, & attolluntur. Praeterea reliqua manus similiter attollitur, ac gestatur: Similiter & genu.

in turn, explains and renders necessary the insertion point. In order to understand the necessity of the final step—in order to grasp the reason why the further out the insertion point, the stronger the motion—one must bring in material considerations. In this case, as we shall see, these considerations include mechanical principles.

The insertion point is one of three features that appear in the body of his discussion briefly, but to which Fabricius gives special attention at the end of the treatise. He opens this final discussion by listing the problems and stating that each has a mathematical and natural cause:

> In the last place there remain three problems, which have been mentioned briefly several times before, but which are to be discussed more exactly in this last part.
>
> 1. Why the origin of muscles is always more raised than its end.
>
> 2. Why muscles whose ends are not in the beginning of the moved bone, but further up move the moved bone more easily.
>
> 3. Why the longer muscles produce not only longer but also stronger motions.
>
> . . .
>
> A natural and a mathematical, or better mechanical, cause can be given for all of these.[145] (416-417)

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[145] Ultimo loco tria supersunt Problemata, quae aliquoties paulo ante memorata sunt: sed in hac ultima parte exactius sunt discutienda.

> 1. Cur musculorum origo perpetuo est suo fine elatior.
>
> 2. Cur musculi quorum finis non est in principio ossis movendi, sed ultra, facilius movent os movendum.
>
> 3. Cur musculi longiores, non solum longiores, sed etiam robustiores dant motus.
>
> 4. His quartum ex Galeno addendum, videlicet cur pondera, quae manibus movere non possumus, aut vectibus adhibitis, moliri & attollere, aut chorda appensa trahere, ac transferre consvevimus.

Horum omnium causa reddi potest, tum naturalis, tum Mathematica, seu potius Mechanica.

He then provides two discussions. In the first, he provides "natural" causes, and in the second, "mechanical" ones.

The "natural" explanation he gives for question 2 is the same as that provided earlier in the text when he first examines variations in insertion point. There he explained the correlation between further insertion points and stronger motions:

> The cause of this is that all the insertions of this kind inasmuch as they subtract part of the length of the bone and member to be moved, so the weight is subtracted and a shorter remaining member to be moved is delivered, and hence it is moved more lightly and easily.[146] (416)

The claim here, then, is that the muscles with insertion points farther from the joint have, effectively, a smaller load to move. The idea must be that the muscle is only moving the part of bone that extends beyond the insertion point. It is this consideration that reveals the connection between stronger motions of limbs and insertion points, and so grounds the hypothetical necessity by which a certain role for the muscle determines the insertion point.

Fabricius returns to this question in his "mathematical" or "mechanical" discussion. Here too the causes identified are meant to ground the hypothetical necessity connecting the role of the muscle and its insertion point. However, the necessary connection is revealed by noting that the muscle and bone have the *ratio* of a lever. Fabricius suggests they have the *ratio* of a lever in at least two ways. He discusses each of these ways and also provides a third discussion of the limb as a lever, grounding the law of the lever in the nature of circular motion. In each case, in

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Fabricius adds a fourth problem to these three: "To these a fourth from Galen is added: why weights which we cannot move by hand, we are accustomed to set in motion and lift by applying levers or drag and transfer by an attached rope."

[146] Causa autem hujus est, quod omnes ejusmodi insertiones uti subtrahunt partem longitudines ossis, & membri movendi, sic pondus subtrahitur & brevius redditur membrum reliquum movendum, ac proinde ad motum levius, & facilius.

order to show how the limb has the *ratio* of a lever, Fabricius identifies the fulcrum, the applied force (*vis movens* or *vis deprimens*), and the weight to be moved or elevated (*pondus elevandum* or *pondus attolendum*). Fabricius treats the limb as an *inverted* lever, with the muscle insertion providing the fulcrum:

> Can it be that the solution to this question is to be sought from the nature of an inverted lever? Can it be then that the cause of this thing is that the moved bone is made just as a lever whose fulcrum is above the end of the muscle? Indeed, it can be considered a lever in two ways.[147] (419)

The first way in which the moved bone can be considered a lever locates the *vis deprimens* in the beginning of the moved bone (the end terminating in the joint flexing). He identifies it as the weight of the bone or at least of its extremity (*gravitas ipsius ossis movendi, vel etiam gravitas ossis extremi*). The weight to be elevated he identifies as the whole load of the bone from the insertion point to the end of the bone (*tutum onus ossis movendi, a fine musculi ad extremum usque*). He then says that the farther the insertion point is from the joint, the longer and therefore heavier is the *vis deprimens* and the shorter and therefore lighter is the *pondus elevandum*. Thus, the farther the insertion point, the easier it is for the beginning of the bone to elevate the rest of the bone (419). Although this account is similar to the natural explanation in treating the portion of the bone extended beyond the insertion as the load, it differs from that natural explanation in treating the insertion point as the fulcrum and the weight of the bone from the joint to the insertion point as the moving force. In the natural explanation, there was no lever; there was simply the muscle moving a load.

[147] An ex natura vectis inversi petenda est solutio quaestionis? An ergo hujus rei causa est, quod os movendum fit veluti vectis, cujus fulcimentum sursum est finis musculi? Duplex vero vectis considerare potest

In describing the second way the moved bone shares the *ratio* of a lever, Fabricius exchanges the moving force and the weight to be elevated. Now the *vis movens* is the heaviness of the end of the moved bone and is in that end (*vis movens sit in fine ossis movendi, ipsius videlicet gravitas*). The beginning of the bone and the adjacent parts are then the weight to be lifted (*pondus attolendum*). He then says that in a lever, the moving force is more powerful the farther it acts from the fulcrum. This, he says, means that the (effective) heaviness of the end of the bone will be greater the farther it is from the insertion point. And this, he claims, means that that end of the bone will press the fulcrum more heavily (i.e., it will press down on the muscle more heavily). Conversely, the closer the insertion point is to the end of the bone (in other words, the farther it is from the joint), the lighter will be the weight of the bone on the insertion point. "So on that account, the further beyond the beginning of the moved bone the end of the muscle is, the easier will the moved bone be moved" (419). It is worth noting that, unlike the first way of considering the moved bone as a lever, here mechanical advantage is involved. In the first case, no change in mechanical advantage was identified, only a change in the magnitudes of the moving force and the weight to be elevated.

After providing these two treatments of the bone as a lever, he rehearses briefly the Aristotelian grounding of the law of the lever, and identifies the insertion point with the center of circular motion and so the fulcrum:

> Furthermore, all these things are sought from the nature of the circle. Certainly the longer a line is from the center, the faster it is carried, and thus more easily raises the shorter line produced beyond the center [i.e., on the other side of the center]. Therefore let the end of the muscle be the center, the parts of the bone

extending on both sides be the lines proceeding from the center, the longer of which will more easily raise the other.[148] (419)

He then goes on to claim that his analysis of the bone as lever is acceptable even if the fulcrum is not fixed but is moved while one end of the lever remains still:

> Nor is it important to this analysis whether one part of the lever is pressed down and the other raised by means of the fixed still fulcrum of the lever, or whether the fulcrum moves itself and one part of the lever by means of the fixed still beginning of the other part of the lever, being endowed with a force for the purpose of raising itself.[149] (419)

He is suggesting that the two situations are equivalent. These he presents using two diagrams (see Figure 5 below, which reproduces Figure 3 for convenience). In the upper diagram, we have a standard lever, with fulcrum L. The applied weight H presses at F, elevating G. This is then said to be equivalent to the situation in the lower diagram. Here we have, says Fabricius, an inverted lever with the fulcrum at M. The portion MB is to be elevated by some moving force. However, this is accomplished not by a force being applied on the other end, but

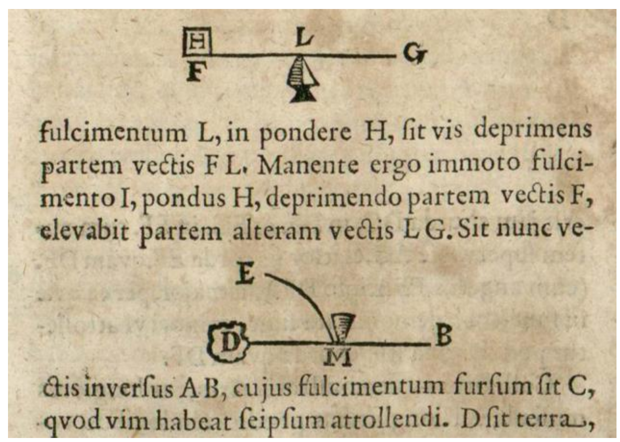

Figure 5. Fabricius, *Opera omnia anatomica & physiologica* (1687), 419.

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[148] Porro haec omnia ex natura circuli petuntur. Nimirum quo longior a centro linea est, eo celerius fertur, ac proinde facilius attollit breviorem, quae ultra centrum producta est, lineam. Fit ergo finis musculi centrum, partes autem ossis utrinque extantes a centro proficiscuntur lineae, quarum quae longior fuerit, facilius alteram attollet.

[149] Nec refert ad rem propositam sive fixo manente fulcimento vectis, deprimatur pars una vectis, & altera attollatur, sine [sic: should be *sive*] manente fixo principio unius partis vectis, fulcimentum ipsum attollat sese, simulq; [i.e., *simulque*] alteram partem vectis, praeditu scilicet vi ad se seipsum attolendum.

rather by having that end fixed (by contact with D); the motion is accomplished by the fulcrum raising itself from M to E, elevating MB and incidentally also the part from M to D. This latter instance, presumably, is supposed to be the situation with a joint. The fulcrum is the insertion point of the muscle into the moved bone, which makes a joint with another bone at D. The muscle contracts and, by means of its attachment to D, elevates the insertion point and the whole bone.

For my purposes, it is not important to consider the skill with which Fabricius attempts to analyze the movement of the limb in terms of levers, or evaluate his equivalence claim.[150] What is important is to return to the question of the role of mechanics in Fabricius's work. The mechanical principles are invoked in order to reveal the cause of the connection between insertion point location and ease of motion. They are grounding the hypothetical necessity connecting the function of a muscle and several of its features. Thus, the mechanical principles play the same kind of role as the principles of matter theory grounding explanations of the usefulness of hot, moist flesh surrounding the contracting fibers of the *nervaceum corpus* or of the presence of large veins in fleshy muscles. Mechanical principles, like those of matter theory more generally, are being integrated into the teleological explanations of part variations at the heart of Fabricius's project in *De musculi utilitatibus*, and indeed in all his discussions of the *utilitates* of parts.

It should be noted that since these mechanical principles are grounding the correlation between the insertion point and the strength of motion, they *could* also be invoked in explanations of the strength of that motion. Given the insertion point and other relevant anatomical facts, one could use mechanical principles to provide such an explanation. Although

[150] The equivalence claim fails, and the whole discussion seems crippled by his identification of the insertion point as the fulcrum.

this *could* be done, this is not what Fabricius *actually* does. Scholars like Jaynes and Baldini, by failing to appreciate Fabricius's Galeno-Aristotelian anatomical project, misinterpret Fabricius's use of mechanics, perhaps tacitly assimilating his efforts to a story of a 17th-century rise of mechanism and the decline of Aristotelianism and its teleological modes of explanation.

3.4 FABRICIUS, ARISTOTELIANISM, AND MECHANICS

But for Fabricius there is no essential give and take between the application of mechanics and the employment of Aristotelian resources. Indeed, Fabricius seems to take his mechanics to be a part of his Aristotelianism, rooted in the *Quaestiones Mechanicae*, and embodying the non-reductive character of an Aristotelian subordinate science.

Recall that it is clear that Fabricius takes the (pseudo-)Aristotelian *Quaestiones Mechanicae* to be the central exemplar of mechanics. First he references the text at numerous places, attributing it to Aristotle.[151] Another clear indicator that he takes this text to be the central exemplar is his rehearsal of the text's grounding of the law of the lever in the properties of circular motion. As mentioned above, he refers the behavior of the lever in his treatment of the usefulness of insertion points to the nature of the circle.[152] He also refers to this approach in a discussion on the action of the joints.[153] Recall also (from the last chapter) that Fabricius's longtime colleague at Padua was Guiseppe Moletti and that for Moletti

[151] See, for example: "An ergo de vecte bene respondet Arist. q. 3. Mechanica?" (419). And: "…juxta Aristotelem in Q. 29. Mechanica." (420).
[152] Porro haec omnia ex natura circuli petuntur. (419)
[153] Quinimmo Aristot ubi agit de admirandis circuli proprietatibus, vult, unum admirabile esse, videlicet circulum constitutui ex contrariis… (429)

> [t]he subject of mechanics … is not simply machines, but rather sensible quantity mobile in circular motion or compounded from it. The properties of mechanics are the powers and virtues of such machines for lifting and drawing weights and for throwing projectiles. (Laird 1986, 61)

We have already noted that Fabricius clearly refers the behavior of levers to the nature of the circle, embedding himself in this tradition.

It is worth emphasizing that in an Aristotelian approach sciences like mathematical optics and mechanics are understood to have a limited but genuine scope—an Aristotelian approach to the mathematical sciences is a non-reductionist one. The natural objects being considered do not exhibit only mathematical properties, but they *do* exhibit those mathematical properties considered by the science. This aspect is also reflected in Fabricius's approach, and distinguishes it from an approach like Descartes's or, perhaps, even Galileo's. For Fabricius throughout his work rallies much of the Galenic and Aristotelian natural philosophy, invoking the elements, elemental qualities, temperaments, faculties, souls, and on and on. Furthermore, there is no evidence that Fabricius thinks the employment of mathematical mechanics will be aimed at providing alternative explanations of phenomena typically referred to these more traditional natural philosophical resources. Nor does he seem to think he will provide more fundamental accounts of these resources themselves in mechanical terms. In addition, we have seen that he does not see any tension or dichotomy between the employment of mechanical principles and the use of teleological explanations.

Fabricius seems to think instead, that mechanical principles and reasoning provide genuine knowledge of certain necessary connections between structures and the effect of moving forces applied to those structures. These necessary connections will be relevant to animal anatomy, because certain parts of animals (muscles and bones) exhibit these structures, and are furthermore the soul's principle and proximate instruments for causing motions, motions which it accomplishes by the application of moving forces. For these reasons, mathematical mechanics will be employed in teleological explanations of those parts, revealing the hypothetical necessity by which the specific functions the instrumental parts play entail and explain features of those parts.

4.0 WILLIAM HARVEY AND HIS SKETCH FOR AN INTEGRATED TELEOMECHANICS OF MUSCLE

William Harvey had significant interest in the study of animal locomotion and muscle anatomy. He announced his intention to publish on the motive organs of animals, and particularly on muscles, in the final chapter of *De motu cordis*.

> This truth concerning local movement, and that the immediate motive organ in every movement of all animals in which there is from the beginning a motive spirit, as Aristotle says in his book *De spiritu* and elsewhere, is contractile, and in what way *neuron* is derived from *neuo*, that is I nod, I contract, and that Aristotle did recognize muscles and not incorrectly referred every movement in animals to the nerves or to that which is contractile and therefore called those muscular bands in the heart nerves, all this I think will be made clear if at any time I shall have liberty to demonstrate from my own observations these matters concerning the motive organs of animals and the structure of the muscles.[154] (68)

[154] Quae veritas de motu locali, & quod immediatum organum motiuum in omni motu , omnium animalium in quo spiritus motiuus (vt Arist.dicit *libro de spiritu & alibi* primo inest) sit contractile, & quemadmodum neuron a neuw, nuto, contraho dicatur. Et quod Aristot. Musculos cognouit, & non operam, omnem motum in animalibus retulit ad neruos siue ad contractile, & proinde illos lacertulos in corde neruos appellauit, si de motiuis organis animalium, & de musculorum fabrica ex obseruationibus nostris, quandoque demonstrare liceret, palam arbitrarer foret. (The translations from the *De motu cordis* are from Whitteridge's edition (Harvey 1976). Page numbers are to the Frankfurt 1628 edition (Harvey 1628).

However, he never did; what we have, instead, is a set of working notes on the subject. These notes have been edited and published by Gweneth Whitteridge as *De motu locali animalium, 1627* (G. Whitteridge 1959). In these notes, Harvey interacts most prominently with the works of Aristotle, Galen, and Fabricius ab Aquapendente. Inspired by resources in their works, Harvey sketches a program for the study of muscles that, like Fabricius's, seeks to integrate mathematical mechanics into teleological explanations of muscle variation. Also like Fabricius's, Harvey's use of mechanics has been misunderstood. What treatment Harvey's use of mechanics has received in the literature rightly connects it with Fabricius's project; but for this very reason, at least implicitly, the interpretations go wrong in the same way they do for Fabricius.[155] Harvey is not primarily interested in providing explanations of animal motion in terms of a descriptive mechanics of the animal. Rather, he is attempting to provide teleological explanations of muscle anatomy. Although they are rough and provide only a sketch for this project, Harvey's notes can be contrasted with Fabricius's work in the way they reflect a more self-conscious effort both to justify this extension of mechanics into the teleological explanations of anatomy and to provide a systematic approach to this extension. Harvey aims to identify a unified pocket of features of muscle for which such a teleomechanical explanation is required. This self-conscious, systematic approach is reflected, not least, in the way Harvey devotes an entire section of his notes to the integration of mechanics into his project, which he calls "*De artificio mechanico musculorum*"

Harvey's project challenges the conceptual and historiographical resources typically brought to the study of "mechanism" in the 17th century. Mechanism in the 17th century is often placed in contrast and conflict with Aristotle, or with teleology, or with appeals to faculties and soul. However, in Harvey's project we find mechanics *and* Aristotle, mechanics *and* teleology,

[155] Both Baldini and Jaynes connect Harvey's efforts to Fabricius's.

mechanics *and* soul and faculties.[156] Similarly, by "the rise of mechanism" in the 17th century is often meant (1) conceptual and technical developments in the mathematical science of mechanics, particularly in the tradition of Archimedes; or (2) the rise of natural philosophies that see as legitimate reference only to a restricted set of attributes, e.g., extension, motion, etc.; or (3) the increasing heuristic and rhetorical use of machine analogies in the explanation of complex natural phenomenon. Once again, Harvey does not fit. His project is not properly characterized by any of these. Harvey's *De artificio mechanico musculorum*, I will argue, is best illuminated by comparing it, not to the work of Galileo, Descartes, or Boyle, but to Aristotle's characterization and presentation of the "science of the rainbow" in *Posterior Analytics* I.13 and *Meteorology* III.

In this chapter, I aim to articulate and argue for this account of Harvey's use of mechanics in his notes on muscle anatomy. In order to do this properly, I need to show how his use of mechanics fits into the general project of these notes. I argue that the notes provide a sketch for an "*anatomia philosophica*" of muscles.[157] However, in order to make this argument in Section 4.2, I must first explain what I mean by "*anatomia philosophica*." To do this, I examine especially Harvey's notes for his Lumleian lectures (Section 4.1). I coax out of these notes Harvey's understanding of the nature, goals, and methods of anatomy, in general, and *anatomia philosophica*, in particular. I also argue that Harvey has an explicit understanding of how his comparative and dissectional method is aimed at arriving at characteristically

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[156] Bertoloni Meli (2011, 12-13) nicely discusses the prominence of the contrast drawn between mechanism and soul in the second, post-Cartesian half of the seventeenth century (his earliest reference is to Henry More's 1659 *The Immortality of the Soul*, which is explicitly responding to Descartes). It is important, however, not to conflate the intellectual landscapes of the early and later seventeenth century.

[157] On the basis of this interpretation of Harvey's project and other textual evidence, I will argue the notes would be better called *Anatomia Musculi*.

Aristotelian understanding of the parts of animals: universal, final causal explanations of parts as present in all animals.

Implicit in my approach is a general dissatisfaction with what one might call "two Harveys" approaches to understanding the anatomist and his works—approaches that are overly preoccupied with establishing strong contrasts between "modern" or "revolutionary" and "traditional" or "Aristotelian" facets in Harvey's works. Such interpretations tend to fracture Harvey's thought, isolating specific works or features of Harvey's method from one another, and so limit our understanding of Harvey's anatomical project. In an effort to counter this tendency, I show how the *De motu cordis* reflects Harvey's unified, teleological, comparative and experimental method in *anatomia philosophica* (Section 4.3). I conclude by examining the place of mechanics and mechanism in Harvey's works, more generally, arguing that even here there was only "one Harvey," a creative Galeno-Aristotelian anatomist, inspired to a large degree by Fabricius (Section 4.4).

4.1 *QUONIAM FINIS ANATOMIAE EST…* : UNDERSTANDING HARVEY'S *ANATOMIA PHILOSOPHICA*

To coax out Harvey's understanding of *anatomia philosophica*, I focus on his *Prelectiones Anatomiae Universalis*.[158] This set of notes is particularly helpful, because they open with an explicitly methodological discussion of the definition, divisions, and goals of anatomy. This

[158] For an orientation to the manuscript and Harvey's tenure as Lumleian Lecture which occasioned them, see Whitteridge's edition of the notes (G. Whitteridge 1964).

accessus of sorts is a rich resource[159]—particularly so, if it can be connected with Harvey's practice as reflected in his discussions of individual organs throughout the *Prelectiones* and in his other works.

4.1.1 Defining and Dividing Anatomy

After the title page, on the first folio of the *Prelectiones*, Harvey provides a series of categorizations of the divisions or parts of anatomy. Above this set of distinctions Harvey inserted a definition of anatomy: "Anatomy is the faculty that by ocular inspection and dissection [grasps] the *usus* and *actiones* of the parts."[160] (1v) Whitteridge notes that providing such a definition is a commonplace in anatomy texts, and she refers us to Fallopius's definition in his *Expositio de Ossibus* (Fallopius 1584, 521): "Anatomy is the art, indeed the habit of the mind, by which with the greatest of θϵωρία (i.e., insight [*speculatio*]) we can divide all and even the very smallest internal and also external parts of the body."[161] A comparison with Fallopius's definition highlights two important features of Harvey's. First, like Fallopius, Harvey identifies anatomy, not with a body of knowledge in the abstract, but primarily with a *principle* in the

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[159] Whitteridge 1964 shows convincingly that in the anatomy proper, after this methodological introduction, Harvey depends heavily on Caspar Bauhin's *Theatrum anatomicum* (Bauhin 1605). However, Benjamin Goldberg argues that Harvey's use of Bauhin is more creative than Whitteridge seems to imply (Goldberg, William Harvey, Soul Searcher: Teleology and Philosophical Anatomy 2012). Regardless, Harvey is more straightforwardly responsible for the content and structure of the methodological introduction.

[160] Anatomia est facultas quae occulari inspectione et sectione partium usus et actiones. This and all translations from the *Prelectiones* are my own. I have consulted Whitteridge's translations. Transcriptions are made from the images of the manuscript provided in the 1886 transcription and reproduction (Harvey 1886). In making my transcriptions I have benefited greatly from consulting both the transcription provided in this edition and Whitteridge's transcription (G. Whitteridge 1964). I provide the folio number for the quotations (e.g. "1v" signifies folio 1 *verso* and "3" signifies folio 3 *recto*).

[161] Anatome est ars, vel habitus animi, quo optima cum *θεωρία*, id est speculatio, omens vel minutissimas corporis internas, ac externas particulas dividere possumus. (As quoted by Whitteridge (1964, 4 n. 1).) This footnote also includes Whitteridge's general point that such statements are common in anatomy textbooks. I thank Benjamin Goldberg for a helpful discussion of Fallopius's definition.

anatomist. Fallopius calls it an art or habit of the mind; Harvey calls it a *facultas*. For Harvey anatomy is primarily a particular ability of an individual that is closely related to a body of knowledge. This reflects an Aristotelian understanding of disciplines as states of the knower.

The second important feature of Harvey's definition involves a subtle but significant difference between his and Fallopius's. For Fallopius, the *habitus* is characterized by the activity involved in its exercise: in the exercise of this *habitus* we divide the parts of the body in a particular way—with the highest theoretical insight. For Harvey, however, the *finis* of anatomy is emphasized. The dissection and ocular inspection are the *means* by which the anatomist comes to grasp[162] the *actio* and *usus* of the parts. As shown in the previous chapter, action (*actio*) and use (*usus*) are Galenic terms important in the anatomical tradition of the 16th and early 17th centuries and particularly prominent in Fabricius's publications. Harvey opens a later section of his notes, *In actionibus partium*, by explaining the place of action and use in anatomy:

> Since the end of Anatomy is to know or grasp the parts and to know [them] through their causes and these [i.e., causes], in all animals,[are the] that for the sake of which and that on account of which; therefore: that on account of which: Action; Use.[163] (6)

Anatomy is the faculty that grasps the actions and uses of the parts *because* the end of anatomy is to have causal knowledge of the parts and the actions and uses *are* the causes.[164] Furthermore, action and use are causes *cuius gratia*; i.e., they are the *final* causes of the parts.

This articulation of the end of anatomy also makes it clear here that, for Harvey, anatomy aims to understand the final causes of a part and its variations not just in humans but *in*

[162] Harvey's definition is elliptical, leaving implicit the verb characterizing the relation between the anatomist and the actio and usus of the parts. I take the relation to be cognitive, and suspect Harvey meant to emphasize the act of discovery. 'Grasp' seems to fit the bill reasonably well.
[163] *Quoniam finis Anatomae est scire vel cognoscere partes et scire per causas et hae in omnibus animalibus cuius gratia et propter quid, ergo propter quid: actio, usus*.
[164] See also his statement in Canon 5 (folio 4), "For the end of anatomy is grasping the reason why of the parts" (*Anatomae enim finis partis cognition propter quid*).

animalibus. This is reflected in the titles of Harvey's two main published works: *Exercitatio anatomica de motu cordis et sanguinis* ***in animalibus***; *Exercitationes de generatione* ***animalium***.[165] For Harvey, anatomy aims at universal, final causal knowledge (i.e., Aristotelian *scientia*) of the parts of animals.[166]

Besides the *finis* or object of the faculty of anatomy, Harvey also defines anatomy in terms of the particular *means* by which it arrives at this causal knowledge: ocular inspection and dissection. In this Harvey is like Fabricius, who understood dissection to be at the service of discovering not just structure, but *actio* and *utilitas* as well.[167] This emphasis on what he sometimes calls *autopsia* is related for Harvey to the Aristotelian emphasis mentioned above on disciplines as states of the practitioner. For Harvey, these states can only be arrived at by virtue of the observations and experience associated with dissection. It is under this heading of *autopsia* and dissection, as the means by which anatomy comes to knowledge of the parts, that I subsume both Harvey's use of vivisection (his "experimentalism") and his emphasis on personal experience.

Before examining Harvey's understanding of the goal and method of anatomy in more detail, it is important to note that they are most fully and clearly exemplified in what Harvey calls *anatomia philosophica* as opposed to popular anatomy, on the one hand, and medical anatomy, on the other. Harvey distinguishes these kinds of anatomy in the section headed by the

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[165] Emphasis added.

[166] This is also reflected in Harvey's criticism, at the beginning of *De motu cordis* Chapter 6, of anatomists who look only at human anatomy. I return to this below, in Section 4.3. On the importance of this Aristotelian approach in Harvey's *De generatione animalium*, see work by James Lennox (2006); Goldberg (2012)

[167] "And all of these things we will hunt through dissection. For dissection (if one judges correctly) has this use, (1) to manifest those things that belong to the eyes, that is structure, *historia*; (2) to lead to the notice of the action and faculty; (3) and finally to uncover and reveal the *utilitates* of the eye." (*Haec autem omnia fere per dissectionem venabimur. Dissectio enim (si quis recte aestimet) eum habet usum, ut tum ea, quae oculis insunt, hoc est structuram & historiam, manifestet: tum in actionis facultatisue notitiam deducat: tum denique oculi utilitates aperiat atque declaret*. (1687, 187))

definition of anatomy examined above. There Harvey makes three main sets of distinctions concerning anatomy. As is typical of Harvey's notes, these are organized spatially using a system of brackets (Figure 6 and Figure 7). The most important division for my purposes is into "popular [anatomy] as in this book on the three bellies" (*popularis quae hic libro iij ventrium*) and "inquisitive (or thorough) [anatomy] ([*anatomia*] *curiosa*). This second category is subdivided into seven parts determined by the organs discussed. More important than these seven parts, however, is the fact that the *antomia curiosa* can be philosophical (*philosophica*) or medical (*medica*).[168] Harvey contrast popular anatomy with *curiosa* anatomy; and this latter can be medical or philosophical.

The first distinction, between popular and *curiosa* anatomy, is reflected in Harvey's Rules for a General Anatomy (*Canones Anatomiae Generalis*)[169] on folios 4 and 4v. These rules provide guidelines for the kind of anatomy he is undertaking in his Lumleian lectures—popular anatomy according to the "three bellies." The three bellies are the abdomen (below the diaphragm), the thorax (above the diaphragm), and the head. These three bellies structure Harvey's notes. After his methodological discussion of the nature, goals, divisions, and methods of anatomy, Harvey turns to a discussion of the general divisions of the body, focusing then on dividing the trunk (as opposed to the limbs). Here he identifies, discusses, and provides a general

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[168] With Whitteridge, I interpret the "partes" in the second main heading to be characterizing what each of the seven subdivision is. See Whitteridge's translation (G. Whitteridge 1959, 5). However, against Whitteridge, I suggest that these seven parts should almost certainly be thought of as belonging not to a distinctly medical anatomy, but to a general kind of anatomy that is described by three adjectives: *curiosa*, *philosophica* and *medica*. Careful examination of the location of the point or caret of the bracket for the sevenfold division along with the spacing between the two ends of the main bracket strongly suggest that the sevenfold division is associated with "*curiosa*" and "*philosophica*" as much as with "*medica*."

[169] It should be noted that Whitteridge's transcription of the header for the *Canones* differs from the 1886 edition. The manuscript reads: "Canones Anatom: general." Whitteridge has "Canones Anatomae Generales" while 1886 has "Canones Anatomiae Generalis". I think that the latter is likely more on track; the distinction between popular and *curiosa* anatomy seems to be reflected in the canons, which are oriented toward a popular anatomy. Such a popular anatomy would be a *general* anatomy. Thus, it is likely that these are rules for a general anatomy, not general rules for anatomy.

comparison of the three bellies. He then turns to the lower belly, beginning by treating skin, fat and membranes as encountered in its dissection. Then after treating the organs of the lower belly, Harvey turns to the thorax and then to the head. Such a public anatomy was to take place over three days (one for each belly) and was to show as much as possible to the audience.

Canon 12 makes it clear that the lectures are to be structured around the three bellies: "12. To serve in ther three cors according to the glass: 1° ventris inferioris, nasty yett recompensed by admirable variety; 2° the parlor; 3° devine banquet of the brayne."[170] "The glass," Whitteridge suggests, is likely a reference to time constraints (an hour glass). The concern to get through as much material as possible is also reflected in Canons 7, 10, and 11. For example: "10. Not to speake any thing which with outt the carcase may be delivered or read att home." Canons 1and 8 also reflects that Harvey wants to get through as much as possible, and so cannot treat each part *curiose* (Canon 11). The primary distinction, then, between *curiosa* and popular anatomy

Figure 6. Reproduction of Folio 1v, Harvey's *Prelectiones*

Anatomia est facultas quae occulari
inspectione et sectione partium usus et actiones.

Anatomiae ad 5 Capita
- Historia
- usus action utilitates propter quid
- observatio eorum quae raro et morbi de
- problemata ex autoribus resolvere
- peritia aut divisionis dexteritas et praeparatio cadaveris conditio

Anatomia
- philosophica
- medica
- maechanica

Anatomia alia
- popularis
- quae hic libro iij ventrium
- curiosa et philosophica medica partes
  1. de partibus externis, physiognomie
  2. ossium sceleton
  3. musculorum ligamentorum
  4. de organis sensetivis et vocis
  5. de vasis venis arteriis nervis
  6. de partibus similaribus
  7. de genitalibus embrione mammis

Figure 7. Transcription of Folio 1v, Harvey's *Prelectiones*

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seems to be one of relative thoroughness and connection to broader theoretical considerations. In contrast, in *anatomia curiosa* one investigates one particular organ or sets of organs in detail, seeking a full understanding.

Harvey's distinction between popular and *curiosa* anatomy would seem to be closely related to the distinction, found in Fabricius, between popular and exact anatomy. (See my discussion of this distinction in the previous chapter.) In his similar distinction between popular and *curiosa* anatomy, and in his Rules for a General Anatomy, we see Harvey attentive to the difference between the pedagogical context of a popular anatomy and the scientific context of specialized anatomical treatment of particular organs (*anatomia curiosa*).

Harvey indicates that *anatomia curiosa* can be medical or philosophical.[171] Here it is not a question of detail or depth of anatomical research, but rather of what that research can provide the doctor or natural philosopher, respectively. This can be seen in Canon 5 (Figure 8, Figure 9, Figure 10). This Canon has two connected parts, the second of which starts on the eleventh line, "Anatomae enim finis…".[172] In both sections Harvey speaks of physicians and philosophers and how they differ in their relation to anatomy.

[171] This distinction can also be seen in his the threefold distinction between anatomy as *philosophica*, *medica* and *maechanica*. (folio 1v) I address the third member of this division, "*maechanica*," below in Section 4.4.
[172] That this is a new section or thought is signaled by the way Harvey moves the start of the line left in comparison to the line above. This is a common technique in Harvey's notes.

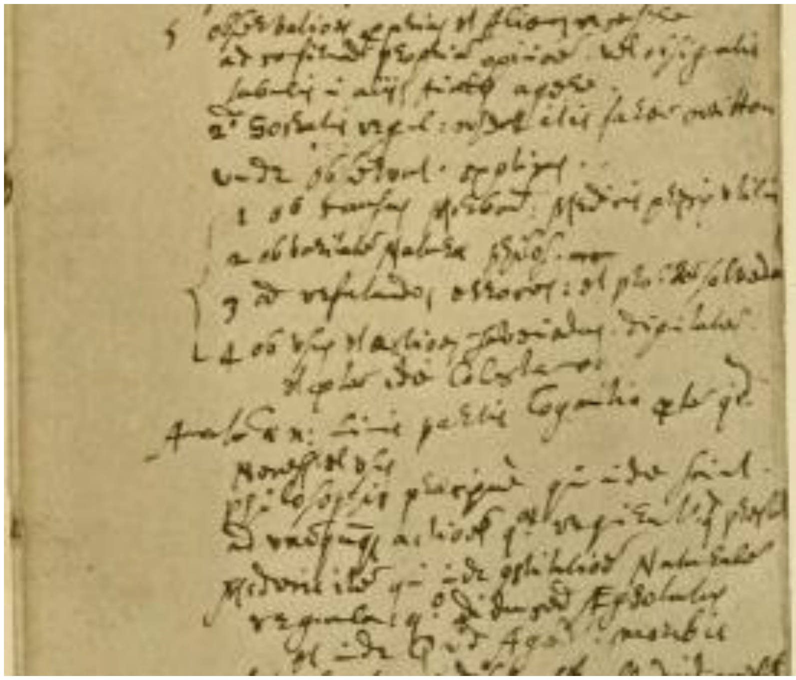

Figure 8. Reproduction of Folio 4, Harvey's *Prelectiones*

5 observationes proprias et Alienas recensere
ad considerandum propriam opinionem . vel obsignatis
tabulis in aliis Animalibus agere .
secundum Socratis regulam where it is farer written.
unde observationes exoticas
1 ob causas morborum, medicis precipue utilis
2 ob veritatem Naturae, philosophis ~~non~~
3 ad refutandos errores et problemata solvenda
4 ob usus et actiones inveniendas, dignitatem
et propter idem colectanea.
Anatomae enim finis partis cognitio propter quid
necessitas et usus
Philosophis praecipuè qui inde sciant
Ad unamquanque actionem quae requiruntur quod prestat
Medicis item qui inde constitutionem Naturalem
regula[m] quo diducendum Aegrotantes
et inde quid agendum morbis.

Figure 9. Transcription of Folio 4, Harvey's *Prelectiones*

5. Review your own and other's observations
in order to consider carefully your own opinion, or, in the strictest form, deal with other animals
according to the rule of Socrates where it is fairer written
Whence observations outside [of humans]

i. for the causes of diseases-of the greatest use to the physicians
ii. for the truth regarding Nature-[of the greatest use] to the philosophers.
iii. for the purpose of refuting errors and solving problem
iv. for discovering the uses and actions of the parts, their excellence and, on account of this, their classification.

For the end of Anatomy is knowledge of the *propter quid* of a part…

Figure 10. Translation of part of Folio 4, Harvey's *Prelectiones*

In the second section, Harvey begins with the identification, discussed in earlier in this section, of the end of anatomy as causal knowledge of the parts. He then articulates the principal ways (*praecipuè*) anatomy is relevant to philosophers (*philosophis*) and to physicians (*medicis*). It serves the philosophers, because from anatomy and its knowledge of the *propter quid* (*actio* and *usus*) of parts, the philosopher can come to "know with respect to each action what things are required and which is most important" (*sciant ad unamquanque actionem quae requiruntur quod prestat*). That is, they can grasp the parts as they are required (rendered necessary) by various animal actions. This is *scientia* of the parts, or as stated in the first section of Canon 5, the "obersvationes exoticas" involved in anatomy help determine the truth of nature (*veritatem naturae*). This is principally useful (*utilis* as implied in parallel to the line above) to the philosophers. In contrast, that these observations can help determine the causes of diseases (*ob causas morborum*) is principally useful to the doctors. Indeed the practical orientation of the doctor to restoring and maintaining health is reflected in the second section. It is chiefly useful to the doctors because from the causal knowledge of the parts they can come to know what the natural constitution of the body is (*constitutionem naturalem*), and a rule by which to distinguish those ailing (*regula[m] quo diducendum Aegrotantes*), and from *these* they can come to know what is to be done for diseases (*et inde quid agendum morbis*).

The principle difference between medical and philosophical *anatomia curiosa* is the end for which the resources of anatomy are used. The philosopher seeks true causal understanding of nature. The doctor has a practical end in view, and bends the resources of anatomy to his task of restoring and maintaining health.[173] It is in the context of Harvey's *curiosa anatomia philosophica* that we see anatomy most developed (because not popular and so not abbreviated) and straightforward (because not subordinated to concerns about health and disease). Harvey's *De motu cordis* and *De generatione animalium* are examples of this kind of anatomy, reflecting his understanding of anatomy as aimed at achieving Aristotelian *scientia* of the parts in all animals by means of ocular inspection and dissection. So, too, I will argue, is Harvey's set of working notes on muscle. In order to make this claim more substantive, I turn now to a more careful examination of the goal and method of Harvey's *anatomia philosophica*.

4.1.2 The Goal of *Anatomia Philosophica*

We have already seen that Harvey understands the end of anatomy to be *scientia* or causal knowledge of the parts, and that he emphasizes the *cuius gratia* or final cause. We have also seen that he, like Fabricius, connects this cause with the Galenic concepts *actio* and *usus* or *utilitas*. It is important to see how these concepts structure Harvey's teleology. Although Harvey does not always use these terms with rigid consistency, and emphasizes them variously in different contexts, we can trace a reasonably clear, if flexible, approach.

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[173] This focus on the usefulness of anatomy for medicine can be seen elsewhere in Harvey's *Prelectiones*: see (e.g.) f. 9 and 24v.

We have already discussed Galen's method for studying the *usus* of the parts in our discussion of Fabricius. For Galen, the study of the usefulness of parts will involve correlating a series of features of a part and its subparts with the recognized action of that part. The features of the part to be considered are broken down into three groups: the temperament of the part (closely related to its essence), the qualities it has in virtue of this temperament (odors, flavors, colors, hardness and softness), and finally other contingent attributes (position, size, contexture, and conformation).[174] Fabricius calls the systematic description of these features *historia* and this makes up the first part of his anatomical treatises.

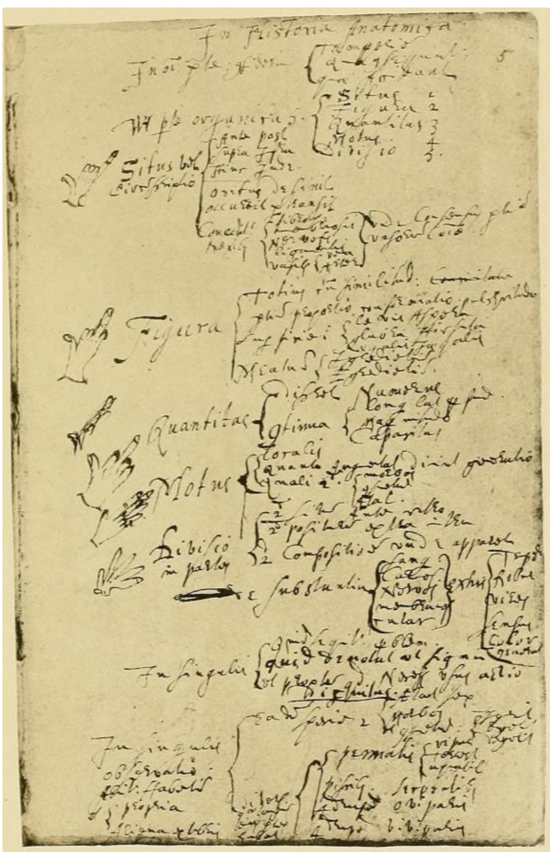

Figure 11. Reproduction of Folio 5, Harvey's *Prelectiones*

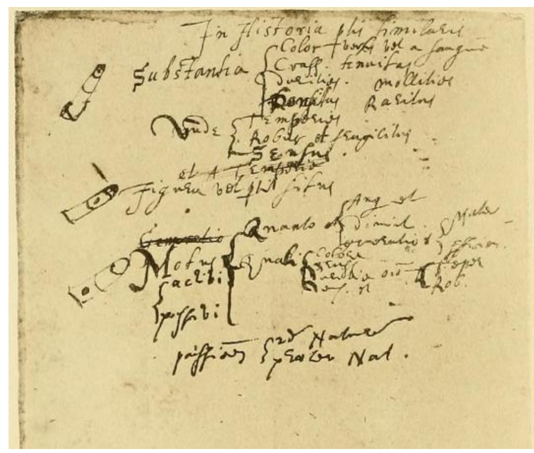

Figure 12. Reproduction of Folio 5, Harvey's *Prelectiones*

[174] See my discussion in the previous chapter.

Harvey also sees the production *historia* to be an important step in anatomy. He heads one section of his *accessuss* "*In Historia Anatomica*" (Figure 11 and Figure 12). There he lists what should be considered in every part (*in omni parte*) and what in instrumental parts (*in parte organica*) and what in the *historia* of similar parts (*in historia partis similaris*). In every part, he says, we should consider the three Galenic categories of feature: temperament (*temperies*), what follows temperament (*quae consequuntur)*, and the other accidents (*quae accidunt*). In organic parts he enumerates five heads: position or surroundings, shape, quantity, motion and subdivision into parts (*situs vel circumscriptio*, *figura*, *quantitas*, *motus*, and *divisio in partes*). This is clearly a list of accidents that is related though not identical to Galen's third category.[175] For the *historia* of similar parts, Harvey includes three categories: *substantia* (substance), *figura vel partium situs* (by this I suspect he means how the similar part is shaped or positioned in the context of a larger, instrumental part) and *motus*. He lists temperament, strength and fragility, and sense (*temperies*, *robur et fragilita,* and *sensus*).[176] I will return to this discussion of *historia* when I consider the place of comparative dissection, vivisection, and experimentation in Harvey's method. For now, it is important only to recognize that Harvey, like Fabricius, organizes his systematic observations around these broadly Galenic categories. These different categories show up frequently as headings in Harvey's treatment of individual organs throughout the *Prelectiones*.

Harvey's brief notes on *actio*, *usus*, and *utilitas* can tell us something about how Harvey understands these terms. After motivating the study of *actio* and *usus* (as the study of the *propter*

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[175] It is interesting to note, in light of Harvey's effective use of vivisection and the title of his most famous work, that Harvey includes motion here in his *historia*. More on this below (Section 4.1.3).

[176] By *sensus* I take him to be referring to Galen's second category, sensible qualities that follow from temperament. It can be noted that here Harvey has provided a mnemonic device to help his listeners remember, particularly, the five things to be considered in organic parts and the three in similar parts. For the organic parts, he associates each of the five categories with one of the fingers on the hand, and for similar parts he associates each of the three categories with one of the sections of the finger.

quid of the parts), Harvey turns to *actio* (Figure 14, Figure 13). Harvey draws on Galenic resources, describing *actio* as *motus activus*.[177] Harvey also introduces the term *functio* for the performance or accomplishment (*effectio*) of an *actio*, except when this accomplishment is something *in materia,* in which case it is called *opus*. Here, I suggest, he is developing the Galenic distinction between *ergon* and *energeia*. In a broad sense both respiration and blood are examples of an *ergon*, but in a narrower sense, respiration is an *energeia* and blood is an *ergon*.

Actio motus Activus: cuius effectio
Functio dicitur in materia vero Opus
Opus et functio { per se cum aliis
principaliter instrumentaliter
adiuvans { perficiens
conservans.

Figure 13. Transcription of part of Folio 6, Harvey's *Prelectiones*

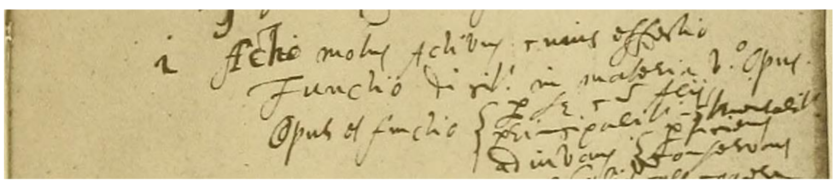

Figure 14. Reproduction of part of Folio 6, Harvey's *Prelectiones*

Blood, which is *in materia*, is an *opus*, says Harvey, while respiration would be a *functio*.

For Harvey, like Fabricius, *actio* will typically be the final cause of a part and its features. In his discussion of the *cerebrum*, for example (folio 91v), when discussing the *cuius gratia* of its convolutions, Harvey seeks to refer them to the *actio* of the *cerebrum* (which he identifies as cognitive processes from sensation to thought). Alluding to Galen's Hippocratic idea that all the features of a part work harmoniously to ensure the *actio* of a part is performed (*Galenus enim*

[177] The requirement that the *actio* be an active motion, one accomplished by the part appears in Harvey's notes on the lungs. See folio 84 where Harvey discusses the controversy surrounding whether the lungs move themselves, are moved by another, or a combination. He also highlights the question of whether inspiration and exhalation are both actions or if one or both are instances of being moved by another.

nihil in parte quod non conducit ad actionem illius), he list possible ways they might be ordered to the action. As we shall see, Harvey's notes on muscle anatomy provide a very clear example. There Harvey notes that although all muscles have the same basic action, there is in this action differences in degree from muscle to muscle.

> Therefore, in muscle there are two things to be considered, namely the composition of the muscle *for the sake of* the action [*gratia actionis*] which it is to perform and its mechanical construction *for the sake* of the strength and power which it requires [*gratia roburis et virium*].[178] (106)

Harvey is distinguishing the features of muscle anatomy that are common to all muscles and have as their final cause the simple action of muscles (contraction, etc.), from the features (like shape and size) that vary and have as their final cause the requirements on that action specific to each muscle (which he calls the *perfectio actionis*). Both the composition and the 'mechanical construction' of the muscles are *for the sake of the action*, the former for the sake of the basic action, the latter for the sake of the perfection of that action.

After considering *actio* Harvey turns to *usus* and *utilitas* (Figure 16, Figure 15). He distinguishes between *usus* and *utilitas*, and between *utilitates* that are *mediae* and *finales*. However, he seems to identify *usus* and *utilitates mediae*. Under *usus* he places three groups of features. These three groups correspond to the three Galenic categories of features to consider: the temperament (the characteristic blend of the four primary qualities, hot, cold, moist, and dry); those features that follow from temperament (here he lists color, hardness and softness, density, and fleshiness); and other contingent features (shape, size, position and composition). For the

[178] Unde in musculo duo animadvertenda sunt, videlicet: composition gratia actionis, arteficium mechanicum gratia roburis et virium. (Emphasis added) Transcriptions and translations from the notes on muscle (of which I have examined a microfilm reproduction) have been greatly aided by Whitteridge's edition (G. Whitteridge 1959). Page references are to the folio number.

first and second set he seems to indicate what contributions these various features and their variations could make. For example, a hot part can heat, bring about concoction, and keep warm; and moisture in a part can lubricate smooth, soften and weaken. These groups of features (temperament and what follows from it) are features that parts have as similar parts. The third group (features not following from the temperament) are features parts have as organic. For Harvey, the anatomist systematically considers all these features of a part and seeks to understand them in terms of how they contribute to the action of the parts.

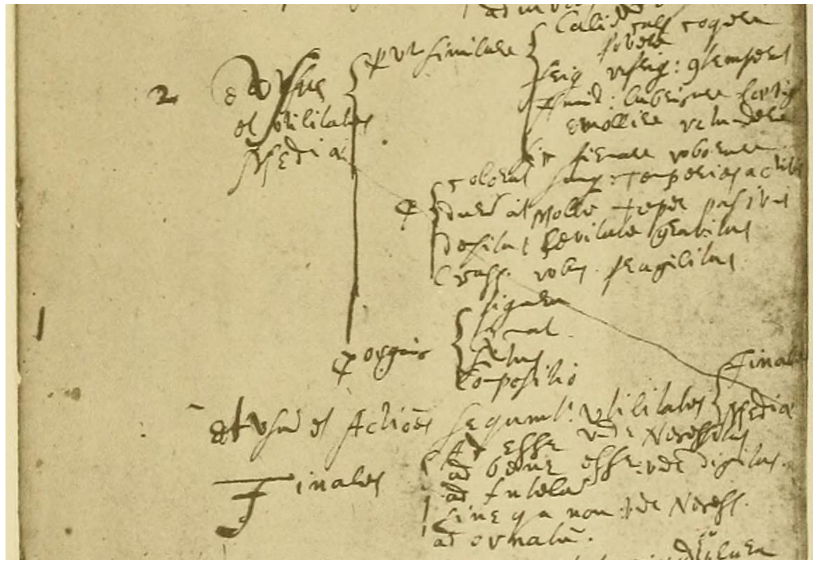

Figure 15. Reproduction of part of Folio 6, Harvey's *Prelectiones*

2. Usus et utilitates mediae
- prout similare
  - calidum, calfacere coquere fovere
  - frigidum refrigerare contemperare
  - humidum lubricare laevigare emollire retundere
  - siccum firmare roborare
- pro
  - coloratum sanguis temperies activis
  - durum aut molle temperies passivis
  - densitate levitate gravitas
  - crassitie, robur fragilitas
- pro organico
  - figura
  - quantitas
  - situs
  - compositio

Et usum et actionem sequuntur utilitates
- finales
- mediae.

Finales
- ad esse unde necessitas
- ad bene esse unde dignitas
- ad tutelam
- sine qua non unde necessitas
- ad ornatum.

Figure 16. Transcription of part of Folio 6, Harvey's *Prelectiones*

Like Fabricius the study of *usus* and *utilitas* is closely connected with providing final causal understanding of the parts. Harvey, however, introduces a distinction between *usus* and *utilitas* and even between kinds of *utilitates*. I have not found these finer grained distinctions in Fabricius. Harvey says that *utilitates* follow form the *usus* and *actiones* of parts (*Et usum et actiones sequuntur utilitates*). He also distinguishes intermediate and final *utilitates*. Intermediate *utilitates*, however, he seems to identify with *usus*. Final *utilitates* he breaks down into five categories:

1. Ad esse unde Necessitats (For the being [of the animal], whence necessity)
2. Ad bene esse unde dignitas (For well-being [of the animal],whence excellence)
3. Ad tutelam (For protection)
4. Sine qua non unde Necessitas (Sine qua non, whence necessity)
5. Ad ornatum (For adornment)

Here, Harvey introduces a hierarchically ordered set of teleological concepts: *actiones*, *usus*, *utilitates mediae*, and *utilitates finales* by which to explain the parts of animals. Parts are for the sake of their actions. These actions, in turn, or for the sake of some *usus* and further *utilitates.* Ultimately, the full teleological explanation of any part or features of a part will terminate in showing how it is essential to the nature of the animal, or contributes to the flourishing of the animal, or to its protection, or to ornamentation, or is a *sine-qua-non* condition of some other feature or part that is so related to the animal. That is, like Fabricius, Harvey understands parts and their features to be hypothetically necessary given the animal and its activities (see my discussion of hypothetical necessity in the previous chapter).

In his notes on muscle Harvey invokes and discusses these distinctions extensively.[179] There he opens the section of the notes headed *Utilitates Musculorum* by discussing the

[179] Harvey does not employ f these finer grained distinctions systematically in his treatment of individual parts in the *Prelectiones.* That he does not is likely a reflection of the notes being for a general and popular anatomy. As is natural for such a context, Harvey provides a simpler analysis, rarely distinguishing between *usus* and *utilitas*, for

distinction between *actio*, *usus*, and *utilitas*. He also distinguishes between primary, secondary and accidental *utilitates*. He characterizes the action, use and utility of the muscles as follows:

> Of muscles: action is contraction. Use [*usus*] is the manner of this [i.e., contraction] or its completion or whatever immediately follows [the action]. *Utilitates* are the works which Nature performs by the use [*usu*] of muscles.
>
> Their use or what follows from their contraction (see above) in their construction [*artificio*] consists in: (1) bringing together of the ends in shortening; (2) the measured separating of the ends in lengthening; (3) keeping the ends back by means of that which is at rest, rigidity and tremor; (4) compression in the thickness of the belly of the muscle by distention and by the direction of the fibers.[180] (113)

He goes on to characterize the three kind of *utilitates* of muscles:

> The *utilitates* [of muscles]: (1) primary; (2) secondary, which arise from the primary; (3) contingent, which arise from their sinewy nature, from their protective capacity (as in the case of the muscles of the abdomen) and from their fleshiness, a padding [*fomentum*].[181] (113)

Harvey says the secondary *utilitates* are *actiones* of either the limbs or of the whole body, and his examples include walking, standing, blinking, and breathing. (114) These secondary *utilitates* of the muscles are ultimately traced back by Harvey to the first four of the five categories of *utilitates finales* from the *Prelectiones* (see above, p. 118). In the opening chapter of the muscle

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example. Nonetheless, the general teleological explanatory structure articulated here guides his treatment of parts throughout the notes.

[180] Muculi: actio, contractio; usus, modus istius vel effectus vel quod immediate sequitur; utilitates, opera quae usu musculorum Natura facit.
Usus vel enim a contractione (vide ante) in artificio sequitur: extremorum appropinquatio abbreviatio; extremorum modulate disterminatio elongatio; extremorum detentio per manentiam, rigiditatem et nutationem de laxo; compressio grassitie ventris distentione et fibrarum directione.

[181] Utilitates: primariae; secundariae ex primis; accidenatriae: a nervositarte, tutela (abdominis); a carne, fomentum

notes, Harvey discusses why animals move; he closes that chapter with the summary statement, "Local motion is present in animals on several accounts: necessary [i.e., in the being of animals], as a sine qua non, for better and for protection, conservation."[182] (70v)

For Harvey, the anatomist aims to arrive at Aristotelian *scientia* of the parts. By this *scientia* the anatomist grasps final causal explanations of the parts and their features, seeing how the essence of the animal, or its well-being, or its protection and ornamentation are the final causes of various activities, and how, in turn, these actions are the final causes of the parts and their features. This explanatory structure exhibits Aristotelian hypothetical necessity. The parts and their features are rendered more or less necessary, given the being of the animal (or its well-being, protection or ornamentation). Furthermore, as Harvey's distinction between the composition of the muscle and its mechanical construction exhibits (see above, p. 116), the anatomist's understanding reflects the Aristotelian attention to variation among related parts, providing explanations at the right level of generality for features present in all (e.g.) muscles and for features that vary from muscle to muscle.

4.1.3 Harvey's Comparative Method and the 'Rule of Socrates'

For Harvey, anatomical method is ordered to achieving this universal, final causal knowledge of the parts as they appear across animal kinds. Harvey articulates clear ideas about anatomical method in the *accessus* of the *Prelectiones*, and these ideas are reflected in his anatomical practice. Harvey includes a (minimal) articulation of anatomical method in his definition of anatomy, "Anatomy is the faculty that *by ocular inspection and dissection* [grasps] the uses and

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[182] Motus localis inest animalibus pluribus nominibus: necesse, *sine qua non*, ad melius, ad tutelam conservandam

actions of the parts.” (*Prelectiones* 1v) Harvey sees personal observation and dissection to be the characteristic means to achieving anatomy’s end; however, it is not simply a case of untutored or random dissection and observation—this would not count as a method. Rather, this dissection, which for Harvey includes vivisection, is systematic, deliberate, and aimed at producing *historia* of the parts. We can understand Harvey’s method, then, by looking in more detail at how *historia* is ordered to achieving anatomical *scientia*.

As we saw above, in his methodological introduction to the *Prelectiones*, Harvey has a section, *In historia anatomica*, devoted to characterizing the systematic approach to dissection and observation that produces *historia*. Two features of Harvey’s approach to *historia* need to be stressed. First, for Harvey, *historia* involves systematic observations of the *motions* of parts. The inclusion of motion in the list of attributes to examine reflects his understanding of the highly suggestive character of observed motions in grasping the actions and uses of the parts. The distinction between the motion of a part and its action is not one that Harvey spells out. In *De motu cordis* Harvey uses both *motus* and *actio* in Chapter 5, sometimes referring to the “motion” of the heart, sometimes to the “motion and action,” and sometimes only to the “action.” A careful examination suggests that Harvey tends towards “motion” when he relates what is going on using descriptions that do not embed it in the broader physiology and towards “action” when he is characterizing it as it contributes to the life of the animal. When he is describing the "motion" of the heart, he articulates the various contractions occurring: first this contraction, than that one, then the other, and they happen with this timing. The harmonious timing of these, however, makes them one "motion and action," like swallowing. Finally, he identifies one "action" of the heart as the transference of the blood and its propulsion to the extremities via the arteries. The first description is most abstracted (but not completely) from the larger physiology of the animal; the second description begins to see a unity in the motions with implications for the rest of the animal. The last makes this explicit. Because of this intimate connection between motion and action, the observation of motions (and so vivisection as means to that observation) becomes a crucial part of Harvey's method.

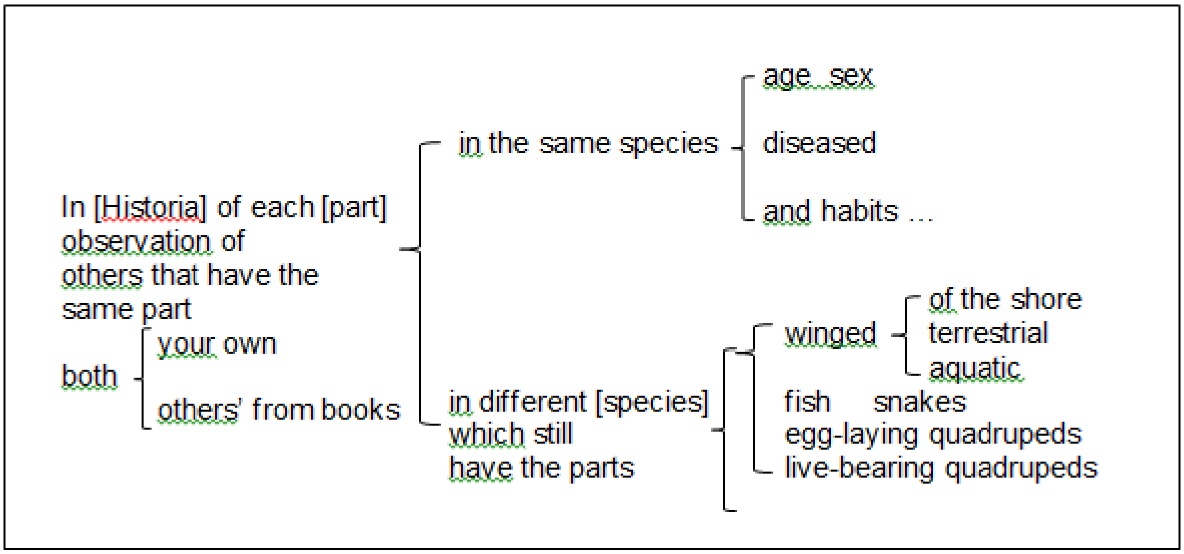

Figure 17. Translation of part of Folio 5, Harvey's *Prelectiones*

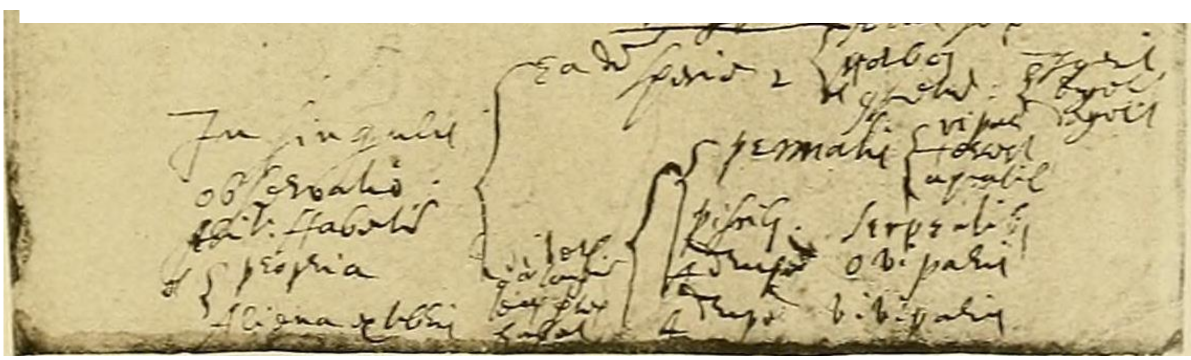

Figure 18. Reproduction of part of Folio 5, Harvey's *Prelectiones*

The second feature of Harvey's *historia* is as important to Harvey's method as his commitment to vivisection. In his discussion of *historia*, Harvey stresses that the anatomist should gather systematic observations regarding *the variations in particular parts across animals* (Figure 17, Figure 18). He suggests that this variation should be examined across animals of the *same species* that differ in age, sex, state of health or disease, and habits. In addition, he suggests that this variation should be noted across animals of *different species*, with attention to the larger groups or kinds to which they belong and the environments in which they live.[183]

This preoccupation with the systematic observation of variation across species does not reflect merely an encyclopedic aspiration to completeness. Rather, for Harvey this feature of *historia* is meant to enable the anatomist to identify the causes of the parts. This is reflected in Harvey's discussion of *actio*, *usus*, and *utilitas* later in the *accessus* to the *Prelectiones*. There, as we saw, he identifies the *actio* and *usus* as the *propter quid* of parts. He then discusses how to attain this causal knowledge (Figure 19, Figure 20). Besides noting that one should consider one's own observations and others' views, he stresses that this causal knowledge is to be acquired precisely from the consideration of the parts' variation in different animals. For Harvey, it is particularly the comparison of these parts as they vary that is crucial to discovering causes.

In his *Canon* 5 (Figure 21), Harvey suggests that if one is going to undertake anatomical research most properly, one should look at other animals "according to the rule of Socrates where it is fairer written." *Observationes exoticas*—observations of other animals (outside humans)—are relevant to anatomy. Harvey says that these observations are ordered to, among other things, the knowledge of truth regarding nature, and of the uses and actions of the parts. To understand what Harvey means by the Rule of Socrates, and how by it, such observations can lead to this knowledge, we need to turn to Plato's *Republic* (as the phrase "where it is fairer written" suggests).

[183] Harvey shares this Aristotelian approach with Fabricius, as discussed above (see 3.2.3, p. 69ff).

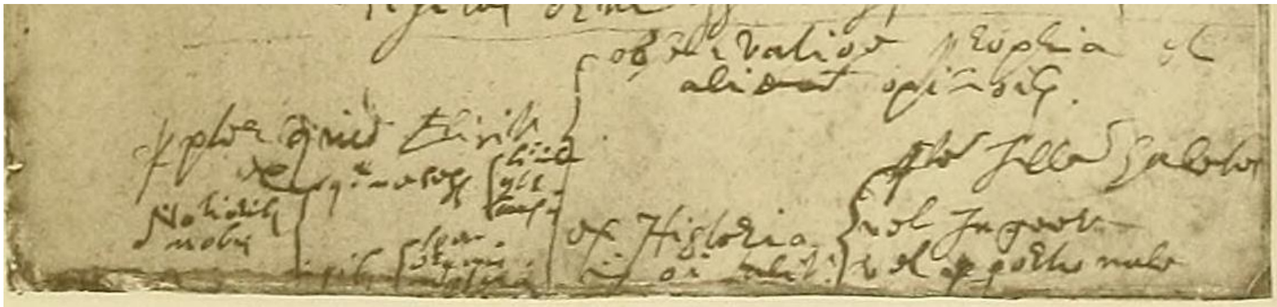

Figure 19. Reproduction of part of Folio 6, Harvey's *Prelectiones*

The *propter quid* is ascertained from

- your own observations and others' opinions
- from *historia* of all that are such
  - having that part [the same]
  - either in kind
  - or by analogy

Figure 20. Translation of part of Folio 6, Harvey's *Prelectiones*.

5. Review your own and other's observations
in order to consider carefully your own opinion, or, in the strictest form, deal with other animals
according to the rule of Socrates where it is fairer written
Whence observations outside [of humans]

i. for the causes of diseases-of the greatest use to the physicians
ii. for the truth regarding Nature-[of the greatest use] to the philosophers.
iii. for the purpose of refuting errors and solving problem
iv. for discovering the uses and actions of the parts, their excellence and, on account of this, their classification.

For the end of Anatomy is knowledge of the *propter quid* of a part…

Figure 21. Translation of part of Folio 4, Harvey's *Prelectiones*

The topic of Plato's *Republic* is established by the challenge put to Socrates to show that it is better to be just than unjust, even if all external consequences normally associated with being just or unjust are reversed. Socrates is to show that being just is, in itself, better.

> But the rewards and the honors that depend on opinion, leave to others to praise. For while I would listen to others who thus commended justice and disparaged injustice, bestowing their praise and their blame on the reputation and rewards of either, I could not accept that sort of thing from you unless you say I must, because you have passed your entire life in the consideration of this very matter. Do not, then, I repeat, merely prove to us in argument the superiority of justice to injustice, but show us what it is that each inherently does to its possessor—whether the one is good and the other evil.[184] (*Republic* II 367d-e)

To do this Socrates must first understand what justice in the soul is. Famously, Socrates says that such an undertaking is serious and very difficult and suggests an approach to make the inquiry easier.

> Glaucon, then, and the rest besought me by all means to come to the rescue and not to drop the argument but to pursue to the end the investigation as to the nature of each and the truth about their respective advantages. I said then as I thought, The inquiry we are undertaking is no easy one but calls for keen vision, as it seems to me. So, since we are not clever persons, I think we should employ the method of search that we should use if we, with not very keen vision, were bidden to read small letters from a distance, and then someone had observed that these same letters exist elsewhere larger and on a larger

[184] Translations from the *Republic* are taken from the *Collected Dialogues*, edited by Edith Hamilton and Huntington Cairns (Plato 1996).

> surface. We should have accounted it a godsend, I fancy, to be allowed to read those letters first, and then examine the smaller, if they are the same. (368c-d)

Socrates suggests that we consider the nature of justice in a state first, for this will perhaps be easier. Then, after determining the nature of justice as it is "fairer written" in the state, they can turn to the more difficult case of the individual. In Book IV, when he turns his attention to justice in the individual, after a long discussion of justice and the other virtues in the state, he clarifies an important aspect of his method.

> The proper functioning of the money-makers, the helpers, and the guardians, each doing his own work in the state…would be justice and would render the city just.
>
> I think the case is thus and no otherwise, said he.
>
> Let us not yet affirm it quite fixedly, I said, but if this form, when applied to the individual man, is accepted there also as a definition of justice, we will then concede the point—for what else will there be to say? But if not, then we will look for something else. But now let us work out the inquiry in which we supposed that, if we found some larger thing that contained justice and viewed it there, we should more easily discover its nature in the individual man. And we agreed that this larger thing is the city, and so we constructed the best city in our power, well knowing that in the good city it would of course be found. What, then we thought we saw there we must refer back to the individual and, if it is confirmed, all will be well. But if something different manifests itself in the individual, we will return again to the state and test it there and it may be that, by examining them side by side and rubbing them against one another, as it were from the fire sticks we may cause the spark of justice to flash forth, and when it is thus revealed confirm it in our minds. (*Republic* IV 434d-e)

Socrates's method (what Harvey is calling the Rule of Socrates) is aimed at universal knowledge of what justice is, i.e., in both the human and the state. In addition, this Rule of Socrates governs a kind of three-stage process. One first encounters a question (what is the nature of justice in the soul) which in its original context is obscure and difficult. Then one turns to the same question in another context, in which the answer may be easier to discern, where the same letters exist "larger and on a larger surface." Finally, one returns to the difficult case and if, guided by the insight gained in the easier case, the enquirer can arrive at knowledge of the answer in that original context, and if they agree, "we will then concede the point." If the two accounts do not agree, then this process is iterated, and the comparisons continue until the answer "flash[es] forth."

It is this three-step comparative methodology that Harvey calls the Rule of Socrates. It governs and motivates the systematic *historia* of the variation of the same or related parts across different animals. Harvey believes that often anatomical questions that are obscure in the context of human anatomy (or some other particular context) will be significantly clearer in other contexts: in the anatomy of other animal kinds, or of older or younger animals, or of animals in different states of health or disease, or with differing habits. He thinks that by bringing the insight or suggestions gained by examining these clearer cases to the more difficult cases one can be guided to an answer—an answer that is true of all instances of that part across different animals.

A brief example of this can be seen in Harvey's discussion of the *caecum*, the only other place in the *Prelectiones* where the Rule of Socrates is explicitly mentioned.[185] Although there is some confusion and disagreement about terminology, Harvey seems to follow Fabricius and

[185] The most detailed and conspicuous example is actually found in Harvey's *De motu cordis*. I examine his use of the Rule of Socrates in Section 4.3.2.

Vesalius, using the term to refer to what we call the appendix. Harvey discusses the part twice, first when providing a preliminary sketch of the location of all the parts in the Lower Belly and again when he turns to a more detailed discussion of each organ, focused more explicitly on their actions. In the first discussion (Figure 22, Figure 23) he notes that the *caecum* is "obscure in its function [*officio*]" and also that it is very small in humans, but its size varies significantly in other animals, and in the developing fetus, as well.[186] Because of these two features (that its function is obscure in humans, and it varies significantly in different kinds of animals), Harvey invokes the Rule of Socrates. As explained above, it is in just such cases that the anatomist should especially turn to comparative considerations, leaning on *historia* of the variation of the part, in his efforts to determine the function of the part. Harvey does not here discuss or identify that function. He simply notes the most conspicuous aspects of the variation in the part.

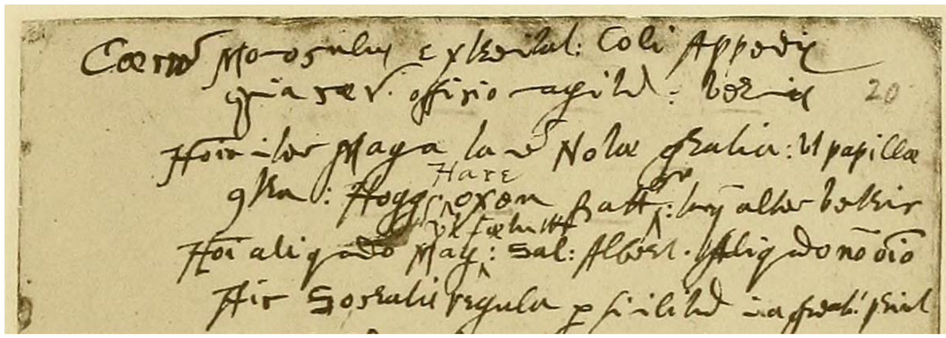

Figure 22. Reproduction of part of Folio 20, Harvey's *Prelectiones*

The caecum, *monoculus*, Appendix of the extremity of the colon
[It is called caecum] because it is obscure in its function; size is that of a worm.
In man, nonetheless, it is among the great guts *notae gratia*: like nipples.
In contrast: [in] hogs, hare, oxen, rat, etc. [it is very large], as if another stomach.
In man sometimes large--as in fetus WH. Salomon Albertus [says]: sometimes entirely absent
Hence the rule of Socrates through similarity in a great print

Figure 23. Translation of part of Folio 20, Harvey's *Prelectiones*

[186] It is worth noting that here, as in the detailed use of the Rule of Socrates in the *De motu cordis*, Harvey looks both at different kinds of animals, and at the developing fetus.

However, when he returns to the *caecum* in the second discussion, where he is focused on action and use (Figure 24, Figure 25), he identifies its *officium*: "The *officium* of the *caecum* is to store and preserve such concocted food to continue its concoction." Importantly, he also indicates that this is clear from looking at the variations in non-human animals ("Wherefore in some animals *caecum* plainly [is] a second stomach: in the badger, mouse, rabbit, ginneycunney, it is exceedingly wide. It is long, very wide, filled with chyle and has fibres which run along its length…").

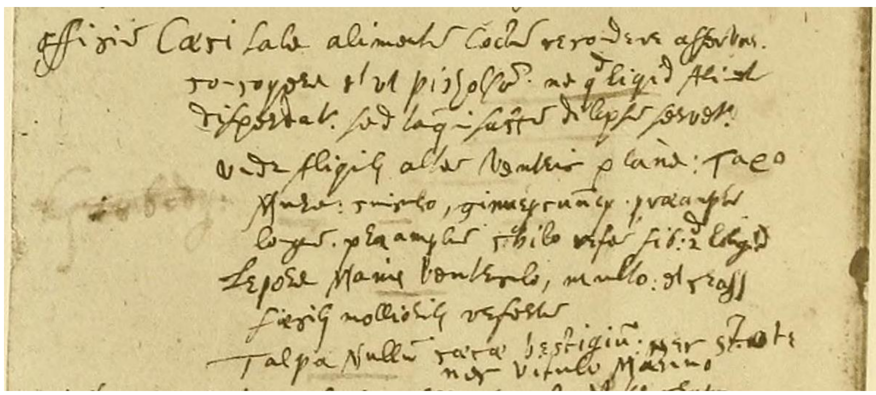

Figure 24. Reproduction of part of Folio 26v, Harvey's *Prelectiones*

The office of the caecum is to store and preserve such concocted food
to continue its concoction so that, as Piccolomini has said, nothing of the liquid food
be spoiled but kept safe, dissolved as it were in juice.
Wherefore in some animals caecum plainly [is] a second stomach: in the badger,
mouse, rabbit, ginneycunney, it is exceedingly wide.
It is long, very wide, filled with chyle and has fibres which run along its length.
In the hare it is much larger than the stomach and thicker
filled with rather soft faeces.
In the mole there is not a vestige of a caecum, nor in the stoat
nor in the seal.

Figure 25. Translation of part of Folio 26v, Harvey's *Prelectiones*

Harvey's preoccupation with dissecting not just humans, but also other animals, reflects this comparative method, encapsulated in his "Rule of Socrates." Harvey understands anatomy to be aimed at universal knowledge of part as they appear in all animals and he recognizes that a systematic comparison of variations in parts across different animals can be a powerful tool to arrive at this knowledge. This insight, as much as his appreciation of the suggestive character of observing motions, leads Harvey to the dissection (including vivisection) of animals.

4.2 HARVEY'S *ANATOMIA MUSCULI* AND *DE ARTIFICIO MECHANICA MUSCULORUM*

As noted above (p. 100), in the *DMC* Harvey announces his hope to publish a work on muscle and the organs of locomotion.[187] Harvey's discussion of his plan to publish on muscles and the motive organs is found in the final chapter. The working notes for this never completed project are a fascinating but challenging source. Scholars have given limited attention to these notes. The most extensive work on them has been carried out by Gweneth Whitteridge in her edition of the notes (G. Whitteridge 1959). Whitteridge's work has succeeded admirably in making the difficult manuscript more accessible to scholars. However, much work remains to be done to understand the notes and to mine them for insights into Harvey as an anatomist. Here, I argue first that they constitute a unified set of notes aimed at providing *scientia* of the muscles and the motive organs more generally—i.e., these notes are an instance of *anatomia philosophica*. Second, I argue that Harvey sketches a program for systematically integrating mathematical mechanical resources into his characteristic final causal explanations of the parts and their

[187] Harvey also announces a similar desire to publish on the organs of respiration: "And of the lungs, their use and movement, and of all manner of cooling, of the necessity and use of air and of other things of this kind and of the various organs and the differences made in them in animals on this account, although I have discovered many things from the countless observations I have made, yet I shall leave them to be more conveniently set forth in a treatise by themselves…" (Chapter 6). His interest in the organs of respiration is reflected in his *Praelectiones*, where they receive, after the heart, the most detailed consideration. The heart is the topic of folios 73-80; the lungs occupy folios 81-87.

variation. Harvey is critically and creatively responding to, integrating, and developing resources in the Aristotelian corpus and in Fabricius's works on muscle anatomy. I suggest that Harvey's teleomechanics is helpfully compared to the "science of the rainbow" that Aristotle mentions in the *Posterior Analytics* and develops in *Meteorology* III.

My interpretation reveals a stronger unity between the first and second halves of the notes than Whitteridge identifies and corrects the tendency in the scholarship to see these notes, and especially the use of mechanics in them, as having animal locomotion (rather than the motive organs) as their primary explanandum. The tendency is encouraged by and likely reflected in Whitteridge's questionable decision to entitle the notes (and the treatise Harvey hoped to base on them) *De motu locali animalium, 1627*. This title could imply that the notes are primarily concerned with and aim to explain animal locomotion. That would be a mistake. Indeed, there is significant evidence, independent of my broader interpretation of the notes, that Whitteridge's choice of title is mistaken. I will begin, then, by examining this evidence; then I describe the structure and aim of the notes.

4.2.1 The Title, Structure, and Aim of the Notes

Whitteridge takes her title from the heading at the top of folio 70, "*De Motu local[i] animal[ium]*" and the date, 1627, written beneath this heading (see Figure 26, left). However, it is clear from the manuscript that this is meant by Harvey to refer only to the first chapter of a larger work. We can see this from the "Cap. 1" scrawled in the upper left hand corner of the folio, corresponding to the chapter numbering Harvey employs for much of the manuscript.[188]

[188] As we shall see below Harvey numbers the first eight chapters.

Each of these chapters has a heading similar in size and spacing to "*De Motu locali Animalium*." For example, folio 71 is labeled "Cap. 2," and is headed, "*Species Motus loc[alis] Ani[m]a[lium]*" (Figure 26, right). These chapter numbers and headings correspond to a sort of "table of contents" in Harvey's hand found on folio 69 (see Figure 27, p. 134). This table of

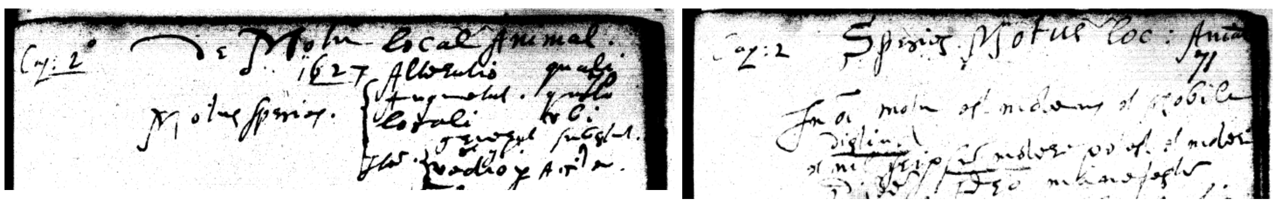

Figure 26. Reproduction of tops of Folios 70 (left) and 71 (right), Harvey's *Anatomia Musculi*

contents, itself, has the heading "*Anatomiae Musculi Capita*." Although it refers to the list of chapters that follows, and not to the notes as a whole, still this heading strongly suggests an alternative title, *Anatomia Musculi* or *The Anatomy of Muscle* (*AM*). Such a title also seems appropriate, given Harvey's description of the project of the notes, found in Chapter 17 of *DMC* (quoted above, p. 100). This description closes, "all this I think will be made clear if at any time I shall have liberty to demonstrate from my own observations concerning the motive organs of animals and the structure of the muscles (*de motiuis organis animalium, & de musculorum fabrica*)." Harvey conceives of his project as one concerning muscle (and the motive organs, more generally). Thus, *Anatomia Musculi* is a more appropriate title. For these reasons, I refer to the notes by this title, rather than Whitteridge's *De motu locali animalium*.

In the introduction to her edition, Whitteridge characterizes the manuscript in the following way:

> The notes for the treatise…begun in 1627, were added to on several occasions but never cast into a final literary form. They remain the rough draft for Harvey's intended book. They have been altered and crossed out and additions have been made often with little

regard for the continuity of the thought or the proper ordering of the material. As a result they are frequently repetitive and at times it is difficult to follow even the main lines of the argument or to know what was Harvey's own opinion of the points that he was discussing. (G. Whitteridge 1959, 3)

Although these are indeed preliminary notes and far from polished, Whitteridge's characterization here is exaggerated with respect to the "proper ordering of material"—at least at the large scale.

The notes are broken into two main sections. This division is reflected in the table of contents Harvey provided for the notes. There he lists eight numbered *capita* of the anatomy of muscles and draws a line between the first seven and the eighth (Figure 27, p. 134). This line marks the division between the two main sections. The note below the eighth chapter, "see below" (*vide post*), refers us to Chapter 8 itself. There we find a kind of 'map' or further table of contents for what is to be treated in the second part (Figure 28, p. 135). By combining these two and correlating them with the rest of Harvey's notes, we arrive at a complete table of contents that accurately characterizes Harvey's understanding of the main topics and structure of the notes (Figure 29, p. 136). [189]

[189] This table of contents differs slightly from Whitteridge's.

Anatomiae Musculi
Capita

1. De Motu Locali Animalium
2. Species Motus locali Animalium
3. Motus localis secundum totum vel Itio
4. Movens in Animalibus
5. Moventium Differentia
6. Artus
7. Manens

---

8. De Musculis Cognoscenda
   vide post

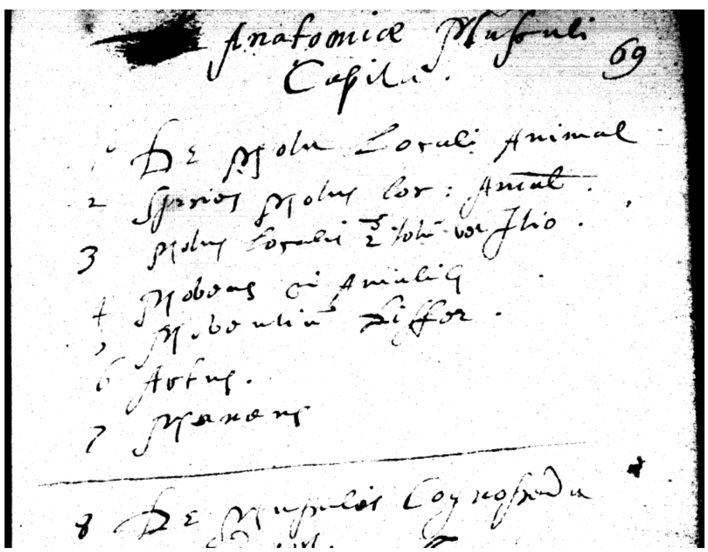

Figure 27. Transcription and Reproduction of part of Folio 69, Harvey's *Anatomia Musculi*

8 DE MVSCVLIS
COGNOSCENDA

I. Nomen, definitio, natura.
Aristotelem cognovisse.

2. Partes:
integrales
Aponeurosis
ligamentum,
tendo,
fibra
caro
~~fibra~~
membrana
vasa ---------------- vena, arteria, nervus
spiritus implantatus principalis
et quae pars praecipua ^
quae [?]Agunt[?] quae non etc.

organicas:
caput oritur
venter occurit, pertransit
cauda desinit.

Deinde
quantitate
situ,
figura, etc

~~Actio contractio ????? ????? esse~~
~~motus simplex~~
~~motus tonicus~~

3. Actio:
Laxatione, WH vide in Manente

contractio: in ventrem,
versus caput; non tamen motus
semper versus caput sed extremorum
appropinquatio: Δ brachium.
firmare, manere
contractum esse
tenere
tonico: Δ
miluo vento,
trowt torrente

media constitutio et 4 in Galeno
partim agit partim non, etc.

4. Passiones musculi.
6. **Utilitates: extremorum adductio:**
huius illius
utrorum quilibet,
ventris compression
detentio

Ab harmonia rithmo unde progressus, apprehensio, etc.

5. Robur musculi unde
videlicet arteficium mechanicum
unde vires magna movere
pondera ab
numero
figura, magnitudine
situ, connexione ipsius
substantia, tendine

Figure 28. Transcription of Folio 86, Harvey's *Anatomia Musculi*

THE ANATOMY OF MUSCLE

Chapters of the Anatomy of Muscle	folio 69
Part 1: Animal locomotion and its principles	
1. On the local motion of animals	folio 70
2. The kinds of local motion of animals	folio 71
3. Local motion of the whole [animal]—i.e., Going, Progression	folio 73
4. The mover in animals	folio 75
5. The different kinds of movers	folio 77
6. The limbs	folio 80
7. That which is at rest	folio 82
Part 2: On the things which are to be known concerning the muscles	
8. On the things which are to be known concerning the muscles	folio 86
9. The Name of muscles	folio 87
The Parts of Muscle:	
Integral Parts	
10. Aponeurosis: Ligament, Tendon, Fiber	folio 89
11. Flesh	folio 93
12. Membrane	folio 94
13. Vessels: vein, artery	folio 94v
14. Implanted spirit and the principle part [of muscle]	folio 95
15. The nerves of the muscles	folio 99
Organic Parts	folio 100
16. The Organic Parts: Head, Belly, Tail	folio 101
17. **Action** (with special attention to the principle part, tonic motion, middle position, and the place of contraction)	folio 102
18. **Affections** of the muscle (or the distorting of motion)	folio 105
19. **The Mechanical Construction of the Muscles**	folio 106
19.1. Shape	folio 107
19.2. Number	folio 107v
19.3. Size	folio 109
19.4. Location and position of parts	folio 110
19.5. Substance	folio 111
19.6. Theca and retinacula	folio 112
20. ***Utilitates* of muscles**	folio 113
20.1. Primary *utilitates*, From drawing together the ends	folio 113
20.2. Secondary *utilitates*, From rhythm and harmony [of muscles acting together]	folio 114

Figure 29. Proposed structure of Harvey's *Anatomia Musculi*

The first seven chapters concern themselves with laying out the basic conceptual framework with which to describe and understand animal locomotion. In her brief discussion of the first part Whitteridge says this first part of *AM* is "devoted to an examination, or rather a rehearsal with a certain amount of comment, of Aristotle's teaching concerning movement and animal movement in particular." (G. Whitteridge 1959, 3) It is true that the first part is thick with an Aristotelian analysis of the causes of motion and of animal locomotion; it is also true that several of the chapters in the first part do read like a (selective) presentation of central ideas from *De incessu animalium* and *De motu animalium*. However, Harvey's treatment of these and other Aristotelian works is selective, synoptic, and principled. He is attempting to lay out the principles of local motion in a way that allows us to understand how they are present in the locomotive organs of animals. In the second part of *AM* Harvey makes occasional, explicit reference to the first part.

The second part begins with the chapter eight 'map' of the topics to treat in a systematic anatomy of muscle. The remaining chapters of Part II comprise notes on the anatomy of muscle, following the chapter eight map closely. Harvey interacts especially with Galen's *De motu musculorum*, relevant parts of Aristotle's corpus, and Fabricius's work on muscles, and it exhibits a structure related to Fabricius's *historia-actio-utilitates* approach to articulating *scientia* of the parts.

It begins with a clarification the subject matter to be considered, discussing the appropriate name to use to refer to muscles and the organs of locomotion, in general. He then turns to the *historia* of the muscles, focusing first on the integral parts of muscle: aponeurosis, flesh, membrane, the veins and arteries, the nerves and the motive spirit. Harvey then discusses the organic parts of muscles (head, belly and tail), discussing and criticizing various ways to distinguish the head and tail.

After these notes toward a *historia* of the organ, Harvey turns his attention to the *actio* of the part. Following the standard Galenic approach exemplified by Fabricius, Harvey seeks to identify the *actio* of the muscles and identify the "principal part."[190] He identifies muscle as a species of the *nervus* or of "that which is contractile" and as such causes motion by virtue of this contraction. An important implication of this insight is that all animal motion is ultimately caused by pulls rather than pushes.[191] Harvey suggests that the action of the muscle is threefold: (1) contraction, or a shortening of the extremities; (2) tonic motion;[192] and (3) regulated relaxation.[193] After having identified the action of the muscle, Harvey turns to affections of the muscle, in particular, ways in which muscles' action can be distorted.

The remaining two chapters discuss first the mechanical construction of the muscles (*artificium mechanicum musculorum*) and second the *utilitates* of the muscles. I will return to the chapter on the *artificium mechanicum musculorum* below. I have already analyzed Harvey's discussion in the final chapter of the *actio*, *usus*, and primary, secondary, and contingent *utilitates* of muscle found in the final chapter (see above, p. 118). Besides identifying and distinguishing these, Harvey also gives significant attention in this final chapter to how many muscles work in harmony in the actions of the animal as a whole. He also discusses various ways to understand the role of the brain in causing and coordinating the muscles in these actions.

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[190] It is difficult to determine what Harvey's considered views on the principal part in these notes.
[191] "WH *esse specium nervi sive contractile…et movere tractu non pulsu*." (f. 102)
[192] This is a topic discussed by Galen in *De motu musculorum* 6. It is the kind of action a muscle exhibits when it neither lengthens nor shortens but acts to resist (e.g.) the weight of the limb or part to maintain it in the same position. Galen gives as an example holding ones arm out. Harvey points out that such action of the muscles, despite not moving the part, can still be instrumental in animal progression. His examples include the role such tonic motion plays in the soaring of a kite (the bird).
[193] Harvey's point is that the controlled relaxation of muscle (as opposed to simply going limp) is an important function of muscles.

The overarching structure of the Part II reflects Fabricius's Galeno-Aristotelian understanding of anatomical investigation. As in the *Prelectiones*, here too Harvey sees anatomical investigation to aim at coming to final causal understanding of the muscles in terms of the action, use, and utility of the muscles. Muscle, for Harvey, is primarily for the sake of the locomotion (of parts and of the whole animal) involved in animal operations as diverse as walking, eating and evacuating, and reproducing; this role for motion is identified in chapter 1. The chapters in part II climb the hierarchy, treating in turn the *historia* of muscle, its actions, use, and utility. By the end of the notes Harvey has come full circle. He opens Chapter 1 with a discussion of the various animal actions involving locomotion; in the final chapter he identifies the secondary *utilitates* as just those kinds of animal actions.

4.2.2 *De artificio mechanico musculorum*

Perhaps the most striking feature of Harvey's *AM* is the presence of the chapter he entitles "On the Mechanical Construction of Muscles" (*De artificio mechanico musculorum*). Harvey introduces this long chapter by interweaving general teleological principles of nature (including from the *De incessu animalium*) and a selective paraphrase of the preface to the *Quaestiones Mechanicae*, along with reflections on their implications for the study of muscles. (See Figure 30, Figure 31, Figure 32.) Inspired by and responding to Fabricius's piecemeal efforts, Harvey sketches a self-conscious and systematic integration of mechanics into the teleological explanations of muscle anatomy. Although he does not work out any mathematical details for any of these features, the chapter is noteworthy for its attempt to develop a conceptual framework with which to articulate and carry out such a project.

Harvey articulates the *artificium mechanicum musculorum* by distinguishing between the action of the muscle (which is common to all muscles), and the *functio* of individual muscles, which he calls the perfection or completion (*perfectio*) of the action. This distinction, he says, reflects the fact that in any action there can be “the more and the less.” Because “all the works of God and Nature are perfect,” parts of the same kind (sharing a basic action) will have variations in that action, depending on their precise role and context in an animal body. In this way, “nothing lacks and nothing is superfluous; nor [is] anything in vain” and “[Nature] accomplishes nothing through many that could be through fewer; nor does it attend to fewer, where many [are better].” Because of the distinction between the action of muscle and its perfection, the anatomist must take note of both the constitution of the muscle, which is for the sake of the simple action (common to all muscles), and the *mechanical construction* of the muscles, for the sake of the perfection of that action. The remainder of the discussion (which continues on Folio 106v) is devoted to articulating precisely in what this mechanical construction consists.

To do this, Harvey first invokes the preface of the *Quaestiones Mechanicae*, establishing a parallel between mechanics and muscle anatomy. Mechanics allows us to overcome difficulties and move great weights with small forces in order to accomplish something useful that is *praeter naturam*. Harvey suggests that the same kind of difficulties are encountered in the functioning of muscles (i.e., the need to move large weights by small forces and to accomplish varied ends). Nature never fails to assist in these kinds of difficulties. Thus, in the movement of the bones and the weight of the attached limbs, marvelous things are accomplished. By drawing this parallel, Harvey is suggesting that in the construction of the muscles, nature makes use of the same kind of principles as those invoked in mechanical explanations of artifacts. As we have seen, in mechanics there are typically “slots” for the mover, the moved, and the fulcrum; the arrangement of these allows for the amplification of the effect of the mover on the moved. Harvey, it seems, is suggesting that this also occurs in muscle anatomy, in order that the various muscles' contractions have the precise effect required. This is the mechanical construction of the muscles.

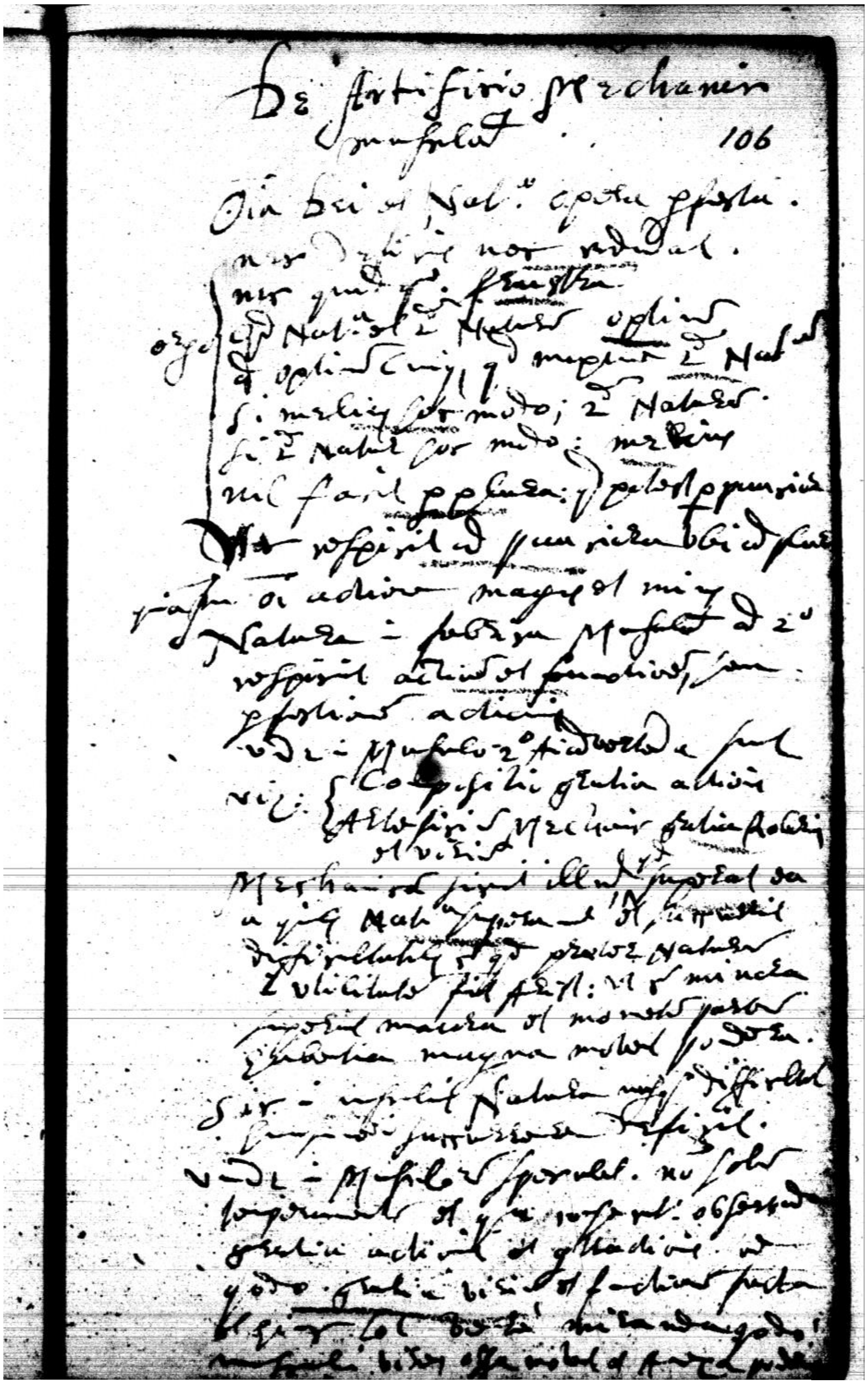

Figure 30. Reproduction of Folio 106, Harvey's *Anatomia Musculi*

De Artificio Mechanico
Musculorum

Omnia Dei et Naturae opera perfecta.

Ergo
nec deficit nec redundat
nec quidquam frustra
quod natura et secundum Naturam optimum
quod optimum cuique quod maxime secundum Naturam
si melius hoc modo, secundum Naturam,
si secundum Naturam hoc modo: melius
nil facit per plura : quod potest per pauciora,
nec [?] respicit ad pauciora ubi ad plura

quia In omni actione magis et minus
Natura in fabrica musculorum ad duas
respicit actionem et functionem, seu
perfectionem actionis.
unde in musculo duo animadvertenda sunt

viz
compositio gratia actionis
arteficium mechanicum gratia roburis
et virium.

Mechanica sicut illud quod superat ea
a quibus Natura superamur et succurrit
difficultatibus cum quod praeter Naturam
et utilitatem fit Aristoteles ut cum minora
superant maiora et momentum parvum
habentia magna movent pondera.
Sic in musculis Natura nusquam difficultatibus
huiusmodi succurrere deficit.

Unde in musculorum speculationem non solum
temperamentum et quae consecuntur observanda
gratia actionis et contractionis, sed
quomodo gratia virium et functionum factum
et hic tot vere miranda quomodo
musculi vires ossa movent et annexa pondera

Figure 31. Transcription of Folio 106, Harvey's *Anatomia Musculi*

On the mechanical construction of the
Muscles

Therefore
All the works of God and Nature are perfect.
nothing lacks and nothing is superfluous
nor [is] anything in vain
what is by nature and according to nature is best
what is best for each is what is most according to nature
if it is better this way, it is according to nature
if it is according to nature this way, it is better
[Nature] accomplishes nothing through many that could be through fewer
nor does it attend to fewer, where many [are better]

since in every action more and less
In the fabric of muscles nature attends to two things:
action and function, i.e.,
the perfection of action
hence in muscle two things are to be noted
viz
composition for the sake of the action
mechanical construction for the sake of strength
and power
which
Mechanica : just as that overcomes those things
by which we are overcome by nature and aids
in difficulties , when [it] accomplishes something outside of nature
and useful. Aristotle as when lesser things
overcome greater and things having little power to move
move great weights.
So in the muscles nature never fails to aid in difficulties
of this kind.
Hence in the study of the muscles not only
temperament and what follows it should be observed
for the sake of the action and contraction, but
how they are made for the sake of their powers and functions
and here there are many things about which to marvel how
the powers of muscle move bones and the connected weight

Figure 32. Translation of Folio 106, Harvey's *Anatomia Musculi*

On 106v, Harvey attempts to articulate with more precision which features are included in the mechanical perfection of the muscles. This is necessary because the perfection of the action of muscle involves more than simply mechanical considerations. He says that the perfection of the action of muscle consists in three things: speed or rapidity or agility (*celeritate, expeditione, agilitate*), measure or harmony (*modus, convenientia)*, and intensity, firmness, strength (*intentione, fumitudine, robure*). (106v) He also suggests that the more and the less in action is twofold: according to the intensity in the active motion (*intentionem motu activo*) and according to something like its ability to overcome resistance (*effectionem motu resistentia*).[194] In muscle, the former is the power derived from its capacity (*vires a virtute*), and the latter is its strength (*robur*). He suggests that the more and less in the first sense is derived from variations in motive spirit and heat in the muscles. The more and less in the second sense (which, note, corresponds to the third aspect of the perfection of muscle's action) derives from variations in (1) number, (2) shape, (3) size, (4) the location and positioning and interconnections of the muscle parts, and (5) the thickness or fleshiness of the substance of the muscles.[195] These features of muscle anatomy are present and vary for the sake of the appropriate strength (*robur*) of the muscle action, contributing to the perfection of the muscle action. The remainder of the *De artificio mechanico musculorum* is structured around these five categories of variations. He devotes a section to each, sketching how they vary for the sake of the perfection of the action of different muscles.

[194] He also calls the first simply *actio* as distinguished from *repassio*, which refers to the second.

[195] He also lists an additional category, but then connects it to one of the others by a line, suggesting he decided it was equivalent. This additional category is difficult to decipher, but Whitteridge reads "compositione, connexione" and Harvey lists under it *tunicis, capite, cauda; ansulis, theca* (tunics, head, tail, retinacula, theca). This he (understandably) identifies with the fourth category, location and positioning of the parts of the muscle.

However, before Harvey turns to this more detailed treatment, he concludes his articulation of the general project by stressing its teleological character: "Therefore, nature does not attend to shape, location, magnitude but for the sake of strength (*roboris*) and for the better, for protection, or as a sine qua non."[196] Thus the *artificium mechanicum musculorum* of muscles consists in the variations in these five features and is for the sake of the perfection of the action of each muscle—in particular, for the strength (*robur*) of the muscle action. These features vary from muscle to muscle, because they are for the sake of the varying perfection of the action of particular muscles. These variations in perfection, in turn, Harvey suggests are traced back ultimately to three of *utilitates finales* articulated in the *Prelectiones* (see above, p. 118): *ad melius*, *ad tutelam*, or as *sine qua non*.

The variations in these features of muscle constitute *mechanical* construction, because they contribute to perfection of the action not by affecting the intensity of the contraction but by exemplifying *mechanical* principles. The intensity of the contraction is the mover, but the effectiveness of that mover on the moved part depends not only on its intensity, but also on the arrangement of the mover and moved according to *mechanical* principles that are ultimately grounded in the nature of circular motion. In Chapter 7, "That which is at rest" (*Manens*), Harvey alludes to the *QM* preface discussion of the marvelous features of circular motion, mentioning, in particular, that circular movement contains contraries in the sense that opposite sides move in contrary directions.[197] In fact, in this chapter, Harvey is trying to work out how to apply Aristotle's analysis of the motion of joints in *De motu* and *De incessu animalium* to the specifics of muscle and bone anatomy and to connect both with the analysis of circular motion in

[196] Natura non respicit ergo ad figuram, situm, magnitudinem sed gratia roboris et ad melius, tutelam vel sine qua non.
[197] "...et habet miraculum circuli ut una pars hac opposite illac in contraries regions" (f. 85)

the *Quaestiones Mechanicae*. That is, like Moletti (see my discussion in Chapter 2), Harvey is trying to connect the internal still point of the *De incessu animalium*, the joint of the *De motu animalium*, and the center or fulcrum of the *QM*.

This attempt to connect mechanical principles, general principles of motion, and the specifics of muscle anatomy is embedded in Harvey's characteristic Galeno-Aristotelian project in the *Anatomia Musculi*. Harvey is not trying to provide explanations of animal motion "found in the descriptive mechanics of the organism treated as a physical system." (Jaynes 1970, 233) Rather, with Fabricius, Harvey aims to integrate mechanics into teleological explanations of the muscle and their variations. In comparison to Fabricius's efforts, Harvey's is particularly self-conscious and systematic: he attempts to articulate in a principled way a set of features of muscle anatomy, the proper teleological explanation of which will invoke mechanical principles; and he attempts to provide an explicit, general synthesis of the specifics of muscle anatomy, the Aristotelian natural principles of animal motion, and the mechanical principles found in *QM*. In this way Harvey's *De artificio mechanico musculorum* is analogous to the "science of the rainbow" that Aristotle mentions in *Posterior Analytics* and articulates in *Meteorology* III.

Recall from my discussion in Chapter 2 that in *Meteorology* III, Aristotle provides a sophisticated mathematical proof to explain why (e.g.) the rainbow has the shape of a segment of a circle, never greater than a semi-circle. This proof is a part of what Aristotle calls the "science of the rainbow" in *Posterior Analytics* I.13.

> Related to optics as optics is related to geometry, there is another—namely the study of the rainbow. Here it is for the natural scientist to know the fact and for the student of

> optics—either of optics *simpliciter* or of mathematical optics—to know the reason why.[198] (79a10-13)

The student of optics knows that optical phenomena exhibit geometrical properties as proper attributes. Some of these attributes are more fundamental and explanatory of the others. However, because these are *geometrical* properties the demonstrations making clear the explanatory relations between them belong to geometry. So, too, the natural scientist knows that meteorological phenomena exhibit certain optical properties as proper attributes. Some of these properties are more fundamental and explanatory of others. And because they are *optical* properties, the demonstrations making clear the explanatory relations between them belong to optics.

Thus, when Aristotle turns to the study of the rainbow (and halos, mock suns, and rods[199]), he says "we must first describe the phenomena and the circumstances in which each of them occurs." (371b21) These are the facts known by the student of nature. After describing them, Aristotle concludes,

> These are the facts about each of these phenomena: the cause of them all is the same, for they are all reflections. But they differ in the manner of the reflection and in the reflecting surfaces and according as the reflection to the sun or some other bright object is.[200] (372a17-21)

Aristotle here says that the various meteorological phenomena described are reflections--i.e., they are *optical* in character). He also says that they vary in three ways: the manner of the reflection, the reflecting surface, and the bright object. These three sound very much like the

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[198] Translation is Barnes's (Aristotle 2002).

[199] I think it likely that Aristotle uses "science of the rainbow" to refer to all of these phenomena. They belong together because the "same causes account for them all." (*Meteorology* III.2 371b18-20)

[200] Translations from the *Meteorology* are from *The Complete Works* (Aristotle 1984).

optical equivalent of the mechanical "slots" that Mark Shiefsky (2009) describes in his analysis of the *QM*. (See my discussion of this in Chapter 2.) Aristotle goes on to explain how these slots are filled variously by the location of the observer, the clouds, and the sun or moon. In this way, he is articulating the ways optical properties are proper attributes of the meteorological subject matter. In addition, he (sometimes explicitly) borrows fundamental principles of optics and applies them. For example, he says,

> We must accept from theory of optics the fact that sight is reflected form air and any object with a smooth surface just as it is from water; also that in some mirrors the shapes of things are reflected, in other only their colors. (372a29-31)

Thus, the science of the rainbow involves the application of optics to meteorological phenomena through identifying optical properties that are proper attributes of the subject matter, showing how, because of this, the "slots" of optical demonstrations can be filled by meteorological phenomena, and exhibiting optical demonstrations of the meteorological phenomena. The science of the rainbow is a unified science because the cluster optical properties are proper attributes of the meteorological subject matter and some of them are explanatory of the rest.

In his *De artificio mechanico musculorum*, Harvey similarly attempts to articulate a cluster of mechanical properties that are proper attributes of muscles and that can fill the "slots" in mechanical demonstrations. Unlike Fabricius, whose application of mechanics is piecemeal and isolated, Harvey attempts to identify the cluster of properties to be considered in a principled and systematic way. In this way, the *De artificio mechanico musculorum* is to mechanics as the science of the rainbow is to optics. There is another connection between mechanics as conceptualized in the preface to the *QM*. Recall that there mechanics is described as that part of art that enables us to overcome nature in order to accomplish something *praeter naturam* that *contributes to the varying human good.* In this way, mechanics has an implicit teleological structure. The human artifice analyzed in mechanics is for the sake of a good. Furthermore, it is because that good varies from context to context that mechanical artifice is required. Similarly, in the case of the *De artificio mechanico musculorum,* it is the varying end for the sake of which muscle is present (the varying perfection of its action), that requires the presence of mechanical artifice. In addition to muscle anatomy exemplifying the principles of mechanics (filling the "slots" of mechanics), it also exemplifies its complex teleological structure.

4.2.3 The Unity, Topic, and Title (again) of the *Anatomia Musculi*

Furthermore, it is the teleological structure of muscle anatomy that connects the two parts of Harvey's *Anatomia Musculi*. In the introduction to her edition of the notes, Whitteridge has little to say about the relation between the two parts. I suggest that it is the Aristotelian idea of hypothetical necessity present in things that are and come to be for an end that provides the key to their unity. Recall, from my discussion of hypothetical necessity in the last chapter, that in order to grasp the hypothetical necessity present in animals, one must grasp both the essence or end for the sake of which of the animal or part, *and* certain broader natural principles, typically at the material level. For example, in order to grasp the necessity of the muscles being provided with many and large veins, one must know both the action of the muscle and certain aspects of matter theory (having to do with the behavior of loose fleshy material in the context of contraction). To grasp the necessity of those features that Harvey call the *artificium mechanicum musculorum*, one must grasp both the function of the particular muscle and mechanical principles. Similarly, to understand the necessity of the action of the muscles, one must grasp the essence of the animal or the character of its "complete" or "comprehensive" activity *and* various other material facts—for example, that nourishment is not always in the same place, or that the temperature of the environment is different from place to place and time to time. These facts along with the nature of the animal render locomotion in place hypothetically necessary.

In the first part of the *AM* Harvey is laying out this structure of hypothetical necessity. This involves showing how, given the nature of the animal and its environment, motion in place is necessary. It involves, showing how, given the goal of locomotion and general principles governing locomotion, certain features of the animal are necessary—for example, that they have an internal complexity, allowing for mover and moved parts; that they have internal and external points of resistance; that the parts be able to flex around a shared center (so as to produces pushes and pulls); and so on. In chapters 1 through 7 of the *AM* Harvey attempts to do precisely this. In these chapters we see Harvey primarily working to articulate the hypothetical necessity that connects the nature of the animal and its characteristic life to the most basic features of the organs of locomotion in terms of the facts about the animal's environment and the nature and the general principles of locomotion (including both basic natural principles of motion and principles of mechanical motion.) Harvey can then draw on this material when he turns to a study of muscles in the second part. This interpretation of the relation of Parts I and II of the notes confirms what the manuscript evidence rallied above (p. 131) suggested. The topic of the notes is not animal locomotion but muscle anatomy, and so the manuscript is more aptly titled *Anatomia Musculi*. In them we see Harvey, the creative Galeno-Aristotelian, working toward final causal *scientia* of the muscles, articulated in terms of their *actiones*, *usus*, and *utilitates*.

This characterization of Harvey and his project in the *AM* might not fit well with the portrayal of Harvey in traditional stories of the Scientific Revolution. Of course, in those stories it was the Harvey of the *De motu cordis* that played the role of revolutionary. In the next section, I turn to *that* Harvey. For all its brevity and apparent accessibility, Harvey's most famous work has been much misunderstood. Below I apply Harvey's own Rule of Socrates to the interpretation of the *De motu cordis*. For the modern reader, it is actually an obscure case of Harvey's anatomical project. I hope that, in the light shed by these first two sections, the truth of the matter will shine forth clear as the noonday sun.

4.3 THE *DE MOTU CORDIS* AND *ANATOMIA PHILOSOPHICA*

Historians of science and medicine have long portrayed William Harvey as an important figure in the Scientific Revolution and his *De motu cordis* (DMC)as a prominent example of the new science of the 17th Century.[201] Two features of this work, its effective use of observation and vivisection and its willingness to set aside the question of the final cause of the circulation, are often identified as innovative and characteristically modern. Referencing also his later comparison of the heart to a pump, historians have portrayed Harvey as an early champion of a new, experimental, mechanical science. However, beginning especially with the work of Walter Pagel,[202] historians have come to see that, at least in his other works, Harvey was unabashedly Aristotelian, eager to identify final causes in nature, and critical of the 'neoteriques'—including proponents of corpuscularian or atomist natural philosophies.[203] The resulting tensions in our

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[201] In this, historians follow the example of many of Harvey's near contemporaries. Hobbes, for instance, in his *De Homine* (Hobbes 1655), identifies Harvey as the first to discover and demonstrate the science of the human body, setting him alongside Copernicus and Galileo as a founder of true science. Descartes and Boyle, too, were clearly impressed by Harvey's work. For Harvey's influence on experimental philosophy in the medical context see French (1994); Frank (1980).

[202] See e.g. Pagel (1967) and (1976).

[203] It should be noted that scholars have disagreed on the precise content and significance of Harvey's Aristotelianism. In addition to Pagel's work, see French (1994); Lennox (2006a, 2006b); For a deflationary discussion of Harvey's famous comments, reported by Aubrey, concerning Francis Bacon and the 'neoteriques', see

understanding of Harvey have not yet been entirely resolved.[204] We are tempted to see in Harvey a man divided, with allegiances to modernity and tradition, to observation and theory, to experiment and *a priori* speculation.[205] My concern here is to show how the *DMC*, despite its place in historiographies of the Scientific Revolution, is the product of the same Galeno-Aristotelian understanding and practice of anatomy reflected in his *Prelectiones* and his notes on muscle anatomy. I will focus on the (1) place of teleology in Harvey's *DMC*, and (2) the Aristotelian motivations for his use of dissection and vivisection.

4.3.1 Final Causes and the Goal of Anatomy in the *De motu cordis*

It is sometimes suggested that Harvey eschews appeals to final causes in the *De motu cordis*, in favor of pursuing empirically established non-teleological knowledge of the structure and motion of the heart and blood.[206] This picture, though, is over-simple to the point of being misleading. Harvey, it is true, suggests that he does not know the final cause of the circulation (though he is willing to speculate). However, careful attention to his treatment of the heart and arteries reveals that he identifies final causes and provides teleological explanations of these parts and their variations across species. In this, the *DMC* reflects Harvey's understanding of anatomy.

In order to appreciate this, it is important to distinguish between the heart and the blood. Harvey himself makes this distinction in the opening lines of the dedicatory epistle, where he characterizes his opinion "concerning the motion and use of the heart and concerning the

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McCaskey (2006), 314-333 (McCaskey, though, still considers Harvey to be a self-conscious Aristotelian). Goldberg (2012) helpfully places Harvey within what Charles Schmitt called "eclectic Aristotelianism" (C. Schmitt, Aristotle and the Renaissance 1983).

[204] This is not to deny the significant progress made (French 1994; Lennox 2006a; Lennox 2006b; Schmitt 1984).

[205] For a striking example, see Pagel (1967), 229; see also Whitteridge (1959), 4-5.

[206] Wear (1983); French (1994), 104, 301, 316.

circulation of the blood [*de motu & usu cordis, & circuitu sanguinis*].” (5) His opinion concerns the motion *and use* of the *heart*, while regarding the *blood* it concerns only its *motion*. Regarding the heart, Harvey believes he has final causal knowledge. Language throughout the *DMC* suggests Harvey that is there reporting an anatomical investigation of the heart (and arteries) successfully aimed at grasping their actions and use.[207] For example, the title of the *Prooemium* reflects its preoccupation with undermining the received view of the motion and *use* of the heart and arteries. In its opening line Harvey says such a preoccupation is important in the context of considering the “motion, pulse, *action, use and utility* of the heart and arteries.” (10; emphasis added) Similarly, in Chapter 1 Harvey identifies his project as searching for the “*use* and *utility* of the motion of the heart” (20) in animals through *autopsia* and reports that he has succeeded (21). In Chapter 6, he identifies his topic as the “movement and use of the heart.” (36)

This language suggests that, despite its title, the *De motu cordis et sanguinis* is best understood as a work primarily about the motion of the heart, and secondarily about that of the blood. More precisely, the motion of the blood is presented as the *action* of the heart, and as such, serves as a kind of explanans in a work devoted to providing a final causal explanation of the heart. The prominence of the motion of the blood in the title, and in the work itself, reflects the especially radical character of Harvey’s claim that the action of the heart is to “drive the blood into a circuit by a kind of circular motion in animals” (58).

To see this, it is helpful to recognize that the *DMC* reflects the *historia*, *actio*, *usus* structure so prominent in Fabricius’s publications. In chapters 2 through 4, Harvey presents a

[207] Cunningham suggests this point (2006, 144-147). Bylebyl (1973) also notes this language.

historia of the heart (and arteries), focused particularly on their motion.[208] In Chapter 5, after summarizing the motions of the heart (and arteries), Harvey identifies its *action*.

> The motion of the heart then is entirely in this manner and one action of the heart is this very transmission [from the veins to the arteries] of the blood and its propulsion to the extremities by the intermediacy of the arteries… (30)

In chapters 6 and 7, after identifying the presence of lungs in humans as a source of confusion for past anatomists, Harvey defends the universality of the identified action. He argues that in *all* animals (including humans and other lunged animals), one action of the heart is the transference of the blood from the veins to the arteries. In Chapter 6 he argues that the identified action is clear in simpler animals and in all animals during fetal development. In Chapter 7 he argues that in lunged animals, too, the heart transfers the blood from the veins to the arteries—doing so via the pulmonary transit. Similarly, chapters 8 through 14, presenting Harvey's central argument for the systemic circulation, are framed by Harvey as concerning the action of the heart. This is clear from Chapter 14, where Harvey concludes his demonstration of the systemic circulation. Claiming that he has shown by observation and argument the direction and amount of the motion of the blood through the heart, arteries, and veins, he states:

> It is necessary to conclude that the blood is driven into a circuit by a kind of circular motion in animals, and is in perpetual motion, and that this is an *action or function of the heart*....[209] (58; emphasis added)

For Harvey, these chapters present an argument for a (momentous) refinement of the Chapter 5 description of the *action of the heart*.[210]

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[208] Recall that, in the *Prelectiones* Harvey lists motion as one of the features to be studied in the *historia* of a part.
[209] The subtle distinction between *actio* and *functio* is not important for our purposes.

Some, like Andrew Wear (1983), agree that Harvey identifies the action of the heart, but argue that this action is not, for Harvey, a teleological notion.

> True, Harvey was concerned with action, more so in *De motu cordis,* but everything that he wrote points to *his inspecting action first as an anatomist rather than as a philosopher searching for causes.* For Harvey, theory (modern physiology) was concerned with purpose or the final cause. Of course, today, teleology has been officially consigned to the scrap-heap, and action or function is now part of theory, but for Harvey *teleology, rather than action*, comprised theory and was vitally important. …Harvey saw *the action as opposed to the purpose* of the heart and circulation as an anatomist saw the structure of the body, that is, by *autopsia*, with one's own eyes.[211] (Wear 1983, 229-230)

Wear, I suggest, makes three related mistakes. First, he invokes a false dichotomy between the "anatomist" and the "philosopher seeking causes." As we saw above, for Harvey anatomy *is* concerned with acquiring causal knowledge of parts. Second, Wear suggests a false dichotomy between observation and causal knowledge ("theory"). Again, as shown above, Harvey thinks that anatomy arrives at its causal knowledge *precisely by means of dissection and visual inspection*. Finally, Wear contrasts purpose and action, claiming that the action is distinct from teleology. However, as I argued above, for Harvey action *is* a teleological notion. According to Harvey's understanding, action is paradigmatically the final cause of a part and its features.

In Fabricius, this final causal relation between the action and the components and features of a part is articulated in terms of the *utilitates* of these components and features and is treated in

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[210] My suggestion here is best understood as a refinement of Bylebyl's analysis of the structure of the *DMC* (Bylebyl 1973 and especially Bylebyl 1977). Bylebyl sees two structures, one (chapters 8 through 16) inserted into and distorting and obscuring the other (*Prooem*, chapters 1 through 5, chapter 17). Bylebyl, however, seems not to notice that Harvey presents the circulation as the *action* of the heart. This identification determines where in the text the argument for the circulation must appear and provides the overarching unity of the *DMC*, a unity centered on articulating *scientia* of the heart.

[211] Emphasis added. French (1994, 316) follows Wear in contrasting action and teleology.

the final section of his works. Harvey shares this understanding and also turns to this topic in the final chapter of the *DMC*. Chapters 15 through 17 are framed by Harvey as providing additional arguments in support of the identified action of the heart, the circulation of the blood. Chapter 15 provides general reasons for thinking the circulation of the blood is appropriate and necessary for animals. Chapter 16 provides a series of arguments *ex consequentiis* in favor of the circulation of the blood. That is, Harvey argues for the proposed action of the heart by showing how it can be invoked as cause in the explanations of a range of (mainly medical) phenomena. Near the end of this discussion, Harvey describes Chapter 17.

> Therefore in this place, that is to say in the following chapter [Chapter 17], I shall endeavor to refer to their proper uses and true causes, only those things relating to the fabric of the heart and arteries which are visible in the course of an anatomy…. (63)

Chapter 17 is here framed as an extension of the project of Chapter 16. In it Harvey shows how the circulation (as an action of the heart) can be invoked in final causal explanations of the heart and arteries and their variation.

Harvey begins the chapter by providing a final causal explanation for why some animals have hearts and some do not. Certain smaller creatures have no heart "as being creatures that have no need of a driving force to dispatch the nutriment to the extremities." (64) In contrast, some animals do have this need "on account of the variety of the organic parts or the density of their substance" (64) and for this reason have a heart. Harvey then provides final causal explanations of intra- and interspecies variety in the heart, moving from simpler to more complex hearts. He explains why some animals have both an auricle and a ventricle:

> In animals which are bigger and warmer, because they are sanguineous there is need of something to impel the food, something that is perhaps endowed with greater force.

Therefore, in fish, snakes, lizards, tortoises, frogs and the like, the heart has both one auricle and ventricle…. (65)

He explains why some have two ventricles, echoing the view he articulates in Chapter 7: the right ventricle is present for the sake of the pulmonary circulation (65).[212] He explains that some hearts have fibrous material crossing the chambers and connecting the interior of the walls of the heart "to supplement, as it were, its contraction and so to give a stronger impulsion to the blood and to assist the heart in driving out the blood to a greater distance…." (66) Harvey also provides final causal explanations of (e.g.) the left ventricle being stronger than the right ventricle, the presence of valves in the heart and their variation across species, the variation in auricles across species, and certain details of the fibrous composition of the heart. Similarly, for the arteries Harvey provides final causal explanations of the thickness of the coats of the arteries and the variation in that thickness. All these explanations invoke the circulation as final cause. Harvey finds this final causal knowledge compelling enough to frame it also as an argument *ex consequentiis* for the circulation.[213]

However, this confidence in the circulation as the final cause of the heart is not extended to the further question of the final cause of the circulation itself. Though he is willing to speculate on the topic when he introduces the circulation in chapter 8, Harvey ultimately sets the topic aside. "But of these things it will be more appropriate to speak when we come to enquire of the final cause of this kind of movement [i.e., circulatory motion]."[214] (42) Similarly, in Chapter 6, Harvey suggests possible final causes for the pulmonary circulation, but says anatomists

[212] In chapter 7, he says 'And in this sense only it is to be said that the right ventricle was made for the sake of the lungs and on account of the transference of the blood…' (40)

[213] In this, I am in basic agreement with Bylebyl's characterization of this chapter as a *'de utilitatibus*' section redeployed as an argument *ex consequentiis* (J. Bylebyl 1977). What is important here is that this argument is from consequents to their *final cause*.

[214] Harvey returns to this topic briefly in Chapter 15 and invokes such a possible final cause in Chapter 17.

should pursue the question further (36). In both the systemic and pulmonary circulation Harvey leaves the question of the final cause of the circulation open, identifying it as an important topic for anatomical research. But since in the *DMC* he seeks to provide final causal knowledge of the heart, and not of the circulation itself, establishing the fact of the circulation is sufficient. Strictly speaking, full *scientia* of the heart would entail being able to trace the features of the heart to the action of the heart as final cause *and* being able to trace that action ultimately to one of the categories of *utilitates finales* (see above, p.118). Still, Harvey considers the investigation reported in the *DMC* to be successful, insomuch as it has identified the action of the heart and shown how that action is the final cause of the presence and features of the heart as it varies in different animals.

4.3.2 Experiment and Anatomical Method in the *De motu cordis*

Besides clearly exhibiting Harvey's understanding of the goal of anatomy, the *DMC* also reflects Harvey's comparative method.[215] In fact, it does so more clearly, perhaps than any other source. As discussed above, the Rule of Socrates provides us with a key to understanding Harvey's systematic insistence and effective use of animal dissection and vivisection in the *DMC*. According to this rule, the anatomist seeks to achieve thorough familiarity with the variations exhibited by a part. This variation allows the anatomist, when seeking to grasp the actions and uses of a part, to identify those instances of a part that are most revealing and informative regarding any particular question, and to compare the tentative understanding achieved there

[215] This section benefits from James Lennox's treatment of experiment, conceptual innovation, and comparative method in *DMC*. Lennox nicely focusses attention on Harvey's integration of vivisectional and comparative methods in the *DMC* and stresses their connection to Harvey's Aristotelianism (Lennox 2006a).

with the more difficult cases in search of general knowledge of the actions and uses of a part and its variations. This understanding of anatomy is most clearly articulated by Harvey in the opening lines of Chapter 6 of the *DMC*. Recall that in Chapter 5 Harvey has identified an action of the heart as the transference of the blood from the veins to the arteries. He closes Chapter 5 by discussing how past anatomists seem to have been confused about the heart's action because of the presence of the lungs. He opens Chapter 6 with a methodological criticism of these past anatomists.

> Since it is probable that the connection which they see in man of the heart with the lungs has been the cause, as I have said, of their error, they are to blame in this, that whilst they desire to pronounce upon and demonstrate and understand the parts of all living creatures, as all anatomists commonly do, yet they look only into man's body, and that his dead body…they act no otherwise than as if from one particular premise, they would frame a syllogism to a universal conclusion.
>
> Were they, however, as well practiced in the dissection of animals as they are experienced in the anatomy of man's carcass, this matter which keeps them all in doubt and perplexity would, in my opinion, shine forth clear and free of all difficulty. (32-33)

This criticism is telling. Notice its logic. Because the scope of anatomy is the parts in all animals, the method utilized by past anatomists is inadequate, indeed blameworthy. These anatomists looked only at the human body and failed to examine the heart in other animals, including vivisected animals. If they were to follow proper method, considering and comparing the heart in all animals, the truth about the action of the heart would "shine forth clear and free of all difficulty."

After this criticism Harvey undertakes a discussion, in chapters 6 and 7, meant to correct for this error. These chapters clearly reflect Harvey's use of the Rule of Socrates. In Chapter 5, he points out that many people have had difficulty achieving a clear grasp of the action of the heart, because the human case is a difficult and obscure one.

> Yet, stumbling as it were in a dark place, they seem to be dim-sighted and clumper up diverse things which are contrary and inconsistent and speak many things by guess as I have shown before.
>
> One thing seems to me to have been the chief cause of doubt and mistake in this business, and that is the connection in man of the heart and the lungs. (31)

Following the Rule of Socrates, Harvey directs anatomists' attention to the heart in other animals, where the action is more easily discerned (where it is written "in a great print"). Because he has identified the lungs as a "confounding variable", as James Lennox (2006) has helpfully put it, Harvey turns first to animals without lungs, and then to those with lungs but with a perforated septum.

> First of all then, in fish which have but one ventricle of the heart, they having no lungs, the matter is clear enough. … Next, it is not difficult to see the same thing in all animals that have but one ventricle, or as it were but one, as toads, frogs, snakes and lizards… (33)

In various ways, all these animals exhibit clearly the path by which the heart transfers the blood from the veins to the arteries. He then turns to the developing embryo—a slightly more obscure case, showing that here too the action of the heart is more apparent.

> Therefore, in embryos also, the truth shines forth as clearly, the truth that the heart by its beating transfers the blood out of the vena cava into the great artery and pours it through as patent and open ways… (36)

Near the conclusion of Chapter 6, Harvey summarizes the results achieved in the examination of the clearer cases, suggesting that, in light of this, we return to the more difficult case.

> Seeing therefore, that in most animals, and in all for a certain time, there exist these most open ways that serve for the transmission of blood through the heart, it remains for us to seek diligently into this business. (36)

Harvey then devotes Chapter 7 to this task, arguing that even in the obscure case, the heart does indeed have as its action the transference of the blood from the veins to the arteries, by way of the pulmonary transit.

Although this is the clearest and most detailed example, Harvey's comparative method is reflected throughout the *DMC*. In Chapter 1, Harvey recounts the goal of his anatomical research and reports his investigations were successful. His language reflects the comparative method he used in those investigations. After identifying final causal knowledge of the heart as his goal, and dissection of animals and ocular inspection (*autopsia*) as his means, Harvey emphasizes the difficulty of the task.

> …I straightway found it a thing hard to be obtained and full of difficulty…. For I could rightly distinguish neither how systole nor diastole came to be, nor when nor where the dilatation and the constriction occurred, and that by reason of the quickness of the motion which in many creatures appeared and disappeared in the twinkling of an eye, like the passing of lightning…. (20)

He also identifies here a main sources of difficulty in the case: the quickness of the motion of the heart. Harvey then relates how it was that he overcame this difficulty.

> At last, using daily more search and diligence, *by often looking into many and different sorts of living creatures, by collecting and comparing many observations*, I believed that I had hit the nail on the head, unwinded and freed myself from this labyrinth and had gained the knowledge I so much desired… (20-21; emphasis added)

Notice that the solution is attained by means of (1) increasing the diversity of animals he examined, and (2) comparing his many observations of the heart as it varies across different animals. This is, essentially, a succinct articulation of his comparative method, guided by the Rule of Socrates.

If we turn from this summary of his efforts and look at the observations he reports in chapters 2 through 5, we find that his choice of observation is guided by this Rule. Many times, Harvey identifies the observations he recounts as particularly clear and revealing. Furthermore, the chosen observations are striking in the way they span a wide range of animals and contexts in a systematic way. For example, in Chapter 2 he isolates particular animals for which the motions will be particularly evident.

> All this is more evident in the hearts of colder creatures, as toads, snakes, frogs, snails, lobsters, crustaceans, mollusks, shrimps and all manner of little fish. Everything is also more evident in the hearts of warmer animals, like dogs and pigs, if you observe attentively until the heart begins to die and to beat more faintly and, as it were, to be deprived of life. Then you may clearly and plainly see the movements of the heart becoming slower and less frequent and its moments of stillness longer; and you may

> observe and distinguish more conveniently both the kind of movement that it has and how it is made. (21-22)

Three things are particularly worth noting. First, the diversity of contexts he considers spans both the kinds of animals, and the state of health and disease (the dying warmer animals). These are two of the categories of variation he identifies in his discussion of *historia* in the *Prelectiones*. Second, he identifies these cases as particularly clear because of the way they remove the first difficulty he identified in Chapter 1, the quickness of the heart's motion. Finally, it seems clear that it is the agreement between insights gained in these particularly clear contexts, and the way those insights illuminate the quicker motions of hearts in other contexts that makes them valuable—i.e., it is by *comparing* the conspicuous and obscure cases that we arrive at universal knowledge of the motions of the heart.

These features are found, more or less explicitly, in all his reports of observations throughout chapters 2 through 4. Two examples will suffice. In Chapter 3, focused on the relation between the motion of the heart and the arteries, Harvey reports

> Again, if any artery be cut or pierced, the blood is forcibly thrust out of the wound at the moment of contraction of the left ventricle. So also, if the arterial vein be cut, you will see the blood burst out forcibly from it at the very moment when the right ventricle becomes tense and contracts.
>
> So likewise in fish, if you cut the vessel which leads from the heart to the gills, you will also see the blood forcibly thrust out through the cut at the very moment that the heart is tensed and contracted. (24)

Here he is stressing the agreement between the behavior of arteries connected to the left ventricle, of the arterial vein connected to the right ventricle (variation of related parts in the same animal), and of the analogous vessels in fish (variation of related parts across animals kinds.) Furthermore, the wounded animal (with a pierced vessel) provides a clear case that sheds light on the timing and nature of the pulse in all cases. Similarly, in Chapter 4, where Harvey is discussing the motion of the auricles in relation to that of the ventricles, he again turns to clear cases to establish that the pulse of the auricle is distinct in place and time from that of the ventricle.

> When all things are already in a languishing condition, the heart dying away, both in fish and in colder-blooded animals, there intercedes between these two motions a short time of stillness, and the ventricle being as it were awakened seems to answer to the motion sometimes swifter, sometimes slower, and at last, drawing towards death, it ceases to answer by its motion and only by gently nodding its head seems as it were to give consent and, moving scarce perceptibly, seems only to give a sign of motion to the beating auricle. (26)

Examples could be multiplied. In all, the emphasis is on the comparison of conspicuous and obscure cases, in order to arrive at a general understanding.

An important feature of Harvey's comparative dissection and vivisection is that he consistently keeps the final causal question in mind. It is clear that Harvey is concerned to correlate a part and its action. Like Aristotle, he thinks that this concern extends also to correlating variation in structure with variation in action. His comparative method involves systematically comparing related or similar parts within the same animal and across animals in search of final causal knowledge that will explain the variation discovered in the parts. In the long *Prooemium*, Harvey is concerned to stress the inadequacies and uncertainty of received views on the "movement, pulse, action, use (*usu*) and utilities (*utilitatibus*)" (10) of the heart and arteries. Toward the end of this long, and often penetrating discussion, Harvey provides a numbered list of particular problems that face the received view of the heart. All of them are articulated in terms of comparing related parts while considering the final cause. He compares in various ways the right and left ventricle, the arterial vein and venous artery, and the arterial vein and other veins. For brevity, I will consider only three.

> 1. Why then, I ask you, since the constitution of both ventricles is almost the same in that they have the same construction…, should we think that they were appointed to such diverse uses, seeing that their action, motion and pulsation is the same in both? …
>
> 3. And why, since the passages and vessels correspond to one another in point of size, that is the arterial vein and the venous artery, why should the one be destined to a particular use, namely to nourish the lungs, and the other to a general use?
>
> 4. And … how is it provable that so much blood is needed to nourish the lungs, for indeed this vessel, the arterial vein, is bigger in size than both the branches of the descending vena cava that supply the femoral veins? (15-16)

In each of these, Harvey considers the similarity and variation among related parts. He considers parts similar in structure but assigned different uses or parts assigned the same uses, but differing importantly in structure. In addition, he considers how variations in the same use in different parts are related to corresponding variations in the features of those parts. The Rule of Socrates indicates that the agreement of the answers to the same question among different cases indicates success. Disagreement, however, requires the investigation to continue and the understanding to be refined. In this light, a dissonance between different part-function correlations is highly suggestive. This methodology is behind his identification and articulation of these problems in the received view of the heart.

Harvey reports that this same cluster of concerns played an important role in the thought process that first led him to suspect the circulation of the blood. They show up prominently in the famous and famously difficult passage from Chapter 8, in which he reports how he came first to suspect that the blood circulates.

> In truth, when, [1] from a variety of investigations by dissection of the living for the sake of experiment and by the opening of arteries, and [2] from the symmetry and magnitude of the ventricles of the heart and of the vessels entering and leaving (since Nature, who does nothing in vain, would not have needlessly given these vessels such relatively large size), [3] from the skillful and careful craftsmanship of the valves and fibers and the rest of the fabric of the heart, and [4a] from many other things, I had very often and seriously thought about…how great the amount of transmitted blood would be [and] in how short a time that transmission would be effected, and [4b] [when] I [then] became aware that the juice of the ingested aliment could not have sufficed without our having the veins emptied, utterly drained, and the arteries on the other hand burst asunder by the too great inthrust of blood, unless the blood were somewhere to return again from the arteries into the veins and to go back to the right ventricle of the heart, I began privately to think that it might rather have a certain movement, as it were, in a circle…[216] (41)

The passage I have labeled [2] is, in essence, a summary of most of the concerns Harvey raises in the *Prooemium*.[217] He stresses both the symmetry of the ventricles and vessels entering and leaving them, and their magnitude. The latter is surely elliptical for their magnitude relative to the other vessels in the body—i.e., it summarizes concerns number 1, 3 and 4 of the *Prooemium*.

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[216] I take this translation from Don Bates's article analyzing this difficult passage (Bates 1992, 364)
[217] Note that this makes a stronger connection between the proem and the "circulation chapters" than Bylebyl suggests.

This suggests that Harvey's famous quantitative argument in *DMC* was motivated in part by insight arrived at by his comparative methodology.

The comparative methodology also appears elsewhere in Harvey's argument for the systemic circulation. It is perhaps most conspicuous in his discussion of the valves in the veins in Chapter 13. Here, again, Harvey compares related parts—within the same animal and across different animals.

> The discoverer of these valves did not rightly understand their use … They do not look upwards everywhere but always towards the roots of the veins and everywhere towards the region of the heart. … It may be further noticed that dogs and all oxen have valves in the dividing of the crural veins at the beginning of the sacral bone, or in the branches near the hip-bone, and in these animals there is no such thing to be feared as that the blood should fall down by its own weight on account of their upright stance. (55)

Harvey argues that "the discoverer of these valves" (Fabricius) did not come to a satisfactory understanding of the veins, precisely by comparing the position and structure of the valves as they appear throughout the human body, and in other animals that do walk upright. It is because Fabricius's answer to the use question does not succeed in all instances that it must be rejected. The investigator must return again to the question until he finds an account of the valves that, like Socrates' account of justice, applies to all instances. Harvey suggests such an answer: the valves do not hinder the flow of blood *downwards* (toward the ground), but rather its flow *away from the heart*. In addition to these two explicitly comparative examples, Harvey also makes appeals to conspicuous cases that will shed light on all other instances. Perhaps the best example of this is his experiment on the vivisected snake in Chapter 10. In this chapter, Harvey is providing additional arguments in favor of the first of the three suppositions that, once confirmed, will together establish the circulation. The first supposition is that more blood is transferred through the heart than can be provided by food ingested. He concludes this chapter by describing the vivisection of a snake. Harvey first walks the reader through seeing clearly all that he discussed regarding the movement of the heart. He then suggests the reader undertake a particular procedure on the vivisected snake: “Now this one experiment in particular can be tried and it is more illuminating than the noonday sun.” (47) The experiment Harvey suggests involves first clamping off the vena cava below the heart and making several observations and then, releasing it, clamping off in turn the arteries just after the heart and making parallel observations. This procedure produces, according to Harvey, an experience that is clearer than “the noonday sun.” That is, Harvey has provided the reader with an illuminating case which provides clear insight into the action of the heart, the one-way and continual transference of blood from the veins into the arteries.

The discussion of this procedure raises the general topic of Harvey’s very effective use in the *DMC* of interventions. As has been implicit in my discussion of other examples, I think Harvey’s use of intervention is best understood as an example of his comparative method. That is, for Harvey the interventions produce new contexts, exhibiting additional, potentially illuminating variation, in which to examine the nature of a part. These interventions produce variations in a part that Harvey would subsume under his category differences states of health or disease. The new variations produced serve then as those cases where the answer is “written in a great print” and from which new or greater insight can be gained. This insight is then brought to other, more obscure cases and illuminates them, giving the investigator confidence in his knowledge. Thus, Harvey’s interventionist methodology is not an *addition* to his Aristotelian comparative method, but rather a particularly powerful *instance* of it. Whether he is comparing a part across kinds, or across various interventions, the methodology is the same. In both, he is hunting conspicuous cases by which to arrive at and establish universal (and, ultimately, final causal) knowledge of all cases.

4.4 CONCLUSION: MECHANICS, MECHANISM, AND HARVEY'S GALENO-ARISTOTELIAN ANATOMICAL PROJECT

In the *De motu cordis* (and beyond), Harvey aims at final causal knowledge. His understanding of the role of non-causal truths in the pursuit of *scientia* do not reflect an anti- or non-Aristotelian epistemology or methodology. However, even if this is so, should we not still see something characteristically modern, novel, and representative of the 'New Science' in his "mechanization of the heart"? In the *De motu cordis* Harvey compares the motion of the heart to that of the firing mechanism of a gun; later he compares it to a pump. What is this but the mechanization of the animal that will be championed by Descartes and others? On the other hand, Harvey defended the existence of a non-mechanical 'pulsific virtue' in the heart and was critical of Descartes's mechanistic theory of the heart and, more generally, of the corpuscularianism associated with (e.g.) Descartes, Gassendi, Hobbes, and Boyle. In his work on animal generation Harvey even criticizes his teacher Fabricius for being overly influenced by the "petty reasoning of mechanics." Perhaps, here, then, we find evidence of a divided or conflicted Harvey, with one foot in modernity and one in tradition. Although such a "Two Harveys" interpretation might fit the texts better than a "Mechanist Harvey," it too is ultimately unsatisfying.

Harvey's attitude towards 'mechanics' and the 'mechanical' is complex. But this should be no surprise, since the nature and meaning of 'mechanics' and 'mechanical' in the 17th century is itself complex and multi-faceted. In an effort to put the final nail in the coffin of the Two Harveys, I conclude here by exploring the complex and varied uses of the "mechanical" in Harvey's works. I argue that, despite apparent inconsistency, Harvey's attitude toward mechanism is actually stable and consistent, reflecting the semantic ambiguities of "mechanics" and the "mechanical" and his own self-understanding as a creative Galeno-Aristotelian anatomist trained by Hieronymus Fabricius ab Aquapendente.

It is important for my purposes to distinguish between Harvey's place in the rise of iatromechanism, on the one hand, and Harvey's own view of "mechanics" and its place in anatomy, on the other. The former concerns Harvey's reception, how he was read, perceived, and even portrayed by others. The latter concerns Harvey's own intentions, what he wrote and what he meant by what he wrote. Of course, these two topics are interrelated. Harvey didn't write in isolation nor use a private language. He wrote to be understood, and wrote through much of his reception. Still, the two can and should be distinguished, and my concern here is only with the latter.

In order to disentangle Harvey's various statements about mechanics, it is helpful to make explicit some of the semantic complexity of "mechanical" in the 17th century.[218] In calling something in the 17th century "mechanical" or "mechanics," one could have any of at least six things in mind. First, [1.] one could mean the mechanical or manual arts. In connection with this meaning, one could mean lowly, course, or undignified—in this connection, one thinks of the "Rude Mechanicals" of Shakespeare's *A Midsummer Night's Dream*. One could also mean [2.]

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[218] Here I expand on my brief discussion in Chapter 2.

the mathematical science of mechanics, which was, as we have seen in Chapter 1, already by the 17th century firmly established as a theoretical, mathematical science, typically located within the intellectual landscape as an Aristotelian subordinate science. Here, one could also mean to pick out especially the conceptual developments and progress made in this science through the assimilation and expansion of works by (e.g.) Archimedes or Pappus. Or, again, closely related, but distinct still, is [3.] the transformation of mathematical mechanics into what many called "physico-mathematics" by the end of the 17th century at the hands of thinkers like Galileo, Huygens, and Newton. Another distinct sense [4.] is given the term "mechanical" in the context of the "mechanical philosophy." Here, unlike in the case of physico-mathematics, the successful harnessing of mathematical tools is not of the essence. Rather, the guiding idea is that proper (true or promising or excellent) natural philosophy will invoke only a small set of properties typically employed in our understanding of machines: shapes, size, motion, contact forces, etc. In close connection with this commitment is the employment of sub-visible bodies (corpuscles or atoms) to explain macroscopic phenomena. Such explanations were quite often entirely qualitative and devoid of *mathematical* inference (be it geometrical, arithmetical, or algebraic). As Domenico Bertoloni Meli has recently stressed (Bertoloni Meli 2011, 12-16), the relevant contrast to such mechanism in the context of 17th century medicine was not teleology so much as appeal to the activity of soul or Galenic faculties. In calling a 17th century thinker mechanical one could also mean [5.] that he privileges the use of machine analogies—be it in heuristic, explanatory, or rhetorical contexts. Of course, typically machine analogies were invoked by supporters of a "mechanical philosophy;" but making precisely this point requires distinguishing these two senses.

Finally, in the wake of the seminal paper by Peter Machamer, Lindley Darden, and Carl Craver (2000) , the term mechanism has become an important concept in philosophy of science. Taking a cue from that original paper, and abstracting from a host of subtleties and controversies spawned by it, we can understand a thinker to be mechanistic, in this sense [6.], if he champions or primarily employs a particular kind of explanation: explanation by the description of a "mechanism."[219] Machamer, Darden, and Craver define "mechanism" in the following way:

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions. (3)

Their definition of mechanism is purposely abstract. In the context of my study, a slightly different and less abstract definition is appropriate:

> A mechanism is a system of component parts, such that the spatiotemporally structured exercise of the components' capacities constitutes a behavior of the system.

Such a definition makes clear that the "entities" are spatially defined parts (in our case, within an animal body), that the "activities" are the exercise of capacities of those parts, and that it is a spatiotemporal structuring of the entities and activities that constitutes them being "organized." In addition, my definition does not require the identification of start and termination conditions, but only that spatiotemporally structured exercise of component capacities constitute some "behavior" that is attributed to the system as a whole (in our case, the behaviors will be various activities attributed to either an animal as a whole or to some subsystem of the animal). To call a 17th century thinker "mechanist," in this sense, would be to suggest that they privilege this kind of explanation: the description of this kind of "mechanism."

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[219] See the opening line of their paper: "In many fields of science what is taken to be a satisfactory explanation requires providing a description of a mechanism." (1)

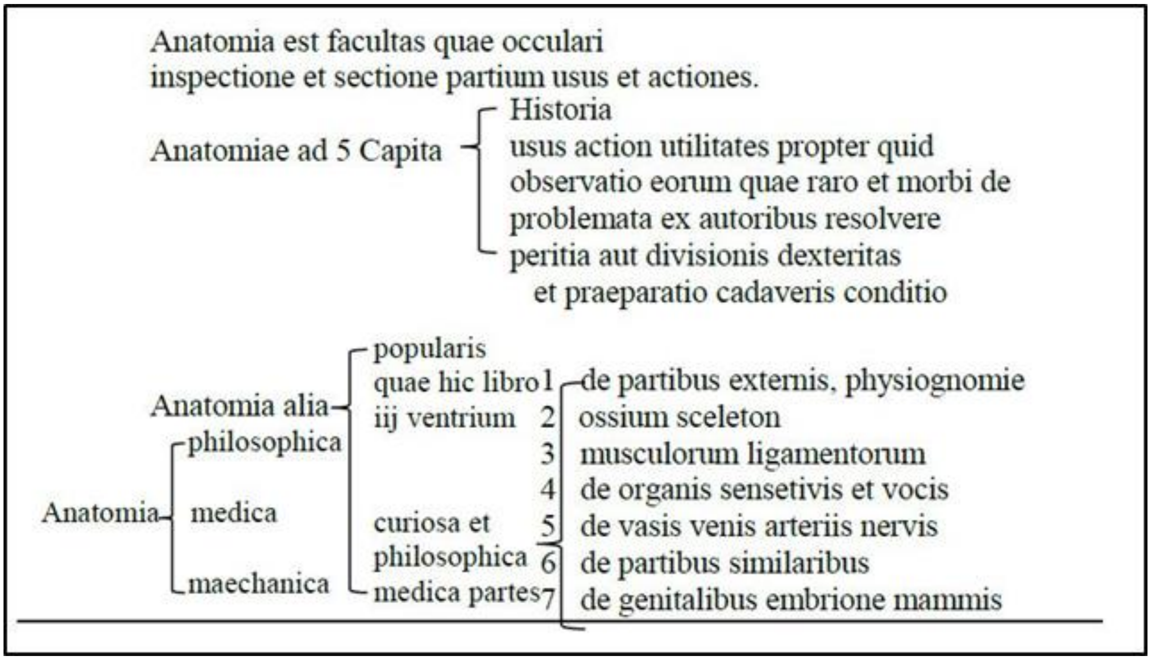

Figure 33. Transcription of part of Folio 1v, Harvey's *Prelectiones*

I am concerned here, particularly to understand Harvey's attitude in these various texts toward the "mechanical" in the first five senses. But I also consider the place in Harvey's anatomical project of "mechanism" in the final sense. In the *Prelectiones* presentation of several different ways of dividing anatomy, one is of particular interest in this context. He divides anatomy into philosophical, medical, and mechanical (*maechanica*). (See Figure 33; this division is in the lower, left hand corner of the transcription.) Although it may be tempting to connect this use of "*maechanica*" with one of the other senses of mechanical, it is most likely that Harvey employs it here in the first sense (the mechanical or manual arts). *Anatomia maechanica*, understood in this way, is the manual or craft-like skills involved in anatomy: the technological know-how and hand-eye coordination required to successfully dissect. This mechanical aspect of anatomy appears in Harvey's list of five *capita* of anatomy on this same folio. The last of these is "know-how and skill at dissection and the preparation of the preserved cadaver (*peritia aut divisionis dexteritas et praeparatio cadaveris conditio*). It also appears in the fourth of his *Canones Anatomiae Generalis* (folio 4): "Cut up as much as may be in present so that know-how is learned along with *historia*.” (Cutt up as much as may be in present *ut cum historia peritia innotescat*.) Recall that Harvey defines anatomy in terms both of what it grasps, and its method: “Anatomy is the faculty which [grasps] the uses and actions of the parts by ocular inspection and dissection.” For this reason, anatomy includes a “mechanical”—i.e., manual—component.

When we turn to Harvey criticism of Fabricius’s for employing the “petty reasoning borrowed from mechanics,” he again uses the term in the sense of the manual arts. This is clear from the context of the critique in Harvey’s *Exercitationes de Generatione Animalium*. Harvey is disagreeing with Fabricius’s account of the order of the formation of the parts of the chick during its development in the egg:

> But when he asserts that the bones are made before the muscles, the heart, liver, lungs and all the praecordia, and maintains that all the inward parts must exist before the outward, he relies on probable arguments [*rationibus probabilibus*] rather than on ocular inspection, and laying aside the judgment of the senses which is grounded upon dissections, *he flies to petty reasonings borrowed from mechanics* [*ratiunculas e mechanicis*], a thing which is very unbeseeming in so famous an anatomist. For he ought to have told us faithfully what daily changes his own eyes had discovered in the egg before the foetus in it came to perfection. And especially so as he professed to be writing an Historia of the Generation of the Chicken out of the Egg and he illustrated in pictures what happened from day to day. It was, I say, befitting so much diligence to have informed us on the evidence of his own eyes what is made first in the egg, what later and what things happen simultaneously, *and not by using the example of [building] houses [domus] or ships [navis], to have put forward some hazy conjecture [conjecturam*

umbratilem] or opinion [opinionem] concerning the order and manner of the formation of the parts.[220]

The "petty reasonings" are borrowed from "mechanics" in the sense of manual arts like the house and ship building mentioned late in the quotation. That is, instead of depending on sense and dissection (i.e., on the *anatomia maehcanica* we have just discussed), Fabricius turns to the example of the manual arts to determine the order and manner of the formation of the parts of the chick. Harvey's criticism regards the appropriate method in anatomy for producing *historia* and, ultimately, final causal knowledge of the parts.[221]

If we turn our attention from the *Exercitationes de Generatione Animalium* to the *De motu cordis*, we encounter machine analogies that might make us think Harvey is a mechanical thinker in the fifth sense identified above (privileging machine analogies). In Chapter 5, Harvey summarizes the *historia* of the motions of the heart laid out in the previous chapters before identifying the *actio* of the heart. In this summary, he compares the heart to machines.

> Nor is this otherwise done than when, in machines, [*machinis*] one wheel moves another and they all seem to move together; or in that mechanical contrivance [*mechanico illo artificio*] which is fitted to firearms where, by compressing the trigger, the flint falls, strikes forcibly upon the steel and brings forth a spark which falls onto the powder which is ignited, enters the touch-hole and explodes, and the bullet flies out and pierces the mark, and all these movements by reason of their swiftness appear to happen simultaneously as in the twinkling of an eye. (30)

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[220] Translation is Whitteridge's (Harvey 1981, 18).

[221] I suspect that Harvey is also concerned that Fabricius underestimates natural processes, reversing the order of imitation in the Aristotelian principle "Art imitates Nature." Fabricius seems to think rather that nature imitates art.

Here Harvey employs a machine analogy in his articulation of the motions of the heart. However, the *point* of the analogy is that in both there is a quick, coordinated series of motions producing one action. The point is *not* that in both there is a series of motions carried out entirely by the shape, size, and motion of (rigid) parts, and by their contact. The machine analogy is not being employed to make some kind of "mechanical philosophy" more plausible. It is not meant to help the reader appreciate the explanatory power of a restricted "mechanical" ontology. Furthermore, it is not Harvey's preferred analogy. He immediately provides a second analogy. This second analogy is not to a machine but to another animal activity:

> So likewise in swallowing, the food or drink is thrown into the gullet by the elevation of the root of the tongue and the compression of the mouth, the larynx is closed by its own muscles and by the epiglottis, the top of the gullet is lifted up and opened by its muscles …. And yet, notwithstanding that all these motions are made by several and contradistinct organs, whilst they are done in harmony and order, they are seen to make but one motion and action which we call swallowing. (30)

It is this analogy that he carries forward into his discussion of the action of the heart: "It clearly happens thus in the motion and action of the heart, which is a kind of swallowing and transfusion of the blood from the veins into the arteries." (30) In fact, careful examination reveals that the comparison between the coordinated and harmonious motions involved in swallowing and those found in the heart is *more* than an analogy. Harvey says that the action of the heart "is a kind of swallowing."

When we look through Harvey's unpublished notes we find other cases in which he employs analogies for other multi-component activities. In the *Prelectiones*, for example, he draws an analogy between the organs of digestion and chemical apparatus.

> Wherefore Nature has established diverse offices and employs diverse instruments, *just as in boiling in chimistria diverse heats, vessels, furnaces* [are used] to draw away the phlegm, raise the spirit, extract oil, ferment and prepare, circulate and perfect. So Nature makes use of the mouth, stomach, guts, mesenteric vessels, liver and so forth. (24v)

However, he elsewhere uses another analogy, this time to politics.

> Just as in some rather small state the same man is judge, king and counselor, while in larger states these offices are separate, so is it in animals and their parts; politicians indeed take many analogies from our medical art….And so in the lower belly where are made diverse concoctions needing different heats, different preparation and different nutriment, there are diverse organs besides the heart which provides the heat, and these diverse organs are the tutelary deities and the diverse artificers of the different functions, that is the liver, the spleen, the stomach and so forth. (91)

Elsewhere, in the *AM*, in contemplating how muscle contraction is brought about, Harvey provides a series of diverse analogies, under the heading *Ratio mechanica*:

> How appetite brings heat, Δ prick ... , ... water.
>
> How heat brings spirit: Hermes oven and gunpowder.
>
> How spirit works in fibre, Δ wet rope, barterole of veins.
>
> How fibre drives tendon, Δ legs of guinea-fowls, peru
>
> How tendon moves bone, Δ sucking fish, seaweeds, sponges.
>
> So the motor organs in some animals, and likewise in man, are: spirit, fibre, muscle, nerve and tendon. (111v)

Although, in this case, it is not easy to decipher Harvey's hand, let alone his mind, still the diversity of analogies is striking. He compares the components of the process to gunpowder, ropes, various animals, and to other anatomical features (veins).

Thus, we see that Harvey does not privilege machine analogies, and when he does use them, they are not aimed at establishing the explanatory adequacy of a mechanical philosophy, devoid of Galenic faculties. Thus, Harvey can integrate mathematical mechanics into his muscle anatomy in the *AM*, while still employing a Galeno-Aristotelian matter theory and conception of soul. Of course, one need not be a mechanical philosopher to be "mechanical" in the final sense distinguished above. Is Harvey, in these various contexts discovering "mechanisms" or providing explanations by describing them? One might think that chapters 2 through 5 of the *De motu cordis* are doing just that, describing a mechanism for the transference of blood from the veins to the arteries and thereby providing an explanation of a behavior of the heart.

This, however, does not accurately describe what Harvey is doing in those chapters. Of course, anatomy is about the parts. It involves a systematic breakdown of the animal into parts and parts of parts. So it does involve localization of animal activities in the parts and so the identification of a "system of component parts, such that the spatiotemporally structured exercise of the components' capacities constitutes a behavior of the system." However, recall that the goal of anatomy for Harvey is final causal *scientia* of the parts of animals, articulated in terms of their *actiones* and *usus* or *utilitates*. For Harvey the *actio* of the heart (transference of the blood from the veins to the arteries and back again) is not *explained* by describing the mechanism for it. Rather the *actio* explains the components of the mechanism. Chapters 2 through 4, by providing a *historia* of the motions of the heart, are meant to establish, not explain, the *actio* of the heart. It is by means of systematic (*historia* producing) ocular inspection and dissection that we come to grasp the causes.

This misinterpretation of *De motu cordis* chapters 2 through 5 involves the same mistake made by Baldini and Jaynes in their interpretation of Fabricius's and Harvey's use of mathematical mechanics in the *AM*. Recall that they understood these anatomists' project as providing an explanation of animal motion in terms of a descriptive mechanics of the animal. But both there and in the *De motu cordis*, the goal is final causal explanations of the parts. In the *De motu cordis* Harvey identifies one action of the heart (he suggests there could be others) and, in Chapter 17, provides final causal explanations of the components and features of the heart in terms of that action. It is true that he does not identify the final cause of the circulation, but even in the highly polemical context of the 1649 Second *Exercitatio Anatomica* to Riolan, Harvey assumes that this is the ultimate goal. There he insists that one could only have such open questions (*problemata disputanda*) if such facts could be established before we determine their final cause: "If nothing could be admitted by sense without the evidence of reason, or on occasion against the dictate of reason, there would now be no *problemata disputanda*." (Harvey 1649, 97)

We are mistaken, then, to think of Harvey as a man divided, with one foot in modernity and one in tradition—at least if we are considering Harvey's own project. If we want to find "Two Harveys" we should look instead at his reception. If we were to distinguish Harvey's self-understanding from how he was received, interpreted, and invoked by his contemporaries, then we might find two or more Harveys—one for each of the ways his contemporaries and near contemporaries criticized or lionized him, resisted or incorporated his discoveries or his insistence on and successful use of *autopsia*, dissection, and vivisection. But Harvey was not

Riolan; nor was he Descartes, Hobbes, or Boyle. Regardless of how they saw him and his project, Harvey understood himself to be a critical and creative anatomist who takes Aristotle as his leader and Fabricius as his guide. He understands the goal of anatomy to be Aristotelian *scientia* of the parts of animals, articulated in terms of the Galenic *actio* and *usus* of the parts. In pursuit of that goal, he develops and self-consciously employs a coherent and highly effective vivisectional and comparative method, one that he sees as a continuation and refinement of the methodological ideas of Aristotle and Galen. This method and goal consistently shapes his research and writing. He understand his work to be "locally" new, in the specifics of his discoveries, but "globally" continuous with the aspirations and methods of Galen and Aristotle (especially as exhibited in Fabricius's work)—and this because, thinks Harvey, these ancients got so much right. As Aubrey reports (Aubrey 1898, 300), Harvey thought one could do no better than to turn to the ancients—"the fountain head"—in comparison to which the "neoteriques" are mere "shitt-breeches."

5.0 DESCARTES'S TELEOMECHANICS IN MEDICAL CONTEXT

In Part I of his *Discourse on Method*, Descartes reflects on his own education, its value and limitations. Here we encounter a thinker with a very different attitude toward the ancients and the traditions rooted in them. In the case of philosophy he can muster only faint, ironical praise: "philosophy gives us the means of speaking plausibly about any subject and of winning the admiration of the less learned." (AT VI 6, CSM I 113) Of medicine, law he says that they "bring honours and riches to those who cultivate them." (AT VI 6, CSM I 113) And although he says reading the ancients is like "having a conversation with the most distinguished men of the past," its value does not outstrip travel.

> It is good to know something of the customs of various peoples, so that we may judge our own more soundly … . But one who spends too much time travelling eventually becomes a stranger in his own country; and one who is too curious about the practices of past ages usually remains quite ignorant about those of the present. (AT VI 6, CSM I 113-114)

And philosophy, although it has been pursued by these most distinguished men for centuries, "yet there is still no point in it which is not disputed and hence doubtful." (AT VI 8, CSM I 115) Medicine is equally suspect, because it and the other sciences "borrow their principles from philosophy." (AT VI 8, CSM I 115) By the end of his schooling, says the Descartes of the *Discourse*, he had abandoned letters to become a man of experience. When aspirations to learning did return, says Descartes, he vowed to reject the opinions formed in his youthful education. “My plan has never gone beyond trying to reform my own thoughts and construct them upon a foundation which is all my own.” (AT VI 15, CSM I 118)

Of course, Descartes calls this intellectual autobiography “a history or, if you prefer, a fable” (AT VI 4, CSM I 112), and of fables and histories, Descartes gives his own warning.

> [F]ables make us imagine many events as possible when they are not. And even the most accurate histories, while not altering or exaggerating the importance of matter to make them worthy to be read, at any rate almost always omit the baser and less notable events; as a result, the other events appear in a false light, and those who regulate their conduct by examples drown from these works are liable to fall into the excesses of the knights-errant in our tales of chivalry, and conceive plans beyond their powers. (AT VI 6-7, CSM I 114)

So, too, with Descartes’s own history or fable. His various claims of attending only to his own observation, experiments, and reasoning notwithstanding, we know Descartes read widely in natural philosophy and medicine. His physiology, in particular, shows much dependence on the views of Galenic medical tradition—so much so that Thomas Steele Hall devotes an section of his introduction to Descartes’s *L’Homme* “Derivative Nature of Descartes’s Physiology” (Descartes 2003, xxxi-xxxiii). In his translation, Hall documents in some detail Descartes’s dependence on Galenic views and the writings of more and less recent medical writers. Descartes’s dependence on these sources is dressed in a rhetoric of independent and self-reliant investigation of physiology.

Of course, Descartes’s dependence on anatomical and other medical writers is not total. It is true that Descartes’s functional anatomy was almost entirely derivative. And unlike Harvey, study Descartes’s physiology has never been prompted by any significant anatomical discoveries. Indeed, Descartes himself lays no claim for the novelty of his functional anatomy—nor does he stress its importance to his project. In *L'Homme*, Descartes says of his "machine[s] made of earth"

> Now I shall not pause to describe the bones, nerves, muscles, veins, arteries, stomach, liver, spleen, heart, brain, or any of the various other parts from which this machine must be composed. For I am supposing that they are entirely like the parts of our own bodies which have the same names, and I assume that if you do not already have sufficient first-hand knowledge of them, you can get a learned anatomist to show them to you—at any rate, those which are large enough to be seen with the naked eye. (AT XI 120-121, CSM I 99).

Similarly, in the much later *Passions of the Soul*, in Article 7, "A brief explication of the parts of the body and some of its functions,"[222] Descartes says, "Everyone knows …. We know too…. Those who have heard anything at all about medicine know in addition…. It is known, moreover… Finally it is known that…" (AT XI 331-332, CSM I 330) Descartes's reform of physiology is not a reform of anatomical knowledge, nor of visible functional anatomy. "But it is not commonly known how these animal spirits and nerves help to produce movements and sensations, or what corporeal principle makes them act." (AT XI 333, CSM I 331) Descartes efforts to transform medicine and place it on firm foundations has rather to do with replacing the accounts of how the visible organic structures can and do actually accomplish what all know that they do. He aims to banish vegetative and animal souls as well as Galeno-Aristotelian matter theory, temperaments, and faculties. These are not the principles of the functioning of the body.

[222] CSM translates this "A brief account of the parts of the body and of some of *their* functions." This is a mistranslation of the French, "Breve explication des parties du corps, & de quelques unes de *ses* functions." (AT XI 331). Descartes is describing functions of the *body* not of its *parts*. Stephen Voss translates it properly (Descartes 1989).

The principle of these functions is the heat in the heart and the mechanisms by which they are executed are sub-visible. As he says *in L'Homme*,

> As for the parts which are too small to be seen, I can inform you about them more easily and clearly by speaking of the movement which depend on them. Thus I need only give an orderly account of these movements in order to tell you which of our functions they represent. (AT XI 121, CSM I 99-100)

One of Descartes's claims to novelty lies here, in his attempt to provide such "micro-mechanical" accounts of the functions of the body in terms of his matter theory and sub-visible structures.

However, as suggested above in Chapter 1, there was another feature of Descartes's physiology that commanded the attention of even those sympathetic to this project: his rejection of teleology. Descartes famously and explicitly rejects appeals to final causes in natural philosophy, suggesting that such appeals depend on knowledge of God's (philosophically) inscrutable ends.

> For since I now know that my own nature is very weak and limited, whereas the nature of God is immense, incomprehensible and infinite, I also know without more ado that he is capable of countless things whose causes are beyond my knowledge. And for this reason alone I consider the whole kind of causes, customarily sought from an end, to be totally useless in physics; there is considerable rashness in thinking myself capable of investigating God's ends.[223] (Meditation IV; AT VII 55, CSM II 39)

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[223] Translation adapted. References are to *Oeuvres de Descartes* (11 vols.), edited by Charles Adam and Paul Tannery (Descartes, Oeuvres de Descartes 1897-1913)—abbreviated "AT." "CSM" refers to *The Philosophical Writings of Descartes* (2 vols.), translated by John Cottingham, Robert Stoothoff, and Dugald Murdoch (Descartes 1985). "CSMK" refers to *The Philosophical Writings of Descartes. Volume III: The Correspondence*, translated by John Cottingham, Robert Stoothoff, Dugald Murdoch, and Anthony Kenny (Descartes 1991). "G" refers Stephen

As mentioned above in Chapter 1, this rejection[224] did not go unnoticed nor without controversy. In the *Fifth Objections*, Pierre Gassendi takes Descartes to task, suggesting that the study of the *usus* (plural: *usus*) of the parts of plants and animals can lead one to knowledge of such ends (AT VII 308, CSM II 215). In his reply Descartes resists Gassendi's line, arguing that one cannot determine God's purposes even for such parts (AT VII 374-5, CSM II 258). Boyle was similarly disturbed by Descartes's rejection of final causes in natural philosophy and in his *Disquisition about Final Causes* argues that they have a legitimate but limited place in a Christian natural philosophy. Boyle went further and insisted that at points Descartes himself appeals to such ends (Boyle 1688).

Recently a number of scholars have reexamined the nature of Descartes's rejection of final causes, and many, with Boyle, suggest that Descartes does indeed employ teleological resources in his natural philosophy, particularly in his physiology.[225] While Descartes avoids the strongest, most explicit teleological language available in the tradition (e.g., *finis*, *cuius gratia, causa finalis*), some understand his reference to function (*functio*/*fonction*) and use (*usus*/*usage*)[226] to be implicitly teleological.[227] In addition, in a number of places Descartes says that this or that part or feature is instituted or given by nature "*ad X*" or "*pour X*." This, too, is sometimes taken to involve implicit appeals to final causes or divine purposes.[228] However, it

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Gaukroger's The World *and other Writings* (Descartes 1998). All English translations are from CSM and CSMK, unless noted.

[224] Descartes articulates this rejection explicitly numerous times. See, e.g., AT VII 374-5 (CSM II 258), AT VIII 15-16 (CSM I 202), AT VIII 80-1 (CSM I 248-9), and AT V 158 (CSMK III 341).

[225] See, e.g., Allison Simmons (2001), Gary Hatfield (2007), and Gideon Manning (2006) and (2012). Peter Machamer, while looking briefly at physiology, gives more attention to other parts of Descartes's work and argues that his philosophy exhibits a deep, systemic need for teleological thinking (Machamer, Causality and Explanation in Descartes' Natural Philosophy 1976).

[226] In this paper, I assume Descartes uses *usage* and *fonction* as French translations of the Latin *usus* and *functio*. Although I will not argue for this here, I think an examination of 17th century translations of Descartes's works from Latin to French and from French to Latin substantiates this assumption.

[227] E.g., Simmons (2001), Manning (2006), Dennis Des Chene (2001), and Hatfield (2008).

[228] E.g., Des Chene (2000), who nicely draws attention to this construction.

can and has been suggested that the use of such language is ambiguous and is perhaps best understood as a kind of metaphor, *façon de parler*, or “stance” taken by the investigator.[229]

In this chapter, I examine this interpretive difficulty, by focusing on the medical context of Descartes’s physiology. I argue (in Section 5.1) that Descartes intends to and primarily does employ the language of *usus* and *functio* in micro-mechanical explanations meant to replace the metaphysically more extravagant but still efficient (not final) causal explanations present in the medical tradition, as exemplified by Book VI of Jean Fernel’s influential medical text *Physiologia*.[230] This explanatory project is helpfully compared to Robert Cummins’s account of functions and function-analytical explanations (Cummins 1975). The explanandum is a given complex behavior of the living thing (a *functio*). The explanans is the spatiotemporally structured exercise of simpler (for Descartes, mechanical) capacities. After clarifying different notions of teleology and mechanism relevant to understanding this point(in Section 5.2), I then argue (in Section 5.3) that Descartes at times does nevertheless employ final causal explanations not unlike those characteristic of the explanatory project (as described in Chapters 3 and 4) of anatomists Hieronymus Fabricius ab Aquapendente and his more famous student, William Harvey. I identify two examples: Descartes’s explanation of the bicuspid character of the heart’s mitral valve and his explanation of the particular correlations that hold between pineal motions and sensations in the mind. In these examples, I show, the explanandum is a component of a system, while the explanans includes the role that component plays in a complex behavior of that system. Such explanations, I suggest, are helpfully compared to Larry Wright’s consequence-etiological account of function (Wright 1976). After examining (in Section 5.4) how Descartes’s

[229] Des Chene (2000) and Peter Machamer and James McGuire (2009) lean in this direction.
[230] For an orientation to Jean Fernel and his *Physiologia*, see John Henry’s and John M. Forrester’s introduction in Forrester’s translation (Fernel 2003).

system will not accommodate traditional strategies for grounding such explanations, I argue (in Section 5.5) that he seeks instead to ground them in knowledge of divine attributes (not purposes). I show that he is hard-pressed, using this strategy, to ground at least some of those explanations while still rejecting both divine purposes and non-mechanical principles in natural philosophy.

5.1 DESCARTES'S TELEOMECHANICAL PHYSIOLOGY?

The material in Part V of the *Discourse on Method* provides a helpful example of Descartes's physiological project. It is one of the few explicitly medical and physiological discussions Descartes published in his lifetime. Furthermore, unlike other such material he published (in Meditation VI, the articles on the senses at the end *Principles* IV, and the early articles of *The Passions of the Soul*), the physiology of *Discourse* V is not subordinated to a further philosophical project. It stands simply as an example of the power of his method and natural philosophy in a medical context.[231] Here we find Descartes identifying the *usage* of respiration.

> Then, too, we know from this that the true use [*usage*] of respiration is to bring enough fresh air into the lungs to cause the blood entering there from the right-hand cavity of the heart, where it has been rarefied and almost changed into vapours, to thicken immediately

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[231] See the preface to the *Discourse* where Descartes characterizes the physiology of Part V as considering medical topics (AT VI 1, CSM I 111).

into blood again before returning to the left-hand cavity. For if this did not happen the blood would not be fit to serve as fuel for the fire in the heart.[232] (AT VI 53, CSM I 138)

This is a prominent example of Descartes's invocation of *usage*, and, it has been suggested, an example of Descartes employing ends or final causes.[233] However, in order to understand the extent to which this is so, we must attend more carefully to (1) the context of this passage in Descartes (particularly to the explanatory structures he employs in *Discourse* Part V) and (2) the meaning of *usus* and the related *functio* in the medical tradition.

As we have seen, *usus* and *functio* are prominent technical terms in the medical tradition. The concept of *functio* derives from Galen's discussion of an ambiguity exhibited by the Greek *ergon* (and its relationship to *energeia*) in *De naturalibus facultatibus*.[234] The term *ergon*, suggests Galen, has a broader and narrower sense. It can refer, in its broader sense, to an activity or a product. In its narrower sense, it refers only to the product. For example, both sanguinification[235] and blood may be called an *ergon* of nature in the broader sense. However, only the product (blood) is called an *ergon* in the narrower sense. *Energeia*, for Galen, refers only to the activity. This distinction was often captured by employing *functio* to denote the activity and *opus* to denote the product. Thus, *functio* was employed especially to stress that activities rather than products were the focus of attention. This notion of *functio* as activity was employed in the medical tradition also to distinguish natural (sometimes called vegetative or nutritive), vital, and animal activities (*functiones*). This distinction, rooted in Galen, characterizes nutrition, growth, and generation as natural *functiones*, respiration and the pulse of the heart and

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[232] Translation adapted. CSM translates "*usage*" as "function." I prefer to keep the distinction between *usage*/*usus* and *fonction*/*functio* clear in translation.
[233] For example, Simmons does (2001).
[234] See my discussion in Chapter 3.
[235] The process of producing blood, ultimately from ingested nutriment.

arteries as vital *functiones,* and sensation, desire, and locomotion as animal *functiones*. The medical tradition employs *functio*, then, to refer to and categorize a long-established, familiar set of characteristic activities of living things. *Usus*, in contrast, refers to the contribution a part or activity makes to the exercise of some *functio*. Both parts and *functiones* have *usus*. The *usus* of a part is the contribution it makes to the exercise of some *functio*, and the *usus* of a *functio*, in turn, is the contribution that *functio* makes to some larger or more fundamental *functio*, terminating ultimately in the list of the main natural, vital, and animal *functiones*.[236]

We have already seen how these conceptual resources play an important role in the Galeno-Aristotelian anatomical projects of Fabricius and Harvey. For them, these Galenic concepts are employed in the articulation of Aristotelian final causal *scientia* of the parts. However, these conceptual resources play important roles in another, distinct *explanatory project* present in the medical tradition. The project is well exemplified by Book VI (*De functionibus et humoribus*) of Jean Fernel's *Physiologia*. Fernel's *Physiologia* is in seven books. The first book provides a sketch of the basic anatomy of the human body. The second through fourth books discuss, roughly, medical matter theory, treating the elements, temperaments, spirits, and innate heat. Book Five (*De animae facultatibus*) turns to the soul:

> Everything that nature has implanted in us that is closely allied to an earthly composite body, everything related that she has bound into one harmony (so to speak), whether visible, or hidden and beyond sensory detection: the above account has set it all out…. But we are contemplating not just the body, but man, who comprises body and mind

[236] These fundamental *functiones* are themselves understood to contribute to one complex activity: the life of the animal. Fabricius nicely articulates this hierarchy of actions or functions, terminating ultimately in the life of the animal in the introduction to his discussion of *actio* and *utilitates* in *De formato foetu* (Fabricius ab Aquapendente, Opera omnia anatomica & physiologica 1687, 79). Adelmann provides a translation of this passage in his edition of Fabricius's embryological treatises (Adelmann 1942, 276).

> [animo]; and so, as the account of the body has now been brought to completion, it seems the right moment to set about considering the mind [animi] and its parts and faculties, if we have any concern to acquire a knowledge of man.[237] (Fernel 2003, 303)

Here he discusses the nature of the soul, the natural, vital, animal, and rational faculties, as well as their interrelations and relation to the body and organs. After this discussion of the soul and its faculties, Fernel turns in Book VI, On the Functions and Humors (*De functionibus et humoribus*) to undertake a new project:

> But having turned away from the faculties as causes, I am striving to expound point by point the guiding principle and sequence in which they make use of their spirits, parts, and temperaments as instruments to discharge all their functions, so that at the same time the advantages and uses of all the parts of the human body come to be in full and clear view. (Fernel 2003, 403)

This project, Fernel undertakes in Book VI. Here, Fernel is setting aside the question of the efficacy and role of the soul and its faculties, focusing instead on providing step by step account of how the various *functiones* are carried out by the parts as instruments. He does this for natural, vital, animal, and rational *functiones.* Fernel is providing a kind of efficient causal explanation of the *functiones*. These are the explananda and the spirits, parts and temperaments, and their interactions, will constitute the explanantia. Notice that the *usus* of the parts of will come to be in full and clear view in the course of this explanatory project. That is, the contributions the parts make to the *functiones* will be mentioned and employed in these explanations. Now, to be sure, much of Fernel's treatment is marked by the Galenic matter theory, occult or hidden powers, etc. for which Descartes will have no patience. As he says about Harvey's account of the motion of

[237] Although Fernel uses *animus* in this introduction to Book V, he uses *anima* in the title of the book, and discusses all the faculties of soul, both those shared with (plants and) animals, and those distinctive to humans.

the heart, such explanations invoke faculties more mysterious than what is being explained.[238] However, what is important is the way that, for Fernel, the discussion of function is basically the provision of an efficient causal explanation of identifiable bodily processes. And the identification of the *usus* of parts or sub-processes is the identification of the way they contribute to the bringing about of the bodily process under consideration.

I suggest that Descartes is primarily concerned with *this* project in his physiology. A careful examination of the context of his identification of the true *usage* of respiration confirms this: by identifying the *usage* of respiration, Descartes is picking out the contribution respiration (a *functio*) makes to some further *functio* of the organism, in order to explain how that *functio* is produced. Descartes's discussion of the "true use of respiration" is embedded in his explanation of the heart and arteries. Descartes there describes the cavities of the heart, the competency of its valves, and the heat in the heart and claims that this heat is "capable of causing a drop of blood to swell and expand as soon as it enters a cavity of the heart…." (AT VI 48-49, CSM I 135) Referencing these features, Descartes then provides his account of the motion of the heart, treating the right and left ventricles in parallel as identical systems. He stresses

> that the movement I have just explained follows from the mere arrangement of the parts of the heart (which can be seen with the naked eye), from the heat in the heart (which can be felt with the fingers), and from the nature of the blood (which can be known through observation). This movement follows just as necessarily as the movement of a clock follows from the force, position, and shape of its counterweights and wheels. (AT VI 50, CSM I 136)

[238] See AT XI 243, CSM I 318.

Here Descartes provides parallel, efficient causal explanations of the movement of the ventricles of the heart in terms of their structure and simpler capacities. The behavior (i.e., the *functio*) of the ventricles of heart is the explanandum; and the explanans, importantly for Descartes, makes no reference to Galeno-Aristotelian souls or faculties. He is providing a *mechanical* explanation in accord with his broader natural philosophy.[239]

Descartes, borrowing explicitly from William Harvey,[240] then argues for the pulmonary and systemic circulation. Once the pulmonary circulation, in particular, is established, the right and left ventricles can no longer be treated as identical, parallel systems. Rather they are parts of one, more complicated, cardiopulmonary system. The blood heated in the right ventricle will arrive in the left. It is at this point that Descartes identifies the "true use of respiration" as cooling the blood heated in the right before it reaches the left. He has identified the contribution the respiration makes to the *functio* of the whole cardiopulmonary system. The *usage* identified here is at the service of the same general project of providing a mechanistic, efficient causal explanation of a *functio*, but now of the cardiopulmonary system as a whole.

The vast majority of Descartes's physiology has this character. His project is to provide his own explanations of animal *functiones* meant to replace competing, problematic (for Descartes) Galeno-Aristotelian accounts. This is the project he undertook in *L'Homme*, as he writes to Marin Mersenne in 1632:

> My discussion of man in *The World* will be a little fuller than I had intended, for I have undertaken *to explain all the main functions in man*. I have already written of those that pertain to life, such as the digestion of food, the heartbeat, the distribution of

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[239] Des Chene has emphasized this aspect of Descartes's project (Des Chene 2001, 2005, and 2007).
[240] Harvey is mentioned by name in the margin notes; in the text he is simply an "English physician" (AT VI 50, CSM I 136).

nourishment, etc., and the five senses. I am now dissecting the heads of various animals, so that I can explain what imagination, memory, etc. consist in.[241] (AT I 263, CSMK 40)

Similarly, in the much later *Passions* Descartes provides a summary of just this project. In Article 7 ("Brief explication of the parts of the body, and some of its functions"[242]) Descartes provides a brief description of human anatomy and identifies the most obvious activities, movements or processes (i.e., *functiones*/*fonctions*) of the living body. In Article 8 ("The principle underlying all these functions"[243]) he flags that most are ignorant of the how the *fonctions* are produced. In the following eight articles (Articles 9-16), Descartes identifies the *principe* of these *fonctions* (the heat in the heart) and provides efficient causal, step by step explanations of them.

In the *Principles*, Descartes articulates a kind of functional analysis that he employs in arriving at such explanations, responding to possible concern regarding how he comes to discover these explanations, particularly as they employ sub-visible parts.

> In this matter [discerning sub-visible parts] I was greatly helped by considering artifacts…Men who are experienced in dealing with machinery can take a particular machine whose function [*usus*] they know and, by looking at some of its parts, easily form a conjecture about the design of the other parts, which they cannot see. In the same way I have attempted to consider the observable effects and parts of natural bodies and

[241] Translation adapted; emphasis added.
[242] Breve explication des parties du corps, & de quelques unes de ses fonctions.
[243] Quel est le principe de toutes ces functions.

track down the imperceptible causes and particles which produce them.[244] (*Principles* IV 203; AT VIIIa 326, CSM I 288-289)

The fit between this passage in the *Principles* and Descartes's physiological project highlights one of its important features. Descartes's physiological project does not differ fundamentally from his general natural philosophical project. This methodological passage from the *Principles* is a reflection on the mechanistic explanations *provided in Book IV*. These are almost entirely of non-living, non-human phenomena, culminating in his detailed treatment of magnetic phenomena.

In his account of the magnet, Descartes first lists the magnetic behavior (perhaps taken in large part from Gilbert) to be explained. He then identifies the sub-visible structures in terms of which he can provide their efficient causal explanation. In the physiological context he takes the standard *functiones* of current medical thought (with the notable exception of his endorsement of Harvey's claims regarding the circulation of the blood) as the phenomena to be explained. He also accepts the broad outlines of the anatomy of current medical thought and its basic correlation of parts and *functiones;* in other words, he accepts, in broad outline, the identifications of the *usus* of visible parts of the medical tradition; or, in other words yet, he accepts the basic functional analysis of current medical thought (again with the notable exception of endorsing Harvey on the circulation). What he does not accept is the details of this Galeno-Aristotelian tradition's efficient causal explanations of those *functiones*. These he replaces with sub-visible structures.[245] In both cases—magnetism and physiology—the goal is an acceptable

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[244] In this regard, two other passages come to mind: Descartes's description in his early writings of his fascination with analyzing ingenious inventions (AT X 214, CSM I 2) and his use of the Tantalus vessel in Rule 13 of the *Regulae* (AT 435-436, CSM I 55).

[245] What Descartes accepts and rejects in the medical tradition is perhaps most explicit in the early *Treatise on Man* and in the physiological articles near the beginning of the *Passions*.

Cartesian explanation of prominent phenomena. His employment of functional analysis is not unique to his physiology. What is unique is the presence in the medical tradition of the language of *functio* and *usus* to pick out explanandum and key constituents of the explanans, respectively.

5.2 TELEOLOGY, MECHANISM, AND EXPLANATION

This project is helpfully compared to Robert Cummins's account of "function" and what he calls "function-analytical explanations." Recall that, for Cummins, to identify the function of a component of some larger system is to identify the exercise of a simpler capacity of that component, which exercise is referenced in a function-analytical explanation of a more complex capacity of the larger system. A function-analytical explanation, in turn, is one that explains such a complex capacity by showing how the spatiotemporally structured exercise of simpler capacities of components of that system bring about or constitute the exercise of the complex capacity. The "function" of a component is the contribution it makes in that explanation. In Descartes's and Fernel's projects a *functio* (i.e., a complex *activity* rather than a complex *capacity*) is explained by providing a spatiotemporally structured exercise of simpler capacities resulting in or constituting that *functio*. The *usus* of the component parts and processes are, like Cummins-functions, the contribution those components make in these explanations.

Cummins-style function-analytical explanations can be thought of a species of Machamer-Darden-Craver mechanistic explanations (Machamer, Darden and Craver 2000), as described above in Chapter 4. In a function analytical explanation the explanans involves the identification of a spatiotemporally structured exercise (activities) of the capacities system components (entities), which constitute a behavior of the larger system. This behavior is, in turn, the explanans.[246] The function-analytical explanation, is in effect, the description of the mechanism for the behavior being explained. In this sense, both Descartes and Fernel provide mechanistic explanations of *functiones*. The key difference, for Descartes, is that the mechanisms *he* identifies are mechanical in a further sense. They involve only shape, size, motion, and the transfer of motion by collision—i.e., the involve only *res extensa* and its modes. Descartes's mechanisms are the mechanisms of a mechanical philosopher. Fernel, in contrast, describes mechanisms involving the non-mechanistic (in this sense) entities and activities characteristic of his Galeno-Aristotelian natural philosophy.

In contrast, as we saw in the previous two chapters, Fabricius and Harvey employ the concepts of *usus* and *actio* (in the *functio* sense) in final causal explanations, in which *usus* are like Wright-functions. Recall that, for Wright a part's function is an effect or consequence of that part that appears in the explanation (etiology) of that part's presence. The part is there *because* it performs its function. In the language of *usus* and *functio* this becomes: the *usus* of a component is the effect or consequence of the component that appears in the explanation (etiology) of the presence of that component. In Fabricius's and Harvey's anatomical projects, the explananda are the parts of animals and their features; the explanantia consist of the *usus* (as final cause) of these parts and features.[247]

Such explanations do not provide an explanation of some behavior or process by describing a mechanism, and so are not "mechanistic" in that sense. Furthermore, as final causal explanations invoking Galeno-Aristotelian souls and faculties, neither are they mechanistic in the sense of the "mechanical philosophy." However, it is not necessary that all consequence-

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[246] For Cummins, strictly speaking, it is the complex *capacity* for this behavior that is the explanandum.

[247] As anatomists, their primary concern is the parts; of course, in their system, *functiones* will also be provided final causal explanations in terms of more fundamental ones, and ultimately in terms of the characteristic life of the animals (the one comprehensive action of *Parts of Animals* I.5.

etiological explanations be non-mechanistic in this second sense. Many mechanical philosophers, including, for example, Robert Boyle (Boyle 1688), seek to provide consequence-etiological explanations grounded in divine design.[248] I return to this point below; here the point is meant only to help make clear the difference between two ways of being a mechanistic thinker: embracing a natural philosophy in which bodies are constituted of *res extensa* and its modes (i.e., being a mechanical philosopher); and explaining natural phenomena by the description of mechanisms (in particular, providing function-analytical explanations).

It is helpful, then, in understanding *functio* and *usus* in early modern medicine to distinguish between being a mechanical philosopher (embracing a certain kind of ontology of natural bodies and phenomena), on the one hand, and the precise explanatory projects undertaken, on the other. And among explanatory projects, it is helpful to identify and distinguish two such projects: efficient causal (function-analytical) explanations of a *functio* in terms of the contributions components make (*usus*) to its performance, on the one hand, and final causal explanations of components in terms of their contribution (*usus*) to the performance of a *functio,* on the other. In the former project *usus* are referenced in efficient causal explanations of *functiones*, while in the latter *usus* are referenced in final causal explanations of parts (Table 1).

A further distinction can be made between functional analysis and function-analytical explanations. By functional analysis I mean the identification of *usus* of parts (and sub-processes), i.e., the identification of the contribution the parts (and sub-processes) makes to the exercise of a given *functio*. This functional analysis terminates in the identification of these *usus*. This project is not, in itself, explanatory in character, but can be a preliminary in either of the

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[248] See also, Gassendi's discussion (mentioned above) in his *Objections* (AT VII 308, CSM II 215). I refer the reader, again, to Bertoloni Meli's observation that, as such, iatromechanism was not primarily contrasted with teleology, but with appeals to soul and to Galenic faculties (Bertoloni Meli 2011, 12-16).

projects in Table 1. The identified *usus* can be referenced in function-analytical explanations of the *functiones* (as Fernel does in Book VI of the *Physiologia*). On the other hand, the *usus* can be referenced in final causal, consequence-etiological explanations of the parts or sub-processes (the characteristic project of Harvey and Fabricius).

Table 1. *Usus*, *Functio*, and Explanation

Function-analytical Explanations of *Functiones*	**Final Causal Explanations of Parts**
Efficient causal explanation of the exercise of a *functio* (in terms of parts and their interactions)	Final causal explanation of the varying parts and their features
Usus explain *functiones*	*Usus* explain parts
Project of Book IV of Fernel's *Physiologia*	Project of Anatomy for Fabricius and Harvey

5.3 CONSEQUENCE-ETIOLOGICAL EXPLANATIONS IN DESCARTES'S PHYSIOLOGY

Descartes's physiological project is focused on providing replacement, mechanical (in the "restricted ontology of body" sense) function-analytical explanations of *functiones*. However, there are a number of places where he employs the second explanatory structure. Such explanations appear in his discussions of bodily *functiones* and of *functiones* involving the mind. A helpful example of the first is his explanation of the mitral valve of the heart; an example of the second is found in his famous discussion of the senses in Meditation VI. I will examine each in turn.

The mitral valve of the heart is found at the entrance to the left ventricle from the left auricle and the pulmonary vein (what anatomists then called the venous artery). It is unique among the valves of the human heart in consisting of two rather than three membranes (see Figure 34 and Figure 35). In *Discourse* V, Descartes describes the eleven membranes that stand at the entrances to the ventricles, including those of the mitral valve.

> Likewise two others at the entrance to the venous artery allow the blood in the lungs to flow into the left-hand cavity of the heart, but block its return…. *There is no need to seek any reason for the number of these membranes beyond the fact that the opening to the venous artery, being oval because of its location, can easily be closed with two of them, whereas the other openings, being round, can be closed more effectively by three*.[249] (AT VI 48, CSM I 135)

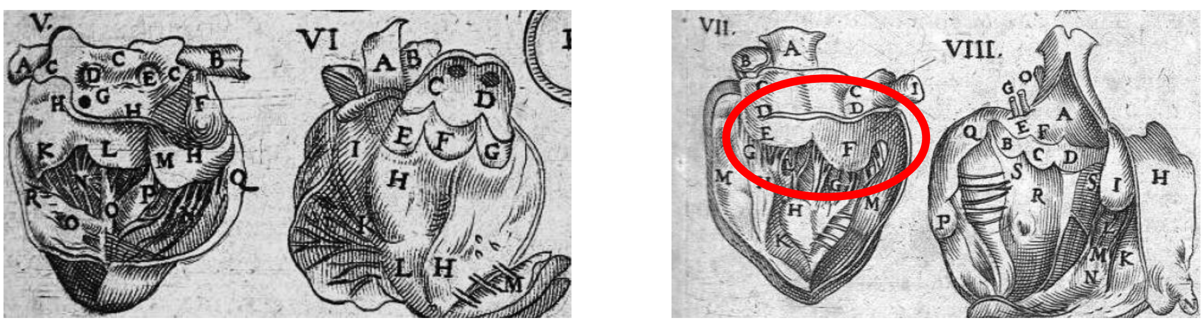

Figure 34. The valves in the heart, Bauhin, *Theatrum Anatomicum* (Bauhin 1605, 417).
Illustrations V, VI, VII, and VIII show each of the four valves in turn. Illustration VII shows the mitral valve. E and F label the two membranes. These can be contrasted with K, L, and M in Illustration V; E, F, and G in VI; and B, C and D in VIII.

The italicized sentence identifies the reason for the presence of the bicuspid valve. This explanation of its presence is an example of an explanation in which the *usus* of a part is given as a reason why the part is present.[250] The explanandum is not the resulting motions or processes, but rather a part. The explanans is variation in the situation of the valves *and* their role: allowing

[249] Translation adapted; emphasis added.
[250] It is worth noting that this same explanation is given in the much later *Description of the Human Body* (AT XI 229-30, G 173).

only one way movement of the blood. That is, his account takes these two—which include the *usus* of the valves—as providing the reason the valves and their differing features are present.[251]

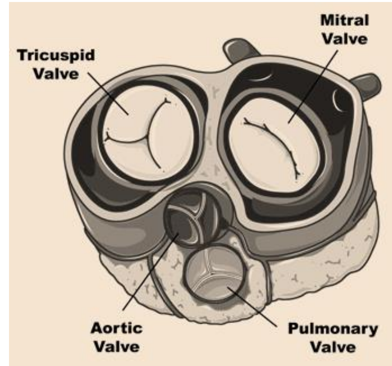

Figure 35. A simplified illustration of the valves of the heart.

In order to bring this explanatory structure into higher relief, it is useful to compare it to another instance where Descartes notes a correlation between *usus* and structure, but for which he does not provide such a consequence-etiological explanation: the differential thickness of the walls of the veins and arteries (AT VI 52, CSM I 137). There Descartes provides a non-teleological, genetic account. The thickness of the arterial walls is due to the more forceful impulse of the blood as it enters these vessels from the ventricles of the heart. In the *Description of the Human* he repeats this explanation in more detail. He notes that the vessel connecting the right ventricle and the lungs (the "arterial vein") has, like the aorta, much thicker walls then those of the vena cava and the vessel connecting the lungs and the left ventricle (the "venous artery"). He correlates this difference with a difference in use and, following Harvey, suggests the venous artery is actually a vein and the arterial vein an artery.

> And it will be noted that these two vessels, namely the arterial vein and the aorta, are composed of skin that is much stronger and thicker than the vena cava and the venous artery. This shows that the latter have a completely different use (*usage*) from the former, and that what is called the "venous artery" is really a vein, just as what is called the "arterial vein" is really an artery. (AT 230, G 174)

[251] It also implicitly invokes an "optimality" principle not unlike the Aristotelian "nature does nothing in vain."

However, having noted this use-structure correlation, Descartes does not provide a consequence-etiological explanation of this difference, as he did for the mitral valve. He *does* provide an explanation of the difference in structure (including also the thick-walled windpipe), but it is genetic in character. In it he compares the way this differential thickness is generated to the way manual laborers develop callouses on their hands.

> For, *just as one sees that the hands of artisans become hard due to the manner of their use* (*outils*), so the cause of the hardness of the membranes and cartilage of which the windpipe is comprised is the force and agitation of the air that passes through it when one breathes. *And if the blood were not more agitated when it enters the arterial vein than when it enters the venous artery, the membranes of the former would be no thicker and harder than those of the latter*.[252] (AT XI 236, G 177)

Here it is not the *contribution* made to the circulation (protecting the arteries from bursting) that explains the presence of the wall-thickness, but rather it is *exposure* to that circulation.[253]

A more prominent example of a consequence-etiological explanation appears in Descartes's discussion of the senses in Meditation VI. There Descartes discusses what is and is not, properly speaking, taught us "by nature" (i.e., by our nature as a mind-body composite), and so what is and is not rendered trustworthy by God as a non-deceiver. Descartes says that his nature as mind-body composite "does indeed teach [him] to avoid what induces a feeling of pain and to seek out what induces feelings of pleasure, and so on." (AT VII 82, CSM II 82)

[252] Emphasis added.

[253] It should be noted that such a genetic explanation is distinct also from a function-analytical one. It can also be noted that although Descartes provides a genetic account of the membranes of the valves later in *Description* (AT XI 278-279, G 201-202), he does not provide such a genetic account of the variation in the number of membranes. In *Description* his only explanation remains the consequence-etiological one provided in *Discourse* V.

Suggesting that determining truths beyond such practical ones "belong to the mind alone," Descartes goes on to claim that,

> …without a doubt sensations are, properly, given to me by Nature to signify to the mind [*ad menti significandum*] what things would be beneficial or harmful to the composite of which it is a part… .[254] (AT VII 83, CSM II 57)

This apparent identification of the purpose of the senses (they are given to us by nature "*ad menti significandum*…") is a paradigmatic example of apparently teleological language, the status of which is unclear. Is it at service of function-analytical explanations of some complex capacity of the mind-body composite (e.g., the capacity for self-preservation), or does it serve rather to ground consequence-etiological explanations of the component parts and processes in terms of their contribution to the complex capacity?

A careful examination of Meditation VI reveals that it is at service of the latter.[255] In his discussion of the problem of erroneous desires in a dropsy patient, Descartes explains a component of the system, the correlation of specific motions in the brain and specific sensations in the mind: "This motion produces in the mind a sensation of thirst, *because* the most useful thing for us to know about the whole business is that we need drink in order to stay healthy."[256] (AT VII 88, CSM II 61) The explanandum in this case is the correlation of the sensation of thirst in the mind and a specific motion of the pineal gland. The explanans includes the identified *usus* of the sensations (signifying to the mind what is beneficial or harmful to the composite). As in

[254] Translation adapted.

[255] Of course, it can also contribute to the former project. Mind-body composites exhibit a markedly complex capacity for self-preserving behavior. By identifying the way sensation contributes to this complex capacity (signifying to the mind what would be beneficial or harmful), Descartes has identified an important component in a function-analytical explanation of that complex capacity. In fact, in the *Discourse* he suggests that an appreciation of the (near universal) breadth of our ability to interact with our environment to solve problems reveals that a function-analytical explanation of this complex capacity will involve a non-corporeal, reasoning component. He thinks the same is true of our use of language (AT VI 56-59, CSM I 139-141).

[256] Emphasis added.

the case of the mitral valve, here Descartes has identified a component's contribution to the exercise of a complex capacity as a reason for the presence of that component. In both of these cases Descartes veers from his function-analytical project to a consequence-etiological one. This raises the question: In what can Descartes ground such explanations?

5.4 GROUNDING CONSEQUENCE-ETIOLOGICAL EXPLANATIONS

It will be helpful to clarify this question by first considering, in broad outline, how such explanations are grounded in the tradition in which Descartes is working.[257] In the physiological context, such explanations were grounded in two (often combined) ways. In the first, the animal as a whole is understood to have *ontological* priority over its parts. In a Galeno-Aristotelian framework the animal (or perhaps its soul) is what fundamentally exists. This is a proper entity and unity. Relatedly, what comes to be in the process of generation is, fundamentally, the animal. The parts of the animal and the processes involved in its generation can thus be explained with reference to the animal as a whole: the primary *functiones* of the animal are constitutive parts of the essence of the animal;[258] in turn, the existence of these essential *functiones* renders necessary the existence of additional "sub-*functiones,*" as well as certain parts that make necessary

[257] I am interested here in the approaches dominant in the medical tradition. Hatfield (2008) argues that a quasi-evolutionary, selected-effects account, not unlike those advocated by (e.g.) Ruth Millikan (1993)and Karen Neander (1991), would be available to Descartes. Hatfield points out that Descartes seems to have hoped eventually to provide a genetic, mechanical account of the appearance of plants and animals in his cosmogony and that Democritean hints of a selected-effects account are present in Lucretius" well-known poem *De rerum natura*. Nonetheless, these Democritean hints do not seem to have been developed in any significant way in the medical tradition. Nor do I think Descartes had nascent or inchoate visions for grounding consequence-etiological explanations in this way. His was another strategy.
[258] Technically, it is the faculties (the exercise of which is the *functiones*) that are essential. But the faculties are understood to be for the sake of these *functiones*, and so we can suppress them for simplicity's sake.

contributions to the exercise of those *functiones* and sub-*functiones*.[259] For this reason the *usus* (i.e., precisely those necessary contributions the parts make to the *functiones*) are explanatorily prior to the parts, which parts come to be as a consequence of the animal coming to be.[260] In the second approach, these explanations are grounded in the intentions of the divine creator. If the whole is what is intended by God, then it can have explanatory priority over its parts. The identification of the *usus* of the parts is explanatory of those parts, in this approach, because God intended or aimed at the whole animal, with its capacities, and the parts are means to that end.[261] The identification of the *usus* of the parts serves to identify why the parts were chosen as means.

Descartes has, of course, firmly rejected this second strategy. In virtually every text in which he rejects appeals to final causes in natural philosophy, Descartes glosses this rejection in terms of the inaccessibility of God's purposes. The first approach would also seem unavailable to Descartes. One would be hard pressed, for example, to interpret Descartes's account of the development of the fetus in *Description of the Human Body* as a process in which the fully formed fetus is ontologically prior to the corpuscles out of which it is constituted, nor plausibly as one in which the coming to be of the fetus is ontologically prior to the various vortices and

[259] The nature of this consequence relation is perhaps problematic. In particular, depending on how the animal's soul or nature is understood, many different means could accomplish a given *functio*. For Aristotle the number of the features of parts being rendered necessary is increased by the restriction of possible means due to the nature of the matter available (Cooper 1987). In addition, the greater the detail encoded (so to speak) in the form or nature of the animal, the larger the number of necessary parts. The complication raised by multiple possible means to accomplish any given end is raised by Carl Hempel (1965).

[260] Wright explicitly articulates his consequence-etiological account of function to make room for a range of ways the function could be the reason the part is present. The "because" in the criterion "the part is there *because* of its function" is meant to be broad enough to include both selected-effect accounts and design accounts. The Aristotelian account, though not considered by Wright, can also be subsumed under Wright's analysis.

[261] This "design" approach is also plagued by the problem of multiple possible means for a given end. The problem is softened if we deny the assumption (embraced by both Aristotle and Hempel) that the explanans must (at least) logically imply the explanandum. If we reject this requirement and note that explaining something is not to be confused with grasping that the feature exists, then it need not be a problem that there are multiple possible means to any given end. We know the end (assuming that we can somehow discern the agent's purposes) and we know the chosen means (by observation, say); we explain the means by pointing out that it is means to the chosen end: even if I could have traveled there by bus, referencing my intention to go to the market is still explanatory of me riding my bike in that direction.

eddies of matter involved in that process. Furthermore, much of Descartes's physiological project is designed precisely to sever the connection between the *functiones* of living things and the soul. Far from being ontologically prior for Descartes, the (nutritive and animal) soul is a fiction. In what then does Descartes ground his teleological explanations? Or are these teleological explanations illicit?

In a recent article on teleology in Descartes's treatment of the senses, Allison Simmons argues that

> Descartes's assault on teleological explanation is not a sweeping assault on finality, but a more directed attack on particular uses of ends in natural philosophy. Descartes's assault leaves standing a form of teleological explanation that proves crucial to his own treatment of sensation. (Simmons 2001, 49-50)

Simmons argues that Descartes's treatment of sensation in Meditation VI invokes neither "directed powers" (by which she means ontologically simple, active powers essentially oriented towards the actualization of a final, rest state) nor divine intentions, but appeals only to natural "ends with which" things are created by God. Such natural ends, says Simmons, are recognized by Descartes only in the case of the mind-body composite. All other things in nature, including the body considered by itself, are simply mechanistic systems without purpose.

> Considered by itself, the body may be just a blind machine. Once it is united with a mind, it becomes for Descartes a machine with a purpose: to provide a home for the mind. At the same time, the bodily organs and the modes of mind that arise from this union are means for maintaining whatever is bodily required for the continued presence of the soul. (Simmons 2001, 63)

For Simmons, the body united to the soul has the natural created end of providing a suitable home for the soul.

Simmons argues that Descartes's rejection of divine teleology need not rule out such natural teleology—even in conjunction with the view that all natural things are created by God. For, she says, we may distinguish between ends "for which" God creates something and ends "with which" he creates it.

> To be sure, it is God who decides that this sort of creature have the means-and-ends structure it does. God is thus the *source* of creaturely means and ends. But the creature's ends are not God's ends (except in the limited sense that he decides to create them); they are ends *with* which (not *for* which) God creates things. (Simmons 2001, 66-67)

Figure 36. A spite house (**http://en.wikipedia.org/wiki/File:AlamedaSpiteHouse.jpg**)

Simmons does not suggest that this distinction is articulated by Descartes—only that it can aid our understanding of him. Although she does not provide such an example, the distinction can be helpfully illustrated in the artifactual realm with reference to "spite houses" (see Figure 36). A spite house is a house constructed or modified with the intention to irritate or inconvenience a neighbor. In this context, Simmons's suggestion amounts to the claim that we can have knowledge of the end with which the structure was built (to provide shelter) without having knowledge of the end for which it was built (to irritate a neighbor). Similarly, in the physiological context we can have knowledge of the end with which the mind-body composite was created (self-preservation) without knowing the end for which it was created. Although there is much that is insightful in Simmons's approach, I believe her interpretation is not without problems. She does not provide an account of "ends with which," such that (1) these ends can ground consequence-etiological explanations and (2) Descartes would allow that the philosopher can have knowledge of them. Relatedly, she does not adequately distinguish between consequence-etiological explanations and function-analytical ones.[262] However, as I suggested in the previous sections, these are distinct explanatory projects in the medical tradition. With this distinction in place, we can recognize and isolate more problematic consequence-etiological explanations in Descartes's physiology.

The less problematic function-analytical use of *usus* and *functio* in physiology does not involve the identification of "natural ends" of a kind unique to the mind-body context. As I suggested above, here Descartes undertakes the same explanatory project he does in other natural philosophical contexts—like his treatment of the lodestone. There Descartes seeks to explain a cluster of attractive and repulsive behavior exhibited by certain bodies. In the physiological contexts his focus is on a complex of self-preserving behavior exhibited by other bodies. In both cases, Descartes is providing function-analytical explanations of a behavior of interest. In the physiological context, Descartes can employ the language of "*usus*" in his articulation of these explanations precisely because "*usus*," in its medical context, picks out the contribution a part or process makes to the complex of behaviors that he is explaining. This project does not require appeals to natural ends unique to the mind-body composite.[263]

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[262] She essentially equates teleological explanation and function-analytical explanation (Simmons 2001, 77), and so seems not fully to appreciate the significance of the presence of consequence-etiological explanations in Descartes's physiology.

[263] There is a tension in Simmons's paper related to this point. On her interpretation, Descartes's teleological project appeals to natural ends unique to the mind-body composite. At the same time, many of the texts she draws on to articulate this project have a broader scope. For example, she treats Descartes's methodological discussion in *Principles* IV 203 as an articulation of this project (73). But Descartes there is not speaking of anything special to the physiological context. Arguably, he has his treatment of the magnet particularly in mind. Similarly, Simmons stresses that in his reply to Gassendi (AT VII 374-5, CSM II 258) Descartes does not object to the language of *usus*

More importantly, Simmons's natural ends "with which" are not sufficient to ground Descartes's more problematic consequence-etiological explanations without collapsing into divine teleology. Simmons argues that Descartes can invoke these natural ends because this involves only means-ends relationships "hardwired" (68) into the nature of the creature. However, given Descartes's ontology, it is not clear how such hardwired means-and-ends relations could result in their ends featuring in the etiology of the means. If by means-and-ends structure, we mean only the relationship between the explanans and explanandum in a function-analytical explanation, then the Cartesian physicist could discover it, but such structure would not support consequence etiologies. If a far-future Cartesian physicist encounters what we know to be a spite house from the mid-20th century, he may recognize that the structure can serve as shelter, and carefully study how its components work together to accomplish this. He may notice, for example, that the ground-level rectangular hole covered by a hinged board allows easy entrance and egress while providing shelter from the elements; and the physicist may do so without any access to the intentions of the builder—or even to whether there was one. In addition, the Cartesian physicist may develop function-analytical explanations of the shelter-providing capacity of the house that invoke the way in which this hinged structure contributes to the whole's capacity to serve as a shelter. But he will not be able to reference ease of entrance and egress as a *reason* why the hinged structure is present.

Another way to highlight this problem is to scrutinize the significance of calling the relationship between the parts and the (behavior of the) whole a *means-and-ends structure* in the first place. To say that the parts are means to the end, and not simply the mechanism responsible for an effect of interest is to imply access to at least some intentions of the maker of the whole.

(72). But here, too, Descartes's concern is not exclusively with the mind-body composite, but with the *usus* of the part of *animals and plants*.

Regardless of whether we know that the maker of the structure built it with the further intention of irritating a neighbor (the end for which), if we know it is a was built with the end of providing shelter (i.e., know that it is actually a *house*), then we know that the home builder constructed the door for the sake, at least, of constructing a house; that is, we know the end *for which* the door was made. In the case of created natural teleology, similarly, knowledge of ends *with which* a whole is created implies knowledge of ends *for which* some of its parts are created. We know not only the end *with which* the sensory system was created (signifying to the mind what is beneficial and harmful to the composite), but also the end *for which* the system was created (survival of the human being). In his reply to Gassendi, Descartes denies that we have access to God's purposes for such parts.

It is worth emphasizing that pointing out that humans have survival as *their* rational end—as something *they* cognize and pursue, choosing means to that end, is not enough to ground such consequence-etiological explanations, either. When Simmons says that ends "with which" are the "creature's ends" and not "God's ends" (67), she does not mean to suggest that these ends with which are the creature's *rational* (i.e., cognized and intended) end.[264] Of course, Descartes recognizes that *we* have an interest in our own survival, and that the body and its union with the mind do, in fact, contribute much to our survival.[265] Furthermore, Descartes believes that a true knowledge of the psycho-corporeal mechanisms underlying the mind-body's self-preserving tendencies (one that understands what is due to the soul and what to the body) will aid humans greatly in pursuing self-preservation.[266] However, none of this implies that human self-

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[264] Simmons rightly rejects this approach.
[265] Des Chene suggests Descartes came to a greater appreciation of this fact later in life in a way that is reflected in his emphasis on the self-correcting tendencies of the mind-body union in the *Passions* and motivating a certain kind of minimalism in medical intervention (Des Chene 2000)
[266] See Descartes's reflection at the beginning of *Description* (AT XI 223-224, CSM I 314).

preservation, human benefit, can be referenced as a *reason why* any of this psycho-corporeal mechanism was created. Descartes is explicit in his rejection of explaining things in the natural world in terms of their benefit to us.

> And it would be the height of presumption if we were to imagine that all things were created by God for our benefit alone, or even to suppose that the power of our minds can grasp the ends which he set before himself in creating the universe. (*Principles* III 2; AT VIII 80-81, CSM I 248)

The relationship between the psycho-corporeal mechanisms and our self-preserving behavior is to the Cartesian physicist one only of cause to effect. It is, of course, a cause-effect relation, the knowledge of which will be of great service to him in choosing means to *his own rational end* of self-preservation. All the same it is not a relation that renders a part's contribution to self-preservation a reason why the part is there.

Simmons does consider a view that understands the relationship between the *functiones* and their physiological base as merely one of (reliable) cause and effect.

> Perhaps Descartes is simply observing the causal mechanisms by which the senses operate and calling attention to the fact that their regular effects in the mind are behaviorally advantageous to human beings. This fact does not entitle us to postulate ends governing the senses. (Simmons 2001, 57)

However, she rejects it, arguing that this cannot be Descartes's understanding because, for him, these physiological systems can *malfunction*, producing a "true error of nature."[267] It is true that Descartes identifies ways in which the psycho-corporeal sensory mechanism produces results detrimental to the human being. However, a careful examination of the crucial dropsy passage

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[267] Simmons 2001, 57

reveals that Descartes does not say that this is a case of the sensory system *malfunctioning*, nor that the dropsy patient has a *corrupted nature*, a nature doing something it is not supposed to do. Rather, he says only that such a case involves a true *error of nature* (*error naturae*). Descartes's point is that the sick human being is taught something false by nature, namely, that drink is to be pursued (or is beneficial). Indeed, in framing the problem, Descartes argues that saying such a nature is corrupt (i.e., malfunctioning)—even in the case of the dropsied mind-body composite—does not resolve the problem. Both the healthy and sick human being are acting according to their God given natures. For Descartes, the problem is that both the healthy *and* sick human beings have their natures from God, and the dropsy patient's God-given nature teaches him something false. Descartes is concerned not with whether a system is corrupted or malfunctioning, but with whether it is deceptive.[268] This suggests that inasmuch as the mind-body union involves additional resources in which to ground consequence-etiological explanations, they will be derived from the fact that the mind-body union makes judgments that can be true or false and divine non-deceptiveness.

5.5 DESCARTES'S STRATEGY AND ITS LIMITS

In the *Principles*, Descartes explicitly states that our knowledge of divine attributes should play a foundational explanatory role in our natural philosophy.

[268] Such deception is only problematic in light of God being a non-deceiver if the deception does not involve us "subverting [*pervertere*] the order of nature' (AT VII 83). However, the order of nature that could be so subverted is not that of the psycho-corporeal sensory mechanism, but the epistemological order according to which we are to make judgments only on the basis of clear and distinct perceptions. Thus, if there is the possibility of subverting any order of nature in Descartes's system, it lies in the will alone, which can make rash judgments. In such a case it is not the sensory system that is malfunctioning, but the will.

> When dealing with natural things we will, then, never derive any explanations from the purposes which God or nature may have had in view when creating them <and we shall entirely banish from our philosophy the search for final causes>. For we should not be so arrogant as to suppose that we can share in God's plans. *We should, instead, consider him as the efficient cause of all things; and starting from the divine attributes which by God's will we have some knowledge of, we shall see, with the aid of our God-given natural light, what conclusions should be drawn concerning those effects which are apparent to our senses*.[269] (AT VIII 15-16, CSM I 202)

Just as Descartes attempts to derive the laws of motion from God as an *immutable* efficient cause, so he tries to derive the pineal motion-sensation correlation from God as a *non-deceiving* efficient cause. This can be seen by embedding our passage in the broader context of Meditation VI. There Descartes is determining the extent to which our knowledge of material things extends beyond knowledge of their mere existence and general exemplification of the properties that "are comprised within the subject-matter of pure mathematics." (AT VII 80, CSM II 55) His starting point is that "everything … taught by nature contains some truth," because

> if nature is considered in its general aspect, then I understand by the term nothing other than God himself, or the ordered system of created things established by God. And by my own nature in particular I understand nothing other than the totality of things bestowed on me by God. (AT VII 80, CSM II 56)

Thus, since the author of our nature is a non-deceiver, anything we are truly taught by that nature must have some truth in it.

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[269] Emphasis added.

As pointed out earlier, Descartes says that his nature as mind-body composite “does indeed teach [him] to avoid what induces a feeling of pain and to seek out what induces feelings of pleasure, and so on.” (AT VII 82, CSM II 57) Descartes says that with respect to their practical import our sensations “are sufficiently clear and distinct.” (AT VII 83, CSM II 57-8) Since God is a non-deceiver, inasmuch as they are clear and distinct, they are true. This argument does not require us to have access to God’s intentions for the senses. It is grounded instead in restrictions placed on creation by divine non-deceptiveness. We know that, whatever his intentions for the senses, since they give clear and distinct (enough) perceptions concerning practical considerations, and since God is a non-deceiver, the correlations he establishes between such sensations and pineal motions must render those sensations veridical—or at least as much as possible.

Descartes’s account is complicated by considerations of the limitations intrinsic to the nature of the mind-body union. These limitations give rise to unavoidable “true error[s] of nature.” Descartes’s famous example of such an error is a human being (as mind-body composite) with dropsy who is “thirsty at a time when drink is going to cause it harm.” (AT VII 85, CSM II 59) He suggests that this kind of error is not fully accounted for by his Meditation IV account of “how, notwithstanding the goodness of God, it may happen that my judgments are false.” This is because in this case (as Descartes has just said) the sensation of thirst is clear and distinct enough with respect to its practical content. Thus, the will is not being rash in making the judgment to pursue drink.[270] (AT VII 83, CSM II 58)

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[270] Thus, that Descartes understands the senses” practical import to be clear and distinct enough to fall under divine guarantee is clear from his statement that “to this extent they are sufficiently clear and distinct” (AT VII 83, CSM II 57-58) *and* also from the fact that he says here that his analysis of the sources of error in Meditation IV is not sufficient to cover “true error[s] of nature” like the one in the dropsy case. It is worth noting that when he first begins exploring the extent of our ability to gain knowledge of the specific features of external bodies, Descartes

Descartes's resolution of this difficulty depends on identifying certain features of the mind-body union that place limitations on the reliability of the senses. These include that the mind is "only [immediately affected] by the brain, or perhaps just one small part of the brain"; that the motion of this small part is not uniquely determined by the state of the rest of the body, but a number of different body states can lead to it exhibiting the same motion; and that there must be a one-to-one (type-type) correlation between these pineal motions and sensations.[271] With these as given, it will not be possible for the sensations to infallibly signify what is beneficial or harmful. Ultimately, for Descartes the pineal motion-sensation correlation is explained by pointing out that, given our nature, these correlations are most frequently non-deceptive in a healthy human being.

However, this raises a further issue. It is not clear what "healthy" can mean for Descartes. Lisa Shapiro has recently attempted to articulate a Cartesian notion of the health of the body in terms of "intrinsic stable structure." (Shapiro 2003) I would suggest that this is nearly correct. Descartes's notion of health involves the notion of intrinsic *self-stabilizing* behavior.[272] Furthermore, I suspect Descartes thinks this self-stabilizing behavior has been effectively identified and analyzed into the main nutritive, vital, and animal *functiones* by the medical tradition through empirical investigation. For Descartes, the healthy human is the one whose psycho-corporeal physiology exhibits these *functiones* in an effectively self-stabilizing way.

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suggests that God's non-deceptive nature requires that for any falsity in my opinions there be some God-given faculty that can correct it (AT VII 80, CSM II 55-56). Machamer and McGuire (2009) draw attention to this passage and argue that, for Descartes, God's non-deceptive nature requires that we be able to correct misjudgments like that involved in the dropsy case by doing science. I see no reason why the accounts should not be combined: Descartes thinks that both our ability to discover the physiological sources of "true error[s] of nature" *and* the general reliability of the practical deliverances of the senses are guaranteed by God's non-deceptive nature.

[271] He sets these out at AT VII 85-88, CSM II 59-61.

[272] This understanding of Descartes's notion of health is related to late scholastic understandings of vital activity as self-perfecting. Des Chene provides a nice discussion of this scholastic notion of vital activity in *Life's Form* (Des Chene 2000, Ch. 3).

However, regardless of how he identifies healthy physiology, in his final explanation of the (qualified) practical veracity of sensation, Descartes has rendered prominent aspects of that physiology *explanatorily prior* to the pineal motion-sensation correlation. For he has invoked a range of more and less general features of the healthy human being in the explanans. These features include general characteristics like the distinction between the mind and the body and the localization of the mind-body interaction, as well as more specific features of our physiology, such as the distribution and structure of the nerves.

But these features are an epistemologically heterogeneous bunch. The difference between the mind and the body seems to follow simply from consideration of our primary notions of mind and body, while most of the other important facts concerning the mind-body union are derived from experience. Of the localization of the mind-body interaction in the brain, Descartes says, "[t]his is established by countless observations, which there is no need to review here." (AT VII 86, CSM II 60) Of the structure of the nervous system, Descartes simply says "physiology [*physica*] tells me… ." (AT VII 87, CSM II 60) So this too is determined by observation.[273] (Descartes gives no indication of how he arrives at his knowledge of the crucial one-to-one correspondence between pineal motions and sensations in the mind.) Importantly, the explanandum is also known by observation. Descartes says, "[a]nd experience shows that the sensations which nature has given us are all of this kind [i.e., most especially and most frequently conducive to the preservation of the healthy man]." (AT VII 87, CSM II 60) For Descartes, God being a non-deceiver is *explanatory* of the self-preservative correlations, but

[273] At least at this point. In the *Discourse* Descartes says that he could not (yet) treat animals in the way he did the system of the world, proceeding from cause to effect (AT VI 45-46, CSM I 134). Rather, he can only accept the zoological and physiological facts as he finds them and attempt to explain how they work. This is the epistemological and methodological import of the *deus ex machina* he employs at the outset of his treatment of animals: "So I contented myself with supposing that God formed the body of a man exactly like our own both in the outward shape of its limbs and in the internal arrangement of its organs, using for its composition nothing but the matter that I had described." (AT VI 45-46, CSM I 134)

knowledge of that divine non-deceptiveness is not needed for *establishing* the fact of this correlation. The *explanatory* structure is, as a result, different from the *justificatory* structure. For this reason, we cannot identify explanatory priority with epistemological priority.

Nor can Descartes ground this explanatory priority in the intentional structure of God's creative act. This would require more than the simple knowledge that God created the human being in all its detail. What is needed is knowledge that God intended to create a mind-body composite *with the features Descartes references in the explanans* and was *restricted by this prior intention* (and being a non-deceiver) to create the mind-body composite with the correlation constituting the explanandum. However, this would involve the kind of insight into the means-ends structure of divine intention that Descartes rules out.

This problem also plagues Descartes's explanation of the mitral valve. There, too, the explanans includes the *usus* of the valve (to effectively close the opening of the vessel) *and the shape of the opening of the venous artery* (due to its position). As in the case of the pineal motion-sensation correlation, Descartes here treats certain aspects of our physiology (the location of the vessel opening and so its shape) as explanatorily prior to others (the bicuspid character of the mitral valve). But even if this problem can be resolved, a second problem remains for the explanation of the mitral valve. Descartes grounds the explanatory priority of the *usus* of the pineal motion-sensation correlation in divine non-deceptiveness. This divine attribute can be understood to place restrictions on the kinds of thought producing physiological systems God creates, because such systems are involved in judgments which can be true or false. The portal-closing *usus* of the valve, however, is not implicated in the production of any thoughts, and so neither is it implicated in judgments. For this reason, Descartes cannot so ground the explanatory priority of this *usus*. This problem generalizes to explanations of any features of non-thought producing physiology. The teleological import of divine non-deceptiveness does not penetrate to physiology far removed from thought production. And since for Descartes this is the physiology we share (in one way or another) with brute animals,[274] neither will it extend to their physiology.[275]

5.6 DESCARTES'S *TWO* TELEOMECHANICS IN MEDICAL CONTEXT

As the opening lines of the *Description of the Human Body* make explicit, Descartes's efforts to establish a true human physiology grounded in his physics was centered on providing explanations that do not "attribut[e] to the soul functions which depend solely on the body and on the disposition of its organs." (AT XI 224, CSM I 314) He believed that finding the true mechanistic function-analytical explanations of bodily *functiones* would lead us to "many very reliable rules, both for curing illness and for preventing it, and even for slowing down the aging process." (AT XI 223-224, CSM I 314) Descartes accepts and employs the language of *functiones* and *usus* present in the medical tradition, as well as the main outlines of the structural anatomy of his day and the delineation of the main *functiones* of the human being.[276]

[274] "And when I looked to see what functions would occur in such a body I found precisely those which may occur in us without our thinking of them, and hence without any contribution from our soul (that is, from that part of us, distinct from the body, whose nature, as I have said previously, is simply to think). These functions are just the ones in which animals without reason may be said to resemble us." (AT VI 46, CSM I 134)
[275] It is not uncommon to suggest that Descartes's treatment of animal physiology is anthropocentric (see, e.g., Manning (2006) and Simmons (2001), and that to the extent that it invokes teleological or normative resources it is based on an "admittedly compelling" (Simmons 2001, 62 n. 17) analogy with human physiology. If this is right, then the problem of limited scope *might* be resolvable if the problem of limited depth were—although I think such a strategy raises subtle questions about the use of animals in research into the *usus* (as explanatorily prior to parts) of human physiological systems.
[276] With one notable exception. Descartes accepts Harvey's account of the circulation of the blood and his identification of the heart as the location of the driving force responsible for that circulation. Of course, he rejects Harvey's account of how that driving force is produced.

Descartes's project was primarily a revision of the efficient causal explanations of those *functiones* made in terms of temperaments and faculties grounded in the nutritive and sensitive soul.[277] As Dennis Des Chene has characterized it, Descartes's physiology "promotes a revolution that is *conservative* over the phenomena, but *radical* in its interpretation of them." (Des Chene 2001, 9) Descartes aims to provide more intelligible explanations grounded in his matter theory and account of the mind. These function-analytical explanations display a kind of systems-teleology: they identify Cummins-functions of components, i.e., the contributions components make to the behavior of the system to be explained.

However, the provision of such function-analytical explanations of *functiones* was not the only explanatory project in early modern medicine. In reading Harvey,[278] Descartes was exposed to a different project, one that pursues final causal explanations of the parts in all animals. These explanations involve consequence-etiological teleology; they identify a particular effect of the component as a reason why it is present. For Harvey (and Fabricius) the most important way to render human physiology intelligible was to situate it within a larger framework that provides such consequence-etiological explanations of the presence, commonalities, and patterns of variation in related animal parts by identifying the final causes of those parts. Descartes largely eschews this explanatory project. However, as we have seen, he does occasionally provide such explanations, most problematically, of the mitral valve of the heart. It is worth noting that Descartes's explanation of the mitral valve is comparative in nature. It provides a *unifying* explanation of *variation* in related parts—the different valves of the heart. In this way it exhibits, on a limited scale, precisely what Fabricius's and Harvey's Aristotelian approach to

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277 Such principles, says Descartes, are as much in need of explanation as the *functiones* being explained. See, e.g., AT XI 25-26, CSM I 89 and AT XI 243-244, G 181.
278 Which he clearly did, and while writing the *Treatise on Man*, although he says he had already worked out his view of the motion of the heart (AT I 263, CSMK 40).

anatomy emphasizes, pursuing a unifying explanatory structure of related parts. Although Descartes finds such unifying explanations hard to resist, they do not fit comfortably in his broader system, and this because in his natural philosophy he rejects *both* the Galeno-Aristotelian metaphysics of living things (in which the animal can have ontological priority over its parts) *and* appeals to the intentions of a divine creator.

6.0 CONCLUSION

The historical and conceptual relationships between mechanism and teleology in early 17th century physiology are various—not least because 'mechanism' and 'teleology' are themselves complex. For this reason, a simple story of the demise of an Aristotelian view of nature as organic and purposeful and the rise of a mathematized view of nature as mechanical and blind is inadequate. At least, this is, I hope, one lesson to be drawn from this study of mechanism and teleology in Fabricius, Harvey, and Descartes. In Fabricius and Harvey, I have argued, we find a creative project to integrate mathematical mechanics, itself understood as an Aristotelian subordinate science, into Galeno-Aristotelian final causal explanations of animal anatomy. In Descartes, we find instead the description of sub-visible mechanisms—exhibiting only extension and its modes—which constitute or bring about characteristic, complex behaviors of living things. Descartes's mechanization of the animal involves both explanation by the description of a mechanism and the elimination of all but what Boyle would later call the "mechanical affections" of matter. Fabricius's and Harvey's projects are not mechanistic in either of these senses. Theirs is a mechanization only in the sense of applying mathematical mechanics to the animal. Descartes's, in contrast, does not involve this application of mathematical mechanics to the animal, nor, in fact, almost any mathematization of the animal. Save his treatment of the eye, Descartes's mechanism descriptions are not articulated mathematically—they are not described in such a way as to allow mathematical inferences.

In my treatment of Fabricius and (especially) Harvey, I have provided a detailed account of a creative and vibrant early modern Galeno-Aristotelianism. In Harvey we find a remarkably fertile and coherent anatomical methodology built upon specialized, expert observation, dissection and vivisection, and self-conscious, systematic comparison. This method was developed and practiced by Harvey for the sake of achieving Aristotelian final causal *scientia* of the parts of animals articulated in Galenic terms of *actio* and *usus*. This method *and* goal were instrumental in Harvey's discovery of the circulation of the blood, and he understood them to be continuous with the main methods and aspirations of Aristotle and Galen.

Finally, in examining Descartes's physiology in this medical context, I have been able to articulate with more precision the nature of his use of the language of *functio* and *usus* in the function-analytical project at the heart of his physiology. I have shown that this project and his use of *usus* and *functio* in it fell comfortably within the bounds of the medical tradition which he was attempting to reform. This reform involved the elimination of what he took to be metaphysically extravagant, mysterious, and so explanatorily weak Galeno-Aristotelian principles: temperaments, faculties, and (vegetative and animal) souls. In addition, this reductionist metaphysics of body was wedded by Descartes to the rejection of appeals to divine ends. Together, these two features of Descartes's system removed from reach the unifying, consequence-etiological explanations also present in the medical tradition and central to the projects of Fabricius and Harvey.

Their Aristotelian approach emphasized and provided explanations for the patterns of commonality and variation across animal kinds. This pattern is a prominent and striking feature of the living world, and it cries out for explanation. Like Aristotle, Harvey and Fabricius understood these patterns to be expressive of a structure of (genus-species) relatedness among animal kinds. Within this structure related animals share certain activities, features, and parts as more fundamental than others. The final causal explanations exhibiting the hypothetical necessity relating these more fundamental aspects (as ends) to the rest of the animal physiology, reflect this structure, providing unifying, final causal explanations of the presence and variation of parts across animal kinds.

Descartes would certainly extend to these explanatory principles, the same judgment he made regarding Harvey's account of the motion of the heart:

> Now if we suppose that the heart moves in the way Harvey describes, we must imagine some faculty which causes this movement; yet the nature of this faculty is much harder to conceive of than whatever Harvey purports to explain by invoking it. (AT XI 243, CSM I 318)

Still, Descartes's system does not have the resources to provide a competing, more intelligible explanation of the patterns of commonality and variation present in the living world, nor to articulate the priority or fundamentality of some aspects of an animal's physiology over others that these patterns suggest. Perhaps in evolutionary theory, we have an account of these features of the living world that Descartes—an explanation in terms, roughly, of the phenotypic and development context of novel adaptation. Such an account, however, was not on the horizon in the 17th century, and in his *Disquisition about Final Causes* Boyle will embrace Descartes's ontology but not his rejection of appeals to divine intentions. It is, I suspect, no coincidence that in that text Boyle is preoccupied with impressing on the reader just these patterns of commonality and variation across animal kinds.

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