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Magnifying the first points of life: Harvey and Descartes on generation and scale

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Abstract
In this essay, I study the contested role of magnification as an observational strategy in the generation theories of William Harvey and René Descartes. During the seventeenth century, the grounds under the discipline of anatomy were shifting as knowledge was increasingly based on *autopsia* and observation. Likewise, new theories of generation were established through observations of living beings in their smallest state. But the question formed: was it possible to extend vision all the way down to the first points of life? Arguing that the potential of magnification hinged on the metaphysics of living matter, I show that Harvey did not consider observational focus on the material composition of blood and embryos to be conducive to knowledge of living bodies. To Harvey, generation was caused by immaterial, and thus in principle invisible, forces that could not be magnified. Descartes, on the other hand, believed that access to the subvisible scale of natural bodies was crucial to knowledge about their nature. This access could be granted through rational introspection, but possibly also through powerful microscopes. The essay thus ends with a reflection on the importance of Cartesian corpuscularianism for the emergence of microscopical anatomy in seventeenth-century England.

Keywords
Early modern medicine, anatomy, generation theory, scientific observation, microscopes, visibility, blood

Introduction: Life in a beat

Sometime in 1628, the English anatomist William Harvey was four days into a series of observations when he suddenly saw something. During the last four days, he had patiently waited while a batch of chicken eggs had been sat on by a hen, and in intervals of

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sometimes hours, sometimes half-days, he had stolen a warm egg, peeled off its shell, and squinted his eyes in order to see what was taking form inside of it. So far he had not really seen anything, but suddenly something showed itself: "there was a point of blood," he wrote, "which did beat, so little, that when it was contracted it disappeared, and vanish'd out of our sight."[1] This little point of blood – "small as the point of a needle" – was the first sign of the future chicken, and the fact that the blood rhythmically appeared and disappeared with a beat "as betwixt being seen, & not being seen, as it were betwixt being, and not being" was exactly what constituted this moment in the chicken's existence as "the beginning of life." To Harvey, life began in a beat.

As with most of Harvey's writing, which is narrative in form and highly eloquent in execution, it is easy to get caught up in this scene and accept at face value the dramatic entry of life with the pulsating blood on the fourth day. But if we pause for a moment, there is something peculiar about Harvey's insistence that it is only at the moment that he is able to see the beating point of blood that life commences. Was the blood not there before it was plentiful enough to beat? And is the vitality of a generating being really determined by the strength of the observer's eyesight?

This essay studies the shifting grounds under the practice of anatomy in seventeenth-century Europe. Harvey's confident designation of the fourth day of incubation as the beginning of chicken life should be seen in the light of the rising epistemic value of *autopsia*, seeing for oneself, in early modern anatomy. Whereas anatomy traditionally had been a discipline based on classical texts and the notions and theories of ancient authors, it was now claimed that it should be based on observations made by the anatomist himself.[2] But it was not given exactly what it meant to see for oneself. First of all, seeing the living body is quite a difficult thing. In life most of it is hidden under the skin, and in death its internal parts turn out to be big, blubbery, and seemingly out of shape.[3] As several scholars have shown, it took a lot of practical and epistemic work to turn the human or animal body into something that could be shared and published as a set of anatomical observations.[4]

1. William Harvey, *The Anatomical Exercises of Dr. William Harvey Professor of Physick, and Physician to the Kings Majesty, Concerning the Motion of the Heart and Blood. With the Preface of Zachariah Wood Physician of Roterdam. To Which Is Added Dr. James De Back His Discourse of the Heart, Physician in Ordinary to the Town of Roterdam* (London: Richard Lowndes, 1653), p.20.
2. Gianna Pomata and Nancy G. Siraisi, "Introduction," in Gianna Pomata and Nancy G. Siraisi (eds.), *Historia: Empiricism and Erudition in Early Modern Europe* (Cambridge, MA: The MIT Press, 2005), pp.1–38; Gianna Pomata, "Observation Rising: Birth of an Epistemic Genre, 1500-1650," in Lorraine Daston and Elizabeth Lunbeck (eds.), *Histories of Scientific Observation* (Chicago: University of Chicago Press, 2011), pp.45–80; Lorraine Daston, "The Empire of Observation, 1600-1800," in Lorraine Daston and Elizabeth Lunbeck (eds.), *Histories of Scientific Observation* (Chicago: University of Chicago Press, 2011), pp.81–113.
3. For early modern anatomical debates, see Dániel Margócsy, *Commercial Visions: Science, Trade, and Visual Culture in the Dutch Golden Age* (Chicago: University of Chicago Press, 2014), chaps. 4–5; Anita Guerrini, *The Courtiers' Anatomists: Animals and Humans in Louis XIV's Paris* (Chicago: University of Chicago Press, 2015).
4. Dániel Margócsy, "Advertising Cadavers in the Republic of Letters: Anatomical Publications in the Early Modern Netherlands," *The British Journal for the History of Science* 42, no. 2

When it came to observing the generating body, the body as it was coming to be, though, another set of issues arose. In the early modern period, the question of generation was wound up in fundamental philosophical debates about the nature of body, the nature of matter, and the nature of change and becoming.[5] Central to these debates was the issue of what really happened in the period before the fetus became visible. Was the visible chicken fetus the product of invisible forces coming together and ending up forming something material and visible, or was it rather a number of material bits that had lumped together so as to make up a body eventually big enough to be seen with the naked eye? This was a lively debate at the time when Harvey formulated his generation theory, and, as I show in this essay, one in which he actively intervened. In designating the visibility of the chicken fetus as the moment of its first existence, Harvey was not just giving a pragmatic solution to the difficult problem of observing generation. He was also making a very clear statement about the nonexistence of a level beneath the visible and the impossibility of making observations of things below the threshold of human vision.

In order to understand this debate better, this essay studies Harvey's position on the use of magnification within embryology in comparison with his contemporary, the French natural philosopher René Descartes.[6] Descartes was making observations and writing on anatomy and generation, and he was, famously, the first author to defend a modified version of Harvey's theory of blood circulation.[7] But unlike Harvey, Descartes was a staunch advocate of magnification as an observational strategy, a position that was entirely entwined with his position on the make-up of bodies. To Descartes, all bodies were composed of small particles that, although invisible to the naked eye, were potentially visible. And, importantly, Descartes believed that it was the behavior of these

(2009): 187–210; Sachiko Kusukawa, *Picturing the Book of Nature: Image, Text, and Argument in Sixteenth-Century Human Anatomy and Medical Botany* (Chicago: University of Chicago Press, 2012); Florike Egmond, *Eye for Detail: Images of Plants and Animals in Art and Science, 1500–1630* (London: Reaktion Books Limited, 2017).

5. For analyses of the debates on generation in the early modern period, see the essays collected in Justin E. H. Smith (ed.), *The Problem of Animal Generation in Early Modern Philosophy* (Cambridge: Cambridge University Press, 2006). See also the chapters making up part II of Lauren Kassell, Nick Hopwood, and Rebecca Flemming (eds.), *Reproduction: Antiquity to the Present Day* (Cambridge: Cambridge University Press, 2018).
6. For studies of magnification and visualisation in eighteenth-century embryology, see Shirley A. Roe, *Matter, Life, and Generation: Eighteenth-Century Embryology and the Haller-Wolff Debate* (Cambridge: Cambridge University Press, 1981); Marc J. Ratcliff, *The Quest for the Invisible: Microscopy in the Enlightenment* (Farnham: Ashgate Publishing Limited, 2009); Mary Terrall, *Catching Nature in the Act: Réaumur and the Practice of Natural History in the Eighteenth Century* (Chicago: University of Chicago Press, 2014).
7. For this, see Roger French, *William Harvey's Natural Philosophy* (Cambridge: Cambridge University Press, 1994); Thomas Fuchs, *The Mechanization of the Heart: Harvey and Descartes* (Rochester: University of Rochester Press, 2001); Annie Bitbol-Hespériès, "Cartesian Physiology," in Stephen Gaukroger, John Schuster, and John Sutton (eds.), *Descartes' Natural Philosophy* (London: Routledge, 2003), pp.349–82; Lucian Petrescu, "Descartes on the Heartbeat: The Leuven Affair," *Perspectives on Science* 21, no. 4 (2013): 397–428; Dennis Des Chene, *Spirits and Clocks: Machine and Organism in Descartes* (New York: Cornell University Press, 2001), pp.15–31.

small-scale particles that determined the appearance of large-scale bodies, and thus he considered the subvisible level of particles to be of upmost epistemic importance to anatomists as well as other kinds of observers. This position included high praise of the microscope, which he believed would enable the anatomist to visually confirm the size, shape, and figuration of the particles of all natural things.

Seventeenth-century naturalists developed a number of strategies to drag imperceptible entities into the realm of the sensible, as Alexander Wragge-Morley has recently put it.[8] Alchemical substances were distilled and dissolved in order for their constituting parts to show themselves, while the fundamental processes of vegetation were made visible through the use of plants as instruments.[9] As I show in this essay, the early use of microscopes should be recognized as part of this broader history of magnification strategies. As is well-known, microscopes were used to enable the naturalist to see small details better and to reveal the various mechanisms making natural bodies work. Yet they were also aimed at revealing the level of fundamental particles, including within the discipline of anatomy.[10] This was not something that happened along the way, but rather, as I show, part of a discussion of magnification that even predated the actual use of microscopes within anatomy.[11]

Through comparison of the possibilities of magnification for Harvey and Descartes, the essay offers a revaluation of the relationship between instrument use and empiricism. Since the analysis of *Leviathan and the Air-Pump*, the promotion of scientific instruments has often been seen as a hallmark of experimental natural philosophy, whereas speculative natural philosophy has been linked to resistance toward the use of such artificial observational set-ups.[12] This essay shows that the opposite could

8. Alexander Wragge-Morley, *Aesthetic Science: Representing Nature in the Royal Society of London, 1650–1720* (Chicago: University of Chicago Press, 2020), p.63.
9. William R. Newman, *Atoms and Alchemy: Chymistry and the Experimental Origins of the Scientific Revolution* (Chicago: University of Chicago Press, 2006); Dana Jalobeanu and Oana Matei, “Treating Plants as Laboratories: A Chemical Natural History of Vegetation in 17th-Century England,” *Centaurus* 62, no. 3 (2020): 542–61.
10. For seventeenth-century use of microscopes in anatomy, see Edward G. Ruestow, “Images and Ideas: Leeuwenhoek’s Perception of the Spermatozoa,” *Journal of the History of Biology* 16, no. 2 (1983): 185–224; Edward G. Ruestow, *The Microscope in the Dutch Republic: The Shaping of Discovery* (Cambridge: Cambridge University Press, 1996), chap. 9; Marian Fournier, *The Fabric of Life: Microscopy in the Seventeenth Century* (Baltimore: Johns Hopkins University Press, 1996), chap. 5; Domenico Bertoloni Meli, *Mechanism, Experiment, Disease: Marcello Malpighi and Seventeenth-Century Anatomy* (Baltimore: Johns Hopkins University Press, 2011), chap. 5. Importantly, the discoveries discussed here took place later than the developments discussed in this essay.
11. As such, this essay agrees with the argument given in Christoph Lüthy, “Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy,” *Early Science and Medicine* 1, no. 1 (1996): 1–27. Lüthy discusses developments within natural philosophy broadly conceived, while the focus of this essay is on the discipline of anatomy.
12. Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985). For discussions of experimental versus speculative natural philosophy, see Peter Anstey, “Experimental versus Speculative Natural Philosophy,” in Peter R. Anstey and John A. Schuster (eds.), *The Science of Nature in the Seventeenth Century: Patterns of Change in Early Modern Natural Philosophy* (Dordrecht: Springer, 2006), pp.214–42; Peter Anstey and Alberto Vanzo, “The Origins of Early Modern

also be the case: Descartes, the deductivist, considered microscopes to be the future of philosophy, while Harvey, whom we normally consider a proponent of observational experimentalism, was entirely skeptical of their use. I argue that in fact this had less to do with their respective positions on observation and experience, which they both promoted, and more to do with their metaphysics. Both were quite dogmatic about the metaphysical make-up of nature and the cause of change: Harvey, the Aristotelian, believed that you cannot observe Aristotelian substances visually, and that the cause of generation is in principle invisible through any means. Descartes believed, in turn, that the causes of generation and change were foundational as well, but unlike Harvey he imagined them to be material, and thus potentially visible through microscopes. Interestingly, as I show in the last section, this position was taken up by a number of anatomical microscopists and used as a framework for their observations of the least parts of bodies. As such, the essay contributes to the growing scholarship on early modern embryology, but goes beyond this as it exposes the philosophical underpinnings that were guiding contemporary debates on generation.[13]

Finally, the essay also adds to the scholarship on the relationship between Harvey and Descartes as it analyzes their respective generation theories. The relationship between these two authors has mostly been examined in light of Harvey's theory of blood circulation, which Descartes was the first to publicly defend in a modified version based on his theoretical assumptions. Importantly, though, my analysis of the differences between Harvey and Descartes with regard to generation is not based on a debate. Although he had been working on his embryological research for some years, Harvey only published his generation theory in 1651, the year after Descartes's death. Similarly, Descartes's work on the human body was written and published in different tempi, and his generation theory was eventually published posthumously in 1664.[14] Thus, Harvey and Descartes developed their thoughts on generation roughly simultaneously.

Experimental Philosophy," *Intellectual History Review* 22, no. 4 (2012): 499–518. For discussions of the meaning of empiricism in the early modern period, see the essays collected in Siegfried Bodenmann and Anne-Lise Rey (eds.), *What Does It Mean to Be an Empiricist? Empiricisms in Eighteenth Century Sciences* (Dordrecht: Springer, 2018).

13. Recent contributions to this body of literature include Eric Jorink, *Reading the Book of Nature in the Dutch Golden Age, 1575–1715* (Leiden: Brill, 2010); Eric Jorink, "Insects, Philosophy and the Microscope," in Helen Anne Curry et al. (eds.), *Worlds of Natural History* (Cambridge: Cambridge University Press, 2018), pp.131–48; Domenico Bertoloni Meli, *Mechanism, Experiment, Disease: Marcello Malpighi and Seventeenth-Century Anatomy* (Baltimore: Johns Hopkins University Press, 2011); Ashley J. Inglehart, "Boyle, Malpighi, and the Problem of Plastic Powers," in Peter Distelzweig, Benjamin Goldberg, and Evan R. Ragland (eds.), *Early Modern Medicine and Natural Philosophy, History, Philosophy and Theory of the Life Sciences* (Dordrecht: Springer, 2016), pp.295–321.
14. Delphine Antoine-Mahut, "The Story of L'Homme," in Delphine Antoine-Mahut and Stephen Gaukroger (eds.), *Descartes' Treatise on Man and Its Reception* (Dordrecht: Springer, 2017), pp.1–29.

The essay begins with a discussion of Harvey's view on the composition of blood. I argue that Harvey believed blood to be of a divine nature, which to him meant that it could not be understood as composed by subvisible particles. After this, I proceed to discuss the two contributing elements to the act of generation, namely the female radical moisture and the male divine mandat. Harvey believed both of these elements to be immaterial and in principle invisible. I show how this led him to the view that microscopes are of no use for the observation of generation, although they might show some anatomical details more clearly. I then discuss how Descartes took the opposite view: blood and embryos, like everything in the world, are made up of particles, and thus it is through consideration of their subvisible composition that knowledge of their nature can be found. Finally, I discuss how Descartes's optimism spurred the following generation of anatomical microscopists to look for the first corpuscles of generation.

True blood and crass gore

In 1599, the young William Harvey left Cambridge and traveled to Padua to complete his medical education at the university, which was known for its excellence in anatomy.[15] At Padua, Harvey was taught by Hieronymus Fabricius ab Aquapendente, who was working on his treatise on generation, *De formato foetu* (1604), at the time.[16] For Fabricius, whose philosophical framework was Aristotelian, anatomy was to begin with descriptive *historiae* of the body's parts based on dissections, then proceed to descriptions of the actions of the parts, and, finally, a designation of the uses and causes of the parts.[17] The final purpose of anatomy, then, was to understand something truly invisible, namely the *functions* or *causes* of the body, and the means was the enumeration of observational facts. Harvey returned to England in 1602, and joined the College of Physicians of London in 1604, but he would remain loyal to Fabricius long after this. In 1651, he would still refer to Aristotle as his general, and Fabricius as his guide.[18]

In 1628, Harvey published his first work, *Exercitatio anatomica de motu cordis et sanguinis in animalibus*, which presented his theory of the circulation of blood. This was

15. For biographical details about Harvey, see Roger French, *William Harvey's Natural Philosophy* (note 7), chap. 3.
16. James G. Lennox, "The Comparative Study of Animal Development: William Harvey's Aristotelianism," in Justin E. H. Smith (ed.), *The Problem of Animal Generation in Early Modern Philosophy* (Cambridge: Cambridge University Press, 2006), pp. 21–46, 31.
17. Ibid., p.30. For the method of *historia* in medicine, see Gianna Pomata, "Praxis Historialis: The Uses of Historia in Early Modern Medicine," in Gianna Pomata and Nancy G. Siraisi (eds.), *Historia: Empiricism and Erudition in Early Modern Europe* (Cambridge, MA: MIT Press, 2005), pp.105–46.
18. William Harvey, *Anatomical Exercitations: Concerning the Generation of Living Medicine and Natural Philosophy* (London: James Young, 1653), Preface (unpaginated). For more on Harvey's relationship to Fabricius, see Distelzweig, "'Mechanics' and Mechanism in William Harvey's Anatomy," in Peter Distelzweig, Benjamin Goldberg, and Evan R. Ragland (eds.), *Early Modern Medicine and Natural Philosophy* (Dordrecht: Springer, 2016), pp. 117–140, 119–20; Karin J. Ekholm, "Fabricius's and Harvey's Representations of Animal Generation," *Annals of Science* 67, no. 3 (2010): 329–52.

followed in 1651 by the *Exercitationes de generatione animalium*, in which he presented his generation theory.[19] According to his friend the physician George Ent, who provided a biographical sketch in the dedicatory epistle to the *Generation of Living Creatures*, Harvey had worked on generation for many years and even had his manuscript ready for some time before he finally let his treatise be published in 1651.[20] One reason for the delay was that all of his notes and, according to John Aubrey (another biographer), even a finished manuscript on the generation of insects, *De insectis*, were destroyed in a raid during the civil war in the 1640s.[21]

The published version of the *Generation of Living Creatures* was much longer than *Motion of Heart and Blood*, as well as being less straightforward, as Harvey was careful to first outline the position of Aristotle every time he began a new observation. His main purpose of the treatise was to propose a new theory of generation, which he called "epigenesis." This he contrasted to the theory of "metamorphosis," a form of spontaneous generation where all parts were created at once, and which he believed to take place in lower animals. According to Harvey's theory of epigenesis, which can be seen as an updated version of Aristotle's generation theory, the parts of the animal were formed in an ordered sequence where the parts that were first needed were formed first. Specifically, Harvey noted that the first part to be formed was the blood, which began moving around the fourth day after incubation. After that, the heart was formed as a container when the blood became too plentiful, and the other organs followed. This description was not a value-free description of development; Harvey believed that the first formed part – the blood – was the most vital part of the animal and was "the beginning of life."[22]

In both his published works, Harvey followed Fabricius's insistence on the value of observation and description. Harvey gave long and detailed descriptions of what he saw and he often invited the reader to see, look, observe, and experience, as well. The situations that he took the reader through, though, were not very advanced or sophisticated. Harvey might cook an egg to make it easier to see its inner structures, but apart from the anatomical dissections he did not set up elaborate experiments. The same was the case for the tools that he used to make the body visible: Harvey did not use the microscope and only rarely did he use magnifying glasses.[23] This is not to say that he was openly against the use of optical

19. These two works were both published in English in 1653; see Harvey, *Motion of the Heart and Blood* (note 1); Harvey, *Generation of Living Creatures* (note 18). Throughout the essay, I refer to these editions of Harvey's works.
20. See Ent's epistle dedicatory to Harvey, *Generation of Living Creatures* (note 18).
21. John Aubrey, *Brief Lives, Chiefly of Contemporaries, Set Down by John Aubrey, between the Years 1669 & 1696*, vol. 1, ed. Andrew Clark (Oxford: Clarendon Press, 1898), p.303.
22. Harvey, *Motion of Heart and Blood*, p.20 (note 1).
23. Alan Salter, "Intimate Converse with Nature: Body and Touching in Harvey's Way of Inquiry," in L. E. Semler and Philippa Kelly (eds.), *Word and Self Estranged in English Texts, 1550–1660* (Farnham: Ashgate Publishing Limited, 2013), p.66; Benjamin Goldberg, "A Dark Business, Full of Shadows: Analogy and Theology in William Harvey," *Studies in*

instruments.[24] In his two major works he mentioned the magnifying glass five times, and he even, speaking directly to his reader, encouraged him to use it as otherwise "you will only loose your labour."[25] But in all of these five passages, the magnifying glass was treated merely as a practical help enabling the anatomist to see properly, not as an instrument that could essentially reveal more about the nature of the body.

There are different ways to interpret Harvey's reluctance to incorporate microscopical observation into his mode of enquiry. Some scholars have argued that Harvey's ambivalence toward the microscope was grounded in an "embodied experimentalist" attitude of sticking to the perceptions of unaided sense experience and combining ocular observation with experience gained from the first-hand sensations of touch, smell, and taste.[26] This kind of embodied engagement with the examined object speaks against an observational practice focusing only on the mediated, visual representation of a specific detail. Others have argued that if only proper microscopes had been available to Harvey, he would gladly have used them in order to see the "missing parts" of his theories: the heart generated before the circulating blood, the blood cell, the sperm cell, and the capillaries.[27] But such comments miss something crucial about Harvey's observational strategy, namely that he did not consider these observations because he did not acknowledge the existence of such subvisible entities.

Let us start with the blood. Importantly, Harvey devised a number of observational methods to study the motion and action of blood, as the title of his first work goes, but not blood in itself. Harvey never tried to make a definite observation of what blood is, and in fact he argued that in principle such an observation could not take place. In the chapter on innate heat, Harvey presented blood as a divine and spiritual substance that partakes in the vital principle of the stars.[28] The heat of the blood is not like that of fire, but of a higher kind above the elements. It does not make sense, Harvey argued, to speak of the parts that

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24. I treat the magnifying glass as being in the same class as the microscope, as it is impossible to establish a distinct line between these two instruments. For more on this, see Lüthy, "Atomism, Lynceus" (note 11). For a discussion of Harvey's understanding of instruments, see Don Bates, "Machina Ex Deo: William Harvey and the Meaning of Instruments," *Journal of the History of Ideas* 61, no. 4 (2000): 577–93, and for mechanisms more broadly, Distelzweig, "'Mechanics' and Mechanism in William Harvey's Anatomy" (note 19).
25. Harvey, *Generation of Living Creatures*, p.90 (note 18). The other passages are found in Harvey, *Motion of Heart and Blood*, pp.18, 94 (note 1), and Harvey, *Generation of Living Creatures*, pp.98 (note 18), 113. Harvey calls this instrument by different names, including "Perspective," "perspective glasse," and "optick glass made for the discovery of the least things."
26. Alan Salter and Charles T. Wolfe, "Empiricism Contra Experiment: Harvey, Locke and the Revisionist View of Experimental Philosophy," *Bulletin d'histoire et d'épistémologie Des Sciences de La Vie* 16, no. 2 (2009): 113–40; Charles T. Wolfe, "Empiricist Heresies in Early Modern Medical Thought," in Charles T. Wolfe and Ofer Gal (eds.), *The Body as Object and Instrument of Knowledge* (Dordrecht: Springer, 2010), pp.333–44; Salter, "Intimate Converse with Nature: Body and Touching in Harvey's Way of Inquiry" (note 23).
27. Goldberg, "A Dark Business, Full of Shadows," 420, 431 (note 23).
28. Harvey, *Generation of Living Creatures*, p.452 (note 18).

make up the blood, for the substance of blood is not the sum of any parts. To specify this, Harvey drew a distinction between *gore*, which is "*blood* being considered absolutely in it self out of the Veins," and *true blood*, which is in the veins and the "*primary seat of the soul*," "the *Fire*, the *Vesta*, the *Houshold deity*, the *Calidum Innatum*, the *Sun* of the *Microcosme*, and *Platos Fire*."[29] Whereas gore is composed of "serous, thin, crass, and concrete parts," and thus can be broken down and observed, true blood is in perpetual motion; "it penetrates every part, and is every where present." It was the perpetual motion, which is to say the circulation of blood, that interested him, but not the particular make-up of the blood itself, which could never be completely comprehended: "No man," he wrote, "can worthily magnifie and extol its wonderful and divine faculties."[30]

Rather than attempting to make observations of the minute composition of blood, Harvey's interest lay in the function of the blood within the body, which he understood as circulation. Even though this circulation might be ever so small, as we saw in the first pulse of a chicken fetus discussed above, it was, importantly, a large-scale phenomenon. Circulation takes place within the entire organized system of the body, and cannot be observed outside of this system – it is "every where," as he put it. Staying on this level, Harvey did what he could to make blood and generation more visible, including studying "stand-in" specimens to get closer to the functions that he wanted to understand. In order to see the entirety of the circulatory system at work uninterrupted, he fished out semi-transparent shrimps from the river Thames, which offered a window to the inner workings of the body, and he got hold of eggs of ostriches and cassowaries, whose structures were bigger than the analogous ones found in his preferred type of fowl, the chicken.[31] In contrast to the minute introspection of parts, these visualization techniques were entirely consistent with Harvey's commitment to the discovery of the body's invisible functions through observations.

Radical moisture and the divine mandat

The formation of the blood, and with it the circulation of blood, or pulse, was the first discernable thing in a newly generated animal, but it was also the divine product of the

29. Ibid., p.458.
30. Ibid., pp.458–9. I would like to thank the anonymous reviewer for their discussion of this quote.
31. For the shrimp, see Harvey, *Motion of Heart and Blood*, pp.19–20 (note 1). In his manuscript on circulation, the experimental philosopher Henry Power would later note regarding his observations of the heart of a shrimp that "through an amber or crystall cased watch the Automaticall Motion of the Nutts and Wheeles are discoverable," see Henry Power, "Circulatio Sanguinis (1652)," in F. C. Cole, "Henry Power on the Circulation of the Blood," *Journal of the History of Medicine XII* (1957): 291–324, 310. For discussion of the transparency of anatomical preparations, see Margócsy, *Commercial Visions*, pp.137–40 (note 3). For the ostrich and cassowary eggs, see Harvey, *Generation of Living Creatures*, pp.60–63 (note 18), and for a brief discussion of this, see Karin Ekholm, "Pictures and Analogies in the Anatomy of Generation," in Lauren Kassell, Nick Hopwood, and Rebecca Flemming (eds.), *Reproduction: Antiquity to the Present Day* (Cambridge: Cambridge University Press, 2018), pp. 209–224, 222.

meeting between two other substances, namely the radical, or primigenial, moisture found within the uterus of the female, and the immaterial spark provided by the male. But like the blood, these substances could not be turned into objects of microscopic observation, as Harvey considered them to be unmagnifiable, though in different ways.

In arguing for the existence and importance of the radical moisture, Harvey took up a theme that ran all the way back to the Roman physician Galen.[32] Hippocratic authors had presented different ideas about the heat and moisture provided by the male and female, and Aristotle used these loose categories to develop his gendered theory of reproduction, where the female provided unformed menstrual fluid (moisture) and the male provided the *pneuma* – the "soul-heat" – which would drive the formation of the matter into a body. To Galen, though, the radical moisture or seed provided by the female gained more agency, as he argued that like the male seed, the female seed possessed principles of change as well, if to a lesser degree.[33]

For Harvey, it was the radical moisture that stood at the beginning of all instances of generation – it was with the radical moisture that every animal life began. From the radical moisture came the ovum, or the egg, and, according to Harvey, it was not only oviparous animals that have eggs, but in fact all animals. The only difference was that oviparous animals lay their eggs before the offspring is fully developed, whereas viviparous animals, such as humans, carry their eggs inside them so that they are hidden from sight. As such, whereas the comparison between the development inside the chicken egg and the development in the womb had been a rhetorical analogy for the Hippocratic writers, Harvey took this to be true in a much more literal way. Harvey even epitomized the importance of the egg, and thus the female's contribution, on the frontispiece to his book, where Zeus held a bisected egg wherefrom a human, a reindeer, a bird, a fish, a crocodile, and a snake, as well as a number of insects, emerged. The egg was inscribed with the Latin phrase "Ex ovo omnia," everything from the egg, which forcefully drove Harvey's point home.

In the chapter devoted to the radical moisture, Harvey interestingly dived into a discussion about whether this substance could be magnified in order to be studied more closely. First, he gave his account of what the radical moisture is. The radical moisture, he argued, is primary in the Aristotelian sense of being undifferentiated and without parts. It is "the most simple, pure, and sincere body imaginable" as everything here exists *in potentia*, but not *in actu*.[34] According to Aristotle's theory of natural change, the potential of a substance was prior to its actualization, which meant that the radical moisture might hold the future characteristics of the natural being, but in an entirely unstructured way. To elucidate this, Harvey used an optical analogy and compared the radical

32. For an overview of debates about the radical moisture from Ancient Greek medicine to Harvey, see Gianna Pomata, "Innate Heat, Radical Moisture and Generation," in Lauren Kassell, Nick Hopwood, and Rebecca Flemming (eds.), *Reproduction: Antiquity to the Present Day* (Cambridge: Cambridge University Press, 2018), pp.195–208.
33. Rebecca Flemming, "Galen's Generations of Seeds," in Lauren Kassell, Nick Hopwood, and Rebecca Flemming (eds.), *Reproduction: Antiquity to the Present Day* (Cambridge: Cambridge University Press, 2018), pp.95–108.
34. Harvey, *Generation of Living Creatures*, pp.462–3 (note 18). For discussion, see Goldberg, "A Dark Business, Full of Shadows," 421–25 (note 23).

moisture to the crystalline humor of the eye, which itself was void and colorless, but was able to take on all colors, just like the other organs of sense that share like features of potentiality. This, too, was a way for him to stress the perfection of the natural senses, and thus unmediated perception.

The fact that the radical moisture was without parts also meant that it was homogeneous. And this, in turn, had important bearings on the use of magnification and the kinds of observations that were meaningful to Harvey. To put it in simple terms, if something is completely homogeneous and structureless, it does not matter if you magnify it or not, you will still see the same image. Imagine an entirely white painting: no matter how much you zoom in, you will simply see a white painting, which cannot be differentiated from all the other versions of it. On the contrary, if something is heterogeneous and of a particulate nature made up of parts, magnification will reveal these parts, and thus the composition of the substance. Harvey used this logic to confirm that his notion of the radical moisture was the correct one. There are those, he wrote, "that follow *Empedocles* and *Hippocrates*," to believe everything a mixture of the four elements or "*Democritus* and the *Epicureans* [. . .] who constitute all things out of the confluence of *Atomes* of *different Figures*."[35] These philosophers held that matter in its most essential form was heterogeneous and made up of either different kinds of elements or of always-smaller parts, a notion that Harvey believed to be absurd. The criticism, he continued, should not only be leveled against the Ancients, for this kind of atomism was indeed "a popular errour at this day."[36]

In order to drive home his objection to this view of matter, Harvey invoked the example of Lynceus, the sharp-sighted mythical hero.[37] Lynceus, or the lynx, was the emblem of the Italian Accademia dei Lincei, which had been founded in 1603 by Frederico Cesi.[38] It was these sharp-sighted academics that produced the *Melissographia* in 1630, which included the first images identified as being made with a microscope. The term "microscope" had been coined by one of the Lynceans, Giovanni Faber, who in a letter of 1625 reported that he had made an observation of a louse through an "optical tube of marvelous clarity" and "decided to call it a *microscope*, by analogy with the telescope."[39] Back in England, the microscope kept being associated with the Academy of the Lynx. When Hooke eventually published his *Micrographia* in 1665, he did so choosing an epistle

35. Harvey, *Generation of Living Creatures*, p.467 (note 18). Harvey seems to refer to Aristotle's discussion of atomism in *On Generation and Corruption*, cf. the discussion in Lüthy, "Atomism, Lynceus," 11–13 (note 11). For further discussion of this, including Robert Boyle's views on chicken generation, see Domenico Bertoloni Meli, *Mechanism: A Visual, Lexical, and Conceptual History* (Pittsburgh: University of Pittsburgh Press, 2019), pp.110–25.
36. Harvey, *Generation of Living Creatures*, p.467 (note 18).
37. For the trope of Lynceus, microscopy and the academy of the lynx, see Lüthy, "Atomism, Lynceus" (note 11).
38. David Freedberg, *The Eye of the Lynx: Galileo, His Friends, and the Beginnings of Modern Natural History* (Chicago: University of Chicago Press, 2003).
39. Giovanni Faber, quote and translation taken from Freedberg, *The Eye of the Lynx*, p.183 (note 38).

from Horace as its epitaph, which reminded his reader that "You may not be able, with your eyes, to see as far as Lynceus / Yet you would not on that account scorn to anoint them, if sore."[40]

But to Harvey, such visual superiority would not count as an anointment. "Had a man *Linceus* his eyes," he wrote, "he could not discerne any thing that were *similar*, one in number, identity, and continuity: but there were nothing but an appearing union, and an assembly or heap made up of a congregation and certain colligation of indivisible bodies."[41] What Harvey objected to here was the view that a natural body, such as the radical moisture, was merely an aggregate or "appearing union" of atoms instead of, as he thought in Aristotelian fashion, a truly unified body. It should be added that this is a somewhat strange piece of criticism: Harvey criticized the atomists for believing that powerfully enhanced vision would reveal natural bodies such as the radical moisture to be made of atoms, but it is difficult to see why atomists would object to that. What Harvey achieved, though, was effectively to link magnification and microscopy with atomism in order to reject both projects. If one were an atomist, the microscope would be a very useful instrument, but since atomism is wrong the project of looking for subvisible entities through lenses is futile. This shows how Harvey's lack of interest in magnification devices deeply reflects his philosophical ideas about the nature of matter. According to Harvey, empirical knowledge of the smallest units of a substance, did these exist, would not provide any real knowledge about the substance. As we shall see, this is where Descartes disagreed wholly with Harvey.

While it was the homogeneity of the radical moisture that made it unfit for magnification, the male's contribution to the act of generation, the "divine Mandat," the incorporeal principle, the form of forms, could not be observed because it was immaterial and thus truly invisible.[42] According to Harvey, while generation had its ultimate beginning in the radical moisture, it was the action of the male's part that set the development in motion. Here, again, Harvey followed Aristotle to some length, but ultimately veered off from his course. In the mid-fourth century BC, Aristotle in his *History of Animals* had given a very detailed description on what happens in incubated eggs: "In the case of the domestic hen, the first signs of the embryo are seen after three days and nights [. . .]. During this time the yolk has already migrated toward the pointed end of the egg, wherein lies the source of the egg and whence the egg hatches; and the heart is a mere blood-spot in the white."[43] For Aristotle, generation was a matter of the soul. What happened in the

40. Robert Hooke, *Micrographia: Or, Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses, with Observations and Inquiries Thereupon* (London: John Martyn and James Allestry, 1665), Frontispiece. For this, see Frédérique Aït-Touati, *Fictions of the Cosmos*, trans. Susan Emanuel (Chicago: The University of Chicago Press, 2011), p.136.
41. Harvey, *Generation of Living Creatures*, p.467 (note 18). This line of criticism resembles the one voiced by the Cambridge Platonists against Descartes and other mechanical philosophers. See for instance Ralph Cudworth, *The True Intellectual System of the Universe* (London: Richard Royston, 1678), p.147.
42. Harvey, *Generation of Living Creatures*, p.468 (note 18).
43. Aristotle, *History of Animals* VI. 3. 561a4–21. For Aristotle's view on generation, including discussion of his observations of chicken eggs, see James G. Lennox, "The Comparative Study of Animal Development: William Harvey's Aristotelianism," pp.22–8 (note 16).

incubated egg was one step in a process that had its causal goal – its “that-for-the-sake-of-which” – in the fully developed, living hen and its beginning in the moment when the egg was imbued with the *pneuma* of the male semen.[44] In Aristotle’s metaphysics, the notion of the “that-for-the-sake-of-which,” or final cause, was part of a larger conceptual framework, which also counted the material, formal, and efficient cause. Natural change, such as the development of the embryo, had its ultimate cause in the fully grown hen. In this way, Aristotle’s generation theory was part and parcel of his wider teleological metaphysics. It was the soul imbued in the male semen, Aristotle argued, that governed the developments taking place within the egg, where uniform, simple matter provided by the female was slowly differentiated into the parts and organs of the new chicken. Importantly, the cause of the development was something principally invisible, namely the *pneuma* or soul of the male semen, while the material was simple and homogeneous prior to the developments.

Harvey followed this in general terms, but maintained “that the Cock conferres neither Matter nor Form to the Egge; but onely that thing by which the Egge is Fertile, and made fit and capable to produce a Chicken.”[45] Harvey had come to this position – that the male only sets the process in motion, but does not provide any matter or a specific form to the egg – through dissections of a number of does in the season of their reproduction. Harvey benefited from being a close member of the court as the king’s many hunting parties provided him with a continuous stock of dead deer. Opening the wombs of the does, Harvey found no evidence of the male’s seminal fluid, which convinced him of the immateriality of the process of conception.[46]

But if the male did not provide any matter to the female, what was provided? As mentioned, Harvey did not rule out spontaneous generation, which would not require anything from the male parent, but that only happened in lower-order animals such as insects. There was no doubt that the male provided something, for observations as well as everyday experience proved that pregnancy was always preceded by copulation. This something was definitely the cause of generation, but not through matter or form. In order to make sense of this, Harvey used a number of metaphors. Generation was, Harvey argued, like catching a disease without touching an ill person, like coming to think of something that is not physically there, or like magnetized iron attracting metal stubs without being in contact with them.[47] What these metaphors for generation – contagion, ideas, and magnetism – shared was that they had real effects, but invisible and hidden causes. Importantly, the fact that these causes were invisible and hidden meant

44. For a concise recapitulation of Aristotle’s theory of generation, see Laurence M. V. Totelin, “Animal and Plant Generation in Classical Antiquity,” in Lauren Kassell, Nick Hopwood, and Rebecca Flemming (eds.), *Reproduction: Antiquity to the Present Day* (Cambridge: Cambridge University Press, 2018), pp.53–66.
45. Harvey, *Generation of Living Creatures*, p.168 (note 18).
46. Ibid., pp.397–447.
47. Ibid., pp.254, 539–40. For discussion, see Goldberg, “A Dark Business, Full of Shadows” (note 23); Justin E. H. Smith, *Divine Machines: Leibniz and the Sciences of Life* (Princeton: Princeton University Press, 2011), p.167; Ekholm, “Pictures and Analogies in the Anatomy of Generation,” pp. 222–3 (note 31).

for Harvey that they were unobservable. This was what the metaphors were meant to convey: there are limits to our observational knowledge of generation, but not to our philosophical knowledge of it, and that observational limit is marked by what is visible to the eyes.

As I now proceed to examine Descartes's theory of generation, we will see that, although he also considered the causes of generation to be invisible to the senses, Descartes thought that this could be remedied through different means, including the use of instruments. Vision, to Descartes, was an entirely physical process, which had its cause in the movement and action of particles.[48] Thus, the invisibility of the substance of blood and the first fetus was provisional provided that the level of particles could be reached.

Scaling generation down to the least level

In 1632, Pierre Gassendi wrote to the French friar Marin Mersenne telling him about Harvey's new theory of blood circulation, and Mersenne, ever the hub of new information, conveyed this to Descartes.[49] It seems, though, that Descartes had already come to a similar conclusion about the nature of the arteries and veins, although he disagreed about the specific role of the heart in the circulatory system.[50] Whereas Harvey considered the circulation of the blood to be the effect of the beating of the heart, Descartes found its cause to be the *feux sans lumière*, the fire without light, which burns inside all living beings rarefying and agitating the blood to make the thermodynamic system of the body-machine work.[51] To Descartes, it was the presence of this inner heat that marked the difference between living and nonliving things, and thus it also played a central part in the generation of new living beings.[52]

Descartes presented his generation theory in the *Description of the Human Body*, a treatise that he wrote in the winter of 1647–8 but never finished. It was finally published posthumously in 1664 by Claude Clerselier in Paris under the title *Treatise on the Formation of the Foetus* together with the *Treatise on Man*.[53] The purpose of the text was

48. Margaret Atherton, "Descartes among the British: The Case of the Theory of Vision," in Tad M. Schmaltz (ed.), *Receptions of Descartes: Cartesianism and Anti-Cartesianism in Early Modern Europe* (Abingdon: Routledge, 2005), pp.200–214.
49. Lucian Petrescu, "Descartes on the Heartbeat" (note 7).
50. Bitbol-Hespériès, "Cartesian Physiology" (note 7); Chene, *Spirits and Clocks*, pp.15–31 (note 7).
51. Peter Anstey, "Descartes' Cardiology and Its Reception in English Physiology," in Stephen Gaukroger, John Schuster, and John Sutton (eds.), *Descartes' Natural Philosophy* (London and New York: Routledge, 2000), pp. 420–444, 421–3.
52. Descartes' concept of life is currently subject to a very lively scholarly debate. For a recapitulation of this debate as well as an argument for the dissolution of the concept in Descartes's philosophy, see Barnaby R. Hutchins, "Descartes and the Dissolution of Life," *The Southern Journal of Philosophy* 54, no. 2 (2016): 155–73.
53. Description of the 1664 publication of *Treatise on Man* and *Description of the Human Body* as well as analysis of this early reception history can be found in Annie Bitbol-Hespériès, "The Primacy of L'Homme in the 1664 Parisian Edition by Clerselier," in Delphine Antoine-Mahut

to make the reader familiar with the functions of his body since "[t]here is no more fruitful occupation than to try to know oneself," as Descartes introduced the text with the Delphic injunction.[54] Knowing oneself, argued Descartes, was not only a question of knowing one's morals – an implicit critique of the Renaissance humanists' ideals of virtue – but also a question of medicine.[55]

Descartes began this part by giving his thoughts on the generation of plants, which he considered to be caused by "the shape and the arrangement of the particles of the seed."[56] The plant seed, he explained, differed from that of animals and humans in that it was harder and more solid, whereas human and animal seeds were more fluid.[57] In animals and humans, he continued, both male and female contributed with liquids, which began to act on each other after intercourse "like a kind of yeast" producing heat and agitation, which again caused the liquids to expand.[58] Descartes drew analogies between the heat produced in this very first stage of life and fermenting wine and drying hay. This was the "heat without light," which now caused the heart to form and begin beating, and which began to divide into "many extremely tiny branches," that formed the rudimentary system of blood circulation in the body.[59] The explanation is telling. Observationally, Descartes did not do much more than mention that liquids expand – he did not see much. So, in order to elucidate what he could not see, he began to bring in his concepts of matter.

Descartes maintained that the matter, which formed these extremely tiny branches, was the finest type of matter imaginable, which he, with reference to the *Principles of Philosophy*, called "matter of the first element." In the *Principles*, Descartes had distinguished between three types of matter, namely matter of the first, second, and third element, respectively, where the first was the smallest and most agitated and the third was the largest and least agitated. Different natural phenomena, different objects, were composed of different types of matter: "The sun and fixed stars are composed of the first element, the heavens from the second, and the earth with the planets and comets from the third."[60] It was precisely matter of the first element, the most minute, the quickest and hottest (which necessarily followed as heat, for Descartes, was

and Stephen Gaukroger (eds.), *Descartes' Treatise on Man and Its Reception* (Dordrecht: Springer, 2017), pp.33–47; Antoine-Mahut, "The Story of L'Homme," pp.1–20 (note 14); Stephen Gaukroger, "Introduction," in René Descartes, *Descartes: The World and Other Writings* (Cambridge: Cambridge University Press, 1998), pp. vii–xxix, xxix; Stephen Gaukroger, *Descartes: An Intellectual Biography* (Oxford: Clarendon Press, 1995), pp.405–6.

54. Descartes, "Description of the Human Body," in René Descartes, *Descartes: The World and Other Writings* (Camridge: Cambridge University Press, 1998), pp.170–205, 170.
55. For the therapeutic ambitions of Descartes's natural philosophy, see Steven Shapin, "Descartes the Doctor: Rationalism and Its Therapies," *The British Journal for the History of Science* 33, no. 2 (2000): 131–54.
56. Descartes, "Description of the Human Body," pp.186–7 (note 54). On the role of botany in Descartes' natural philosophy, see Fabrizio Baldassarri, "The Mechanical Life of Plants: Descartes on Botany," *British Journal for the History of Science* 52, no. 1 (2019): 41–63.
57. Baldassarri, "The Mechanical Life of Plants," 50 (note 56).
58. Descartes, "Description of the Human Body," p. 187 (note 54).
59. Ibid., pp.187–8. For an analysis of Descartes's explanation of the heartbeat and the pulse, see Barnaby R. Hutchins, "Descartes, Corpuscles and Reductionism: Mechanism and Systems in Descartes' Physiology," *The Philosophical Quarterly* 65, no. 261 (2015): 674–85.
60. René Descartes, *The Philosophical Writings of Descartes, Volume I*, trans. John Cottingham, Robert Stoothoff, and Dugald Murdoch (Cambridge: Cambridge University Press, 1985), p.258.

defined by rapidity of motion) that was found in the heart of the fetus and in the circuit of tiny branches. Like Harvey, Descartes likened the blood to the stars, but for him this was a material, not a spiritual, similarity. After he had identified this kind of matter as matter of the first element, Descartes began to refer to it as blood, followed by his explanation of why blood is red.

Descartes began the explanation by referring to his theory of light, which he had developed in the *Optics* and *Principles*, and his theory of color developed in the *Meteorology*. According to his corpuscular theory of vision developed at length in the *Optics*, objects were not visible because the mind connected with them through a shared form, as the prevailing Scholastic theory had it, but because all objects emanated corpuscles that then hit the fibers of the eyes. As such, Descartes's theory of vision was tactile as the sense of touch was paradigmatic to the sense of vision; to see an object was to feel it with the eyes.[61] In the *Meteorology*, Descartes had described how different colors are produced as the effect of the ratio between the speed by which they emanated and the speed by which they spun around their own axis:

> the nature of the colors appearing [here] consists only in the fact that the particles of the fine substance that transmits the action of the light have a stronger tendency to rotate than to move in a straight line; so that those which have a much stronger tendency to rotate cause the color red. And those which have only a slightly stronger tendency cause yellow. [. . .] Green appears where they turn just a little more slowly, and blue where they turn very much more slowly.[62]

In this way, Descartes had explained the sequence of colors of the rainbow, which simply was caused by particles spinning slower and slower.[63] In the *Description*, he used the same theory to argue that blood appeared red because the first-element corpuscles of the tiny branches of the blood circuit move so fast that they made the corpuscles of the second-element matter that came in contact with them spin extremely fast: "But the only

61. Gaukroger calls Descartes's sense of vision a "contact sense"; see Stephen Gaukroger, "Introduction to A. Arnauld," in Antoine Arnauld, *On True and False Ideas* (Manchester: Manchester University Press, 1990), p.17. For Descartes's objection against "form," see René Descartes, *The Philosophical Writings of Descartes, Volume II*, trans. John Cottingham, Robert Stoothoff, and Dugald Murdoch (Cambridge: Cambridge University Press, 1984), pp.174–6; René Descartes, *The Philosophical Writings of Descartes, Volume I*, p.40 (note 60). Also in the *Treatise on Man*, Descartes discusses sensation and vision at length; see René Descartes, "Treatise on Man," in *The World and Other Writings* (Cambridge: Cambridge University Press, 1998), pp.142–69.
62. René Descartes, *Discourse on Method, Optics, Geometry, and Meteorology* (Indianapolis: Hackett Publishing, 2001), pp.337–8.
63. For an analysis of Descartes's theory of the rainbow, including a highly interesting discussion about his excursions back and forth between the visible and invisible realms, see Jed Z. Buchwald, "Descartes's Experimental Journey past the Prism and through the Invisible World to the Rainbow," *Annals of Science* 65, no. 1 (2008): 1–46. Rainbows were not only a phenomenon to be observed under right weather conditions, they were also a marvel artificially produced in the Renaissance garden. For this perspective, see Simon Werrett, "Wonders Never Cease: Descartes's *Météores* and the Rainbow Fountain," *The British Journal for the History of Science* 34, no. 2 (2001): 129–47.

kind of body that could make them turn faster is one whose tiny parts have branches so delicate and so close to one another that the only matter turning around them is that of the first element, and I have shown blood to be like this."[64] Following Descartes's logic in this passage, blood appears red to us because the corpuscles making us see blood acquire such a fast spin when they meet with the tiny branches of the blood circuit filled with matter of the first element.

There are several things worthy of notice in this explanation. First of all, Descartes's explanation is entirely deductive. What Descartes does here is, essentially, to fuse his assumptions about minuteness, his (conjectural) theory of matter, and the "spin" explanation of color taken from the *Meteorology*. Taken together, this explains why blood is red, although it is difficult to see just what this explanation adds to the observation of the redness of blood. In the reflections on the sequence of colors in the rainbow, his spin theory of color does do explanatory work, but here the explanation seems quite poor. Descartes did argue that he had "shown blood to be like this," moving quickly in a circle causing the specific spin, but the observation ("shown") here referred to the previous passage, in which he, again, had argued conjecturally about the formation of the fetus after the mingling of the two seminal fluids.[65]

What is most interesting in this passage for our purposes, though, is to note just how quickly Descartes moved from naked-eye observation (blood appears red) to an explanation that involved the level of corpuscles. Descartes did not stop in between, but moved directly from the level of the visible to the level of corpuscles. Importantly, this does not mean that Descartes was opposed to observation and dissection or that his arguments only rested on deduction, but rather that his scaling attempts always went "all the way down," so to speak.[66] It was the events taking place on the least level of nature that carried the explanatory weight, not the intermediate levels, which were not present in Descartes's natural philosophy at all. In this way, Descartes's natural philosophy was just as essentialist as Aristotle's natural philosophy; just as Aristotle had considered the causes to be foundational, Descartes considered the mechanical behavior of the corpuscles of objects to be foundational to their appearance to us as perceivers.[67] In granting the level of corpuscles the highest epistemic priority, phenomena existing on higher levels

64. Descartes, "Description of the Human Body," p.188 (note 54). For early-modern debates on the color of blood, see Domenico Bertoloni Meli, "The Color of Blood: Between Sensory Experience and Epistemic Significance," in Lorraine Daston and Elizabeth Lunbeck (eds.), *Histories of Scientific Observation* (Chicago: University of Chicago Press, 2011), pp.117–34.
65. Descartes, "Description of the Human Body," p.188 (note 54).
66. Anstey, "Descartes' Cardiology and Its Reception in English Physiology," pp.427–8 (note 51). For discussion of Descartes as an observer and experimenter, see Desmond Clarke, *Descartes' Philosophy of Science* (Manchester: Manchester University Press, 1982); Daniel Garber, "Descartes on Knowledge and Certainty," in *Descartes Embodied: Reading Cartesian Philosophy through Cartesian Science* (Cambridge: Cambridge University Press, 2001), pp.111–29, and for the experimentalism of the Cartesians, see the essays collected in Mihnea Dobre and Tammy Nyden, *Cartesian Empiricisms* (Dordrecht: Springer, 2013).
67. I am here following Gaukroger's interpretation of Descartes's "micro-corpuscularianism," see Stephen Gaukroger, *The Emergence of a Scientific Culture: Science and the Shaping of Modernity 1210–1685* (Oxford: Clarendon Press, 2006), pp.289–303.

could not in themselves work as explanatory elements, but only as phenomena that could be explained through reduction down to their constituting corpuscles.[68] Thus, Descartes did not find his explanations of the generating animal on the same level as the animal itself, but on a deeper, more fundamental level. Like Harvey's use of bigger types of fowl, Descartes scaled to be able to see generation unfolding, but rather than scaling upward, where things were more visible to the eye, he scaled downward to those things he could see clearly and distinctly in his mind.

Within this framework of scaling downward, magnification came forward as a highly promising avenue for research into natural bodies. The promise, as Descartes saw it, was that it would be possible to make actual observations of particles through extreme magnification. In his *Optics*, published in 1637, Descartes spoke with much praise of "telescopes that are used to see accessible objects," which was his term for what came to be known as microscopes.[69] These instruments, he argued, would prove much more useful than celestial telescopes as they would allow us to see "the diverse mixtures and arrangements of the small particles which compose the animals and plants," which was no small feat given that their "total nature and essence – at least those that are inanimate – consists in nothing but the weight, shape, arrangement and movements of their parts."[70]

To Descartes, the microscope was a corpuscularian tool; it was an instrument through which access to the least level of nature could be gained.[71] Although given that Descartes already seemed to know quite confidently that animals and plants were composed of these small particles structured in a certain way, and that generation really was the product of the intermingling of specific particles, what was the epistemic importance of a microscopic observation that seemed to do nothing but confirm this? Did seeing even matter to Descartes? As Daniel Garber has argued, it did, although in a way very different to Harvey.[72] As we have seen in the case of generation, Descartes's explanations proceeded deductively, and he argued in his methodological writings that it is possible to intuitively grasp the true connections between propositions through reason alone.[73] But at the same time he emphasized the value of sense experience and observation, especially within the discipline of anatomy. The way that this fit together for Descartes was that experiment and observation played an important role in aiding the intellect

68. For discussion of Descartes's reductionism and how it sometimes breaks down in his actual explanations, see Hutchins, "Descartes, Corpuscles and Reductionism" (note 59).
69. Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, p.172 (note 62). For Descartes' hands-on knowledge of optics, his relationship to experimental practices, and his attempt to carry out a rationalization of the mechanical arts, see Jean-François Gauvin, "Artisans, Machines, and Descartes's Organon," *History of Science* 44, no. 2 (2006): 187–216.
70. Descartes, *Discourse on Method, Optics, Geometry, and Meteorology*, p.172 (note 62).
71. I take the term corpuscularian tool from Lüthy, "Atomism, Lynceus" (note 11).
72. Daniel Garber, "Descartes and Experiment in the Discourse and Essays," in *Descartes Embodied: Reading Cartesian Philosophy through Cartesian Science* (Cambridge: Cambridge University Press, 2001), pp.85–110.
73. Descartes outlines this in the fourth rule of his *Rules for the Direction of the Mind*: René Descartes, *The Philosophical Writings of Descartes, Volume I*, pp.14–17 (note 60).

toward making the proper deductions and thus acting as a guide for reason.[74] In the end, all scientific propositions were deductive and rational to Descartes (seen with the mind, as it were), but observations could help the enquirer onto the path leading to these propositions.

The fact that Descartes did not see the actual movements of the particles of generation was not a problem to him, as he was able to magnify in his mind. But were it possible to construct microscopes, this would indeed be very helpful, as this would give more information about the particular constellations of the entities of the least level, and thus better opportunities for the anatomist to identify the true causes of generation. Just like Harvey, Descartes regarded the potential of the microscope to be able to grant observational access to the least level of nature. But unlike Harvey, Descartes viewed this opportunity of magnification to be highly promising.

Conclusion: seeing life through lenses

Harvey's epigenetic theory of generation was incredibly successful.[75] Immediately after the publication of *Generation of Living Beings*, contemporary anatomists took up the theory and subjected it to close examination, scrutiny, and test. As part of this appraisal, the observations on the development of the chicken embryo were reproduced, although with one significant change: the anatomists were observing the emergence of life through microscopes. In 1651, the same year as Harvey published his theory, Harvey's once student Nathaniel Highmore published two treatises on generation that were clearly presented within the Harveian framework, and in 1652 the natural philosopher Henry Power finished the manuscript "Circulatio Sanguinis" on Harvey's theories of blood circulation and generation under the supervision of Francis Glisson, who was also one of the first Harveians in England.[76]

But these early promoters were not repeating Harvey's claims uncritically. Both his individual observations and his underlying framework were being reworked, and generation was now increasingly described through the subvisible level of corpuscles. Corpuscularian theories from a variety of sources, including Descartes's writings, were gaining foothold in England, where they were reworked in multiple ways.[77] Natural

74. Garber, "Descartes and Experiment," p.93 (note 72).
75. For the immediate reception of Harvey's theories, see Robert G. Frank, *Harvey and the Oxford Physiologists: A Study of Scientific Ideas* (Berkeley: University of California Press, 1980).
76. Nathaniel Highmore, *The History of Generation. Examining The Several Opinions of Divers Authors, Especially That of Sir Kenelm Digby* (London: John Martin, 1651); Nathaniel Highmore, *Corporis humani disquisitio anatomica* (The Hague: Samuelis Broun, 1651); Henry Power, "Circulatio Sanguinis (1652)" (note 31). For Glisson and Harvey, see Guido Giglioni, "Sentient Nature and the Great Paradox of Early Modern Philosophy: How William Harvey and Francis Glisson Reinterpreted Aristotelian Φύσις," in Adelino Cardosa, Marta Mendonça, and Manuel Silvério Marques (eds.), *Natureza, Causalidade e Formas de Corporeidade* (Lisbon: Edições Húmus, 2016), pp.9–28.
77. For the spread of Cartesianism in the latter seventeenth century, see the essays in Dobre and Nyden, *Cartesian Empiricisms* (note 66). This collection is, though, rather silent on the English reception of Descartes. For an overview of English Cartesianism, see John Henry,

philosophers like Kenelm Digby, Thomas Hobbes, Walter Charleton, and Robert Boyle took up the possibility of looking for causes, including the causes of generation, on the level of least things and explored it further. The causal space of generation was no longer thought to be invisible but conceived to have the potential to become visible. Attempts to access this space took many forms, including experiments with salts, soil, and plants, but it was also pursued in direct continuation of Descartes's prediction that microscopes could grant access to the level of subvisible particles.[78]

In his *History of Generation*, Highmore used his microscope to find that the chicken's heart was already beating half a day before Harvey had been able to see anything.[79] Highmore was not content with seeing the first signs of the pulse through squinted eyes; he wanted to improve this observation through his microscope: "Within the white Circle in the middle, which was much dilated too, appeared a red sparkling line [. . .], it was the heart; as afterwards I saw by the help of a Microscope, exactly shewing me the heart perfectly formed."[80] And in the *Experimental Philosophy*, his only published work building on many years of research, Power went even further as he claimed to have seen the colorless, enfolded heart within the chicken egg just two days after incubation. This, he related, turned out to be "a pretty and beneficial Observation of the *Microscope*."[81] Through microscopes, Harvey's idea that the chicken was thrown into life on the fourth day after incubation was observationally disproved.

Highmore and Power were not only correcting Harvey's observations, they were also criticizing the philosophical framework that, as I have shown, prohibited him from acknowledging microscope-aided observations. In a letter to his former mentor, Highmore took up with Harvey's idea that the male only contributes with a spiritual form, "which spreads & operates like a contagion," and asked rather bluntly, "why should not the touch of the hand breathing or Kisses inject & make this female fruitfull without such expense of sperm and spirits"?[82] As a replacement for the immaterial form,

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"The Reception of Cartesianism," in Peter R. Anstey (ed.), *The Oxford Handbook of British Philosophy in the Seventeenth Century* (Oxford: Oxford University Press, 2013), pp.117–43. For an example of how Descartes's ideas of vision and physiology influenced an English natural philosopher, see Rodolfo Garau, "Springs, Nitre, and Conatus. The Role of the Heart in Hobbes's Physiology and Animal Locomotion," *British Journal for the History of Philosophy* 24, no. 2 (2016): 231–56.

78. Anna Marie Roos, "Nehemiah Grew (1641–1712) and the Saline Chymistry of Plants," *Ambix* 54, no. 1 (2007): 51–68; Antonio Clericuzio, "Plant and Soil Chemistry in Seventeenth-Century England: Worsley, Boyle and Coxe," *Early Science and Medicine* 23, nos. 5–6 (2018): 550–83; Jalobeanu and Matei, "Treating Plants as Laboratories" (note 9).
79. Highmore, *The History of Generation*, pp.70–71 (note 76).
80. Ibid., 70–71.
81. Henry Power, *Experimental Philosophy: In Three Books: Containing New Experiments Microscopical, Mercurial, Magnetical. With Some Deductions, and Probable Hypotheses Raised from Them, in Avouchment and Illustration of the Now Famous Atomical Hypotheses* (London: T. Roycroft, 1664), p.60.
82. British Library, Add MS 29586, f. 21.

Highmore posited the existence of certain "seminal atoms," which carried information about the organization of the future being.[83] Highmore developed this idea through a discussion of the generation theory of Digby, who was deeply influenced by corpuscularian theories, including that of Descartes.[84] Similarly, Power situated his work on microscopy very clearly within a Cartesian framework and argued that the purpose of studying nature through microscopes was the revelation of the particles and atoms that constitute all bodies, including all living bodies.[85]

In this essay, I have argued that the integration of microscopes into the practice of anatomy was not an uninterrupted process toward stronger and stronger vision. When microscopes were first introduced, there were competing conceptions of what they could do. To some anatomists they were considered no more than a practical help, and the idea that they could reveal previously unseen things was cast aside. But to others with more corpuscularian leanings, microscopy came forward as a way to observationally prove the existence of least parts as well as determine their specific make-up, and thus function. Importantly, when microscopy came to be successful as an observational strategy, it did so through its marriage to the theory of corpuscularianism, which also goes to show how little the acceptance of microscopy had to do with the divide between experimental and speculative natural philosophy. This did not mean that the corpuscularian microscopists were successful – after all, seeing atoms is quite difficult. But their stipulation that something essential was to be found on the ever-smaller scale was crucial in another way, as it directed the gaze of the anatomist toward another world: the middling world of cells, bladders, globules, capillaries, tubes, vessels, and fibers.

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83. Highmore, *The History of Generation*, pp.27–8, 46, 89 (note 76).
84. Kenelm Digby, *Two Treatises: In the One of Which, the Nature of Bodies; in the Other, the Nature of Mans Soule, Is Looked into: In Way of Discovery of the Immortality of Reasonable Soules* (New York and London: Garland, 1978). For discussion, see Justin E. H. Smith, "Theories of Generation and Form," in Peter R. Anstey (ed.), *The Oxford Handbook of British Philosophy in the Seventeenth Century* (Oxford: Oxford University Press, 2013), pp.261–84; Andreas Blank, "Composite Substance, Common Notions, and Kenelm Digby's Theory of Animal Generation,," Early Science and Medicine 13, no. 6 (2008): 258–614, 575–6; *Science in Context* 20, no. 1 (2007): 1–20; Karin Ekholm, "Harvey's and Highmore's Accounts of Chick Generation" (2008), 575–6; Anstey, "Descartes' Cardiology and Its Reception in English Physiology," pp.428–31 (note 51).
85. For this, see the preface to Power, *Experimental Philosophy* (note 81).

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