Research and Experiment in Early Greek Thought

by

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To my mother and father

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ABSTRACT

It is almost universally believed that the Greeks practiced science several generations before Socrates. What this claim means in detail, however, is still widely debated. In this thesis, I propose to look at one particularly important facet of the modern scientific method—experimentation—and see whether and, if so, how early Greek thinkers used experimentation in their investigation into nature.

Since there was no overarching idea of a "scientist" current in Greece during this time, I take several types of figures for whom we have textual evidence in turn: natural philosophers, doctors, musical theorists, and historiographers. Despite interpretive issues arising from pseudonymous and fragmentary texts, these authors all had an abiding interest in elucidating the workings of nature. And even though they exhibit differences in their approaches and objects of study, I argue that they all were open to the use of the senses in their investigations. In practice, this included the observation of purposefully-contrived and controlled interventions, which is the core of the modern-day experiment, even if ancient tests did not bear the same relationship to theory as experiments do in our understanding of science.

CHAPTER ONE: INTRODUCTION

Part of the allure of studying the Greeks is that they are simultaneously familiar and foreign. Too often, however, we privilege one side of this dichotomy over another: either we look for the earliest roots of a current idea or practice, or we react against this tendency by stating that, despite superficial similarities, the Greek mindset was one completely foreign to our own. Of course, when this thesis is put in such an extreme way, it should seem obvious that in any historical interpretation, we would do well to respect the Delphic injunction μηδὲν ἄγαν. Yet it bears reiterating that we should always make sure to respect the complexity of all the evidence at hand before asserting or denying any facet of Greek culture is comparable to the present day.

These general remarks hold true perhaps no more than when applied to the study of science. On the one hand, science and technology have grown exponentially more complex in the past two centuries, and increasingly are a part of everyday life. We have seen science become a greater part of both work and education. When scientific insights have been applied to our lives through technological advancement, economic growth and standards of living have grown immensely compared with just several centuries ago, especially when compared to antiquity. Thus, the increasing importance of science has prompted scholars of the past century or so to ask whether we can find the beginning of this wonderfully productive human enterprise among the Greeks, where we trace the beginnings of so much else.

Yet, the question "did the Greeks invent science" has given rise to a long interpretive debate, with no unanimity achieved either for an affirmative or a negative answer. Furthermore,

it has increasingly been doubted that we should formulate the question in such a way.[1] Perhaps the ancient and modern intellectual categories are simply too different, or the traditional question is not specific enough to yield interesting results. It is a debate that reaches across several disciplines and has attracted the attention of historians, philosophers, and practicing scientists as well as that of classicists. Indeed, it is also a debate which has its antecedents in the early modern period, when modern disciplinary boundaries had yet to take hold.[2]

Since the question is very complex and has a long history of its own, I shall begin with a brief survey of the issues concerning the historical comparison of modern and ancient science. First, I will review how the historiography of science can be characterized by two opposed tendencies—teleology and relativism.[3] I will argue that we should avoid both the Scylla of pure antiquarianism and the Charybdis of a "whiggish"[4] or teleological history of science. In order to find this middle ground, we need to be very explicit in laying down the terms used for the study of the natural world in *any* period. Thus, I will then explore what we mean by science and the modern scientific method, followed by how the Greeks understood their study of the natural world. Finally, I will argue that such a complex endeavor must be undertaken in parts and that focusing on an essential part of the modern scientific method—experimentation—in the ancient world, on its own terms, will help us better appreciate exactly how our understanding of science is both indebted to, and separate from, Greek ideals.

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[1] See, for instance, Lloyd 2004.

[2] Francis Bacon is especially important in this regard as he attempted to claim some Greek thinkers as fellow-scientists (on his view of science) and repudiate others (i.e., Aristotle and by extension the scholastics of his own day) as merely disputatious. Cf. Bacon 1620/1900, 233–234, 366–367.

[3] It is important to contrast this *methodological relativism* to the more famous, Protagorean relativism, whereby all ideas are equally true, or there is no such thing as truth. This stronger relativism does not necessarily follow from the relativism under discussion here, since the latter does not seek to evaluate the scientific truth of historical material at all (see below). However, in some cases it can lead to this belief.

[4] The term was invented to refer to and argue against a style of history that studies "the past for the sake of the present" (Butterfield 1965, 16). The name refers to the English political tendency of Whiggery, belief in the consistent progress and enlightenment of humankind over time.

1.1. The Historiography of (Greek) Science: Teleology and Relativism

As mentioned above, there are two major tendencies in the history of science in general, but also in the history of Greek science in particular, which we may call *teleology* and *relativism*. They are not schools of thought with an explicitly formulated agenda, nor specific groups of scholars, but interpretive stances that scholars adopt. In fact, a single scholar or work can show both tendencies at different times depending on the circumstances, and different scholars can exemplify the same tendency to different degrees.

Teleology in the history of science is the tendency to see science as a progressive human enterprise, that is, that the common stock of scientific knowledge improves and increases over time, and it is the oldest approach to the history of science.[5] It holds that science is something objective, and has developed linearly over time. Because there is a direct line of descent between historical science and the present day, we can make more or less straightforward comparisons between science today and the less advanced ancient science of earlier ages. In extreme cases, it is a form of teleology where the historian "mines" historical sources for reminiscences of the present, thus, supposedly, showing that the present followed necessarily from the past. It has also been called, both descriptively and pejoratively, "presentism," in that it uses the ideals of the present as a benchmark for evaluating the past.[6]

For the history of Greek science, the progressive tendency gives rise to the thesis that natural science (in our sense) begins in ancient Greece. It is characteristic of some earlier work on the history of ancient science. For example, early historians of philosophy—like Tannery[7] and

[5] Indeed, one might be able to trace it all the way back to Aristotle with his teleological account of his predecessors (with Aristotle as τέλος, of course).
[6] Fischer 1970, 35–40.
[7] Tannery 1887. Betegh 2011 is a detailed summary of Tannery's work and his philosophical commitments (mainly stemming from the positivist philosophy of Comte).

Burnet[8]—saw early philosophers essentially as natural scientists (in a basically modern sense).[9] Teleology can also be found in early historians of science dealing with Greek science as a distinct category[10] and scientists themselves, who obviously feel some sort of kinship with these early intellectual pioneers.[11] We can also see this tendency in some philosophers of science, such as Karl Popper who saw the Presocratics as the inventors of scientific reasoning in that they were willing to let reason take them beyond immediately apparent circumstances.[12] Nor is this standpoint confined just to the early part of the century: especially outside the history of science as an academic discipline, one can still find the thesis that Greek science is the embryonic form of modern science.[13]

This view is counterbalanced by relativism, which stresses the uniqueness of the historical and cultural circumstances of any period of science. Where teleology is both descriptive and evaluative, relativism only claims to be descriptive. One popular way to formulate this approach is, using terms borrowed from anthropology, to state that we must not present ancient science using "observer's categories" (i.e., our own intellectual categories), but "actor's categories" (i.e., those current at the time and place under study).[14] It is also called "constructivism," as it treats any given culture's science as a product specific to that culture.[15] Thus, this approach to the history of science is self-consciously relativistic in that it treats

[8] Burnet 1920, 24–30, who was followed by Russell in his once-influential history of Western philosophy (Russell 1945, 22).
[9] The question of the distinction between science and philosophy at an early (i.e., pre-Hellenistic) period is a vexed one. Section 1.3 briefly deals with the demarcation of science from philosophy in the ancient world, but the problem is an open one due to many complex factors (cf. Rihll 2002, 7–9). Finkelberg 2017, 1–17 is a good discussion on the historiography of ancient science, which I draw upon here.
[10] E.g., Clagett 1955, 21–33; Cohen and Drabkin 1958, vii.
[11] E.g., Schrödinger 1954/2014.
[12] Popper 1962, 136–162.
[13] E.g., Barnes 1982a, 36–40; Russo 2004, 15–30; Graham 2006, 1–4 and Graham 2013, chapter 1.
[14] E.g., Lloyd 1990, 7–8. It is important to contrast this *methodological relativism* to the more famous, Protagoran relativism, whereby all ideas are equally true, or there is no such thing as truth. This stronger relativism does not necessarily follow from the relativism under discussion here, since the latter does not seek to evaluate the scientific truth of historical material at all. However, in some cases it can lead to this belief.
[15] Golinski 1998, 7 (cf. the critical account in Graham 2013, 19–21).

historical and culturally specific positions independently of how true they are, and hence equally valid to study.

Unlike teleology, relativism is informed by recent work in the philosophy of science, and especially Kuhn's seminal work *The Structure of Scientific Revolutions*.[16] Kuhn noted that ideal definitions of science do not correspond with the actual history of science, which is full of false starts and abandoned projects (e.g., the Ptolemaic model of the solar system, the phlogiston theory of fire, the luminiferous ether). Rather, there are different standards of proof, assumptions, and methods of investigation at different periods, which all make up a "paradigm." When a paradigm fails to explain new information about the natural world, it is either "patched up" *ad hoc* or falls prey to a new paradigm which better explains the phenomena. The lesson for historians is that "sciences" must be spoken about in the plural. Scientific paradigms often are, in Kuhn's words, "incommensurable," that is, cannot be compared, since they rest on radically different assumptions.[17]

Thus, post-Kuhnian historians of science have emphasized differences between historical and modern intellectual categories, even if scholars of classical science were slow to integrate this into their work.[18] Above all, the works of G. E. R. Lloyd are emblematic of this pluralist viewpoint of ancient science. His work has ranged widely, both in terms of chronology and geography,[19] but one recurrent theme has been that "Greek science" is not an early form of a

[16] Kuhn 1962/2012. However, there are significant predecessors to Kuhn, like Koyré (cf. Kuhn 1977, xiii, n3).
[17] Kuhn's influence on the history and philosophy of science is vast in the sense that *Structure* has moved the history of science toward methodological relativism since its publication, rather than turning philosophers and historians of science all into orthodox Kuhnians (Hacking 1983, 6–17).
[18] Cf. Lloyd 1979, 4: "So far as the interpretation of early Greek thought is concerned, the debates of the anthropologists and philosophers have been, at most, intermittently influential." The situation has changed in the meantime, not least because of Lloyd's work.
[19] His latest work has focused on comparative studies of Greek and Chinese science with special attention paid to historical and cultural context. Lloyd 2009 offers a good summary account.

method that spans cultures, but a specific product of Greek culture.[20] We can compare its development within Greek culture to another culture's science in its own cultural context, but each "science" must be taken on its own terms. Moreover, we can and should differentiate between periods and movements in ancient science, as the umbrella category of "Greek science" homogenizes the vast variety of methods and doctrines appearing in the Mediterranean world over nearly a millennium. Following Lloyd's work as well as the general currents of the history of science, relativism has become what we probably can term the "orthodox" methodological position,[21] even if some proponents of the relativist viewpoint are not as measured in their application of it.[22]

Each of these approaches offers its own particular strengths and weaknesses. Scholars coming at the history of science using the relativist approach tend to include more historical detail in their interpretations; there is no need to pass over or explain away "incorrect" scientific facts or theories, since ancient science is conceived of as an entire system of thought separate from science today. It avoids the "twin dangers of anachronism and teleology,"[23] while closely translating, as it were, the historical sources into a language we can understand.

But we also must realize that, while historical fidelity acts as a guiding ideal, we cannot (and probably should not even try) to present ancient material completely in ancient categories. Our current categories always impinge upon our understanding of ancient material, and it is best not to deny that fact, but to be aware of it and explicit in the ways in which we use modern classifications.[24] Moreover, as Graham has noted, a *completely* descriptive account of antiquity

[20] E.g., Lloyd 1979, 226–264, Lloyd 1992.
[21] E.g., Rochberg 1993, 548–549; Lindberg 2010, 1–3. For pluralism in the history of science outside classical antiquity, cf. Cunningham and Williams, 1993, 409–410.
[22] E.g., Bernal 1992.
[23] Lloyd 2004, 9.
[24] Lloyd 1992, 566.

devolves into pure antiquarianism, stripping it of interesting insights that we can apply to the present.[25] Put simply, we do not practice history just for the past, but for ourselves as well. Finally, it is not immediately clear that ideas cannot survive a paradigm shift: we have to look at the actual historical record to see whether there are "genealogical" relationships between us and previous forms of science. We still very well may hold Greek scientific ideas or follow their methods as passed down through intermediaries. In these cases we would not be committing anachronism to analyze historical material using the lens of the present, so long as we take care not to overemphasize similarities nor explain away differences.

The above is obviously a very rough dichotomy that splits over a century of very rich and sophisticated work on the history of science into two, mutually exclusive camps for ease of understanding. We should not be surprised if such a dichotomous summary fails to capture many of the intricacies of the methodological debate in the history of science. However, it does offer a starting point.[26] More specifically, it seems clear that both sides of the debate have strengths and pitfalls, and by adopting a middle course we might be able to harness the former and avoid the latter. Of course by trying to steer between these two extremes, we will encounter some tension: we may be at one point more relativist and at another point more teleological, without being able to stipulate a universal rule as to when to be one or the other. But, rather than seeing this as vacillating between positions, we should see that such openness in interpretation is a more honest approach when we are confronted with complex and contradictory material. Sometimes ancient science seems much like modern science (and indeed sometimes has a direct "genealogical"

[25] Graham 2013, 34. This is partially Popper's point too in his call for modern philosophers to go "back to the Presocratics" in Popper 1962, 136–162.

[26] In dealing with another dichotomy (that of the literary foxes and hedgehogs, adapted from Archilochus fr. 201 West), Berlin puts it well by saying that "like all over-simple classifications of this type, the dichotomy becomes, if pressed, scholastic and ultimately absurd ... [but] like all distinctions which embody any degree of truth, it offers a point of view from which to look and compare, a starting-point for genuine investigation" (Berlin 2000, 437).

relation to it); other times it is quite an unfamiliar way of looking at the world. In order to tell which situations are which, however, we must first lay down the terms that will guide the investigation, and show both the ancient and modern conceptions of science as they were and are.

1.2. Science and the Scientific Method

For a concept as important to the modern world as science, there is very little unanimity on a precise definition. Thus, instead of adopting a definition in the hopes that it covers all possible instances, I will explore several necessary components of science in the modern sense in order that, taken together, they may give us an idea of what a minimal conception of what science looks like.

Our everyday usage offers us a starting point. *Science* in contemporary English means, above all, natural science, despite phrases like "social science" or "political science." This is, however, a fairly new development in the language: "science" comes to mean "natural science" only in the latter half of the 19th century.[27] Of course, the change is not surprising given that it is precisely then that scientific innovation began to be integrated into everyday life as part of the Industrial Revolution. Before this point, English used "science" to mean simply a specific body of knowledge, much like German *Wissenschaft* (as opposed to *Naturwissenschaft*), and this usage is one many modern European languages share with Greek (via Latin).

But natural science is not merely distinguished by its subject matter (i.e., nature). Otherwise, we would have no use for related concepts such as "pseudoscience" or "junk science," for these can have the natural world as their subject matter too. For instance, alchemy,

[27] *OED* s.v. science 5b.

a paradigmatic pseudoscience,[28] is a collection of theories about the chemical makeup of the physical world. Practitioners even performed some experiments throughout its thousand-year span. However, these experiments were not pursued in any methodical fashion, and the fantastic theories, composed of the philosophy and religious doctrine of late antiquity, dictated the interpretation of the results.[29] This stands in direct opposition to our ideal of science where we must revise or discard any theory based on incompatible experimental results.

A definition based solely on subject matter is also open to the criticism that anthropological evidence shows that many traditional, "pre-scientific" cultures have classificatory systems of natural features like plants and animals, and these are sometimes quite discerning.[30] Still, we do not call this science, because, as detailed as these traditional classificatory systems may be, they lack any explicit methodological component. So, just as important as the subject matter of science, if not more important, is the method of investigation, or what we call the *scientific method*.

The more important question, then, becomes: what is this method? Most people have at least a vague idea in mind from their school days.[31] It begins with observation of the natural world. Once a previously unexplained phenomenon has been observed, the scientist forms a hypothesis as to why the phenomenon happens. The scientist then designs an experiment—a situation artificially contrived to test the hypothesis. Based on the results of the experiment, the hypothesis is either confirmed or rejected. If the hypothesis is confirmed, we can be more confident that it is correct (yet never are completely sure); if it is rejected, we simply move on to

[28] Indeed, the term pseudoscience referred to alchemy in its English language debut (*OED* s.v. cites Andrews 1796, 87).
[29] Cf. Bacon 1620/1900, 260: "Chymicorum autem genus, ex paucis experimentis fornacis, philosophiam constituerunt phantasticam et ad pauca spectantem;" "the tribe of alchemists, from a few experiments at the furnace, have created a fantastical philosophy and one that takes into consideration [only] a few things."
[30] E.g., Lévi-Strauss 1966, 6–7; Berlin 1992, 5–8.
[31] One can see this formulation in any number of introductory textbooks to science and the scientific method (cf. Blachowicz 2009).

a new hypothesis. In either case, our scientific knowledge of nature increases. Because we posit a hypothesis, and then deduce whether or not it is false based on the results of an experiment, it is sometimes called the *hypothetico-deductive method*.[32] Although we find traces of it in previous thinkers, in a contemporary context it is most associated with the work of Karl Popper, who endeavored to come up with a model for scientific investigation that was not purely inductive.[33]

While this is commonly thought today to be the *only* way to practice science, this familiar image of scientific investigation used in all times and places is an oversimplification. It has been debated whether practicing scientists actually follow this method or whether it acts as a founding myth for modern science.[34] Indeed some have even questioned whether scientists should follow any method or whether choosing one supposedly universal approach actually hampers scientific progress.[35] Furthermore, although the hypothetico-deductive method accurately describes some branches of science today, it does not seem very applicable to others. Botany, for instance, relies to a great extent on observation and classification based on morphological similarities in plants, but makes no hypotheses; how could the botanist know what to look for, without going out into the field and doing so? Astronomy can sometimes formulate hypotheses and test them by experiment, but it reached a high level of development with no experimental input at all and controlled experiments are limited due to the nature of the subject matter (i.e., since astronomical bodies remain out of our direct reach). Some of the higher realms of theoretical physics like string theory also rest only on very slender and indirect evidence; yet they still seem to explain

[32] This contrasts with an inductive method or a method, such as Aristotle's, that creates general rules by induction and then applies them deductively (Losee 2001, 4–13).
[33] Popper 1959/2002.
[34] E.g., Bauer 1992, 19–41; Lloyd 2004, 11.
[35] Feyerabend 1975 is a forceful statement of this "anarchic" position. However, one can find suggestions of it much earlier in, e.g., Nietzsche 1881, 290 ("es gibt keine alleinwissendmachende Methode der Wissenschaft"), although we must also remember that at this point, Nietzsche is not speaking of only *Naturwissenschaft*.

mysterious facts about our universe.[36] Thus, if we claim that the only acceptable scientific method is the customary one, we end up with an overly restrictive definition of science.

But, more importantly for the historian, it is clear that scientists and philosophers—the two were not always separate—did not share a single scientific methodology. Even in the supposedly resolutely Aristotelian Middle Ages, thinkers like William of Ockham undertook major revisions of Aristotle's thought, doing away with some of the Philosopher's categories with his famous "razor."[37] Yet, Galileo, despite being remembered as the man who experimentally disproved Aristotle, actually saw himself as building upon Aristotle's own scientific work as opposed to the scholastic Aristotelianism which was content with "*ipse dixit*" and logical argumentation.[38] Newton posited four universal rules for scientific reasoning.[39] Descartes, on the other hand, outdid him and came up with twenty one of a projected thirty six.[40] Francis Bacon, whose precise role in the Scientific Revolution is hotly debated,[41] attempted to put forth a "new *Organon*," based on gathering masses of observations and generalizing laws inductively from the data.[42] J. S. Mill agreed with him and believed that scientific reasoning had to proceed by types of induction since different explanations could explain the same data deductively.[43] More recently, the aforementioned Karl Popper, the theorist probably most associated with the current hypothetico-deductive *status quo*, preferred deductive reasoning

[36] 't Hooft 2001. 't Hooft also makes the interesting point that as physics bores down to ever smaller scales, we lose experimental precision because things at sufficiently small, sub-atomic levels are "fuzzy," that is, only allow for probabilistic, not exact, measurement.
[37] I.e., the methodological principle that of two equally explanatory hypotheses, we should opt for the simpler. On Ockham and his rejection of Aristotelian categories except for substance, quality, and relation see Adams 1987, 156–161.
[38] Losee 2001, 48–49.
[39] Newton 1713/1999, 794–796.
[40] Losee 2001, 63–68.
[41] E.g., Kuhn 1977, 31–65; Park and Daston 2006, 3 for an overview.
[42] Gower 1997, 43–63.
[43] Mill 1843/1974a, 388–406.

based on falsifying hypotheses.[44] And these are just some examples of the *explicit* scientific methods that one can find. In a looser sense, A. C. Crombie's magisterial history of Western science from Greek antiquity to the present day has identified six distinct styles of scientific inquiry, including mathematical postulation, statistical analysis, taxonomy, and experimentation.[45] Suffice it to say, then, that if we want to speak of science as a historical category (i.e., not simply as how we understand science today), we must realize that the scientific method is a topic marked by multiplicity and disagreement.

We must proceed with some idea of what the scientific method entails *diachronically*, otherwise there seems little point to studying ancient science other than pure antiquarianism. Thus, instead of offering a general definition of the scientific method in the hopes of capturing all the diverse ways in which science has ever been practiced and how that practice has been understood, I will merely explore several methodological factors that either seem necessary or particularly important to science historically. Taken together, they will act as the categories guiding our investigation into ancient material in the absence of any universally accepted definition of the scientific method.

1.2.1. Observation

No natural science is completely *a priori*, so one necessary ingredient for any method of practicing science is *observation*, the gathering of data using via sensation. As one would suspect, this usually entails the use of sight (as the non-technical usage of the word suggests), but scientific observations are made through all the human senses, rather than just one of them.[46] For instance, the study of acoustics in the ancient and modern worlds rests just as much on recording measurements by ear as by sight. Nor are pure observations always dependent on the unaided use

[44] Popper 1959/2002, 9–10 and *passim*.
[45] Crombie 1994, 56–89.
[46] E.g., Mill 1843/1974b, 7–8. Cf. Arist. *Met*. 980a22–27.

of our senses; they must often be made with the help of instruments such as a telescope or microscope when the matter under observation is outside the usual range of human sensation.[47] There is no one method for carrying out pure observation: one can develop a knack for being a good observer,[48] but often the best observations are matters of luck.[49]

Because of this, the role of pure observation in science can vary. As opposed to the usual account of the scientific method, where observation of a previously unknown phenomenon is the first step, sometimes scientific progress rests on reinterpreting an old observation in a new way. Natural selection, for instance, provides a good example. Humans have long known that parents pass down traits to their children and that there are ways to select for beneficial traits in breeding animals. The original insight, as Darwin himself noted, is that nature carries out the same process without human direction, which does not rest upon an observation of something new.[50] At other times, we do observe a previously unknown phenomenon, which cannot be explained by the current scientific orthodoxy or which disproves a then-available theory. For instance, the (accidental!) discovery of microwave background radiation made the then-current steady state theory of an always existing universe untenable.[51]

The fact that the same observation can be interpreted in many different ways has led some scholars to claim that there is no such thing as a "pure" observation free of theoretical biases; seeing, hearing, etc. are not simply our senses receiving information, but also an act of interpretation on the part of the viewer, listener, etc. Often this can take the form of a linguistic claim, that all observation statements are "theory-laden," or are inextricable from the multitude

[47] Hacking 1983, 186–209.
[48] Ibid., 180.
[49] Mill 1843/1974a, 559–561.
[50] Cf. Darwin 1868, 3: "Man, therefore, may be said to have been trying an experiment on a gigantic scale; and it is an experiment which nature during the long lapse of time has incessantly tried."
[51] Kragh 1996, 343–344.

of theoretical assumptions that back up any statement.[52] Yet, as Hacking has argued, when we consider this position, it becomes clear that this is a rather expansive, and trivial, use of the term "theory." A theory is properly a set of intellectual commitments about a specific topic based on active investigation and reflection, and it is a mistake to call our subconscious and culturally-specific use of language "theory."[53] It is better said that different theories take the same observation as evidence for different things, and it is precisely by examining our and others' unstated assumptions that we can see which theories are more plausible.

Hacking has also noted that pure and unaided observation does not figure all that prominently in the history of science.[54] On reflection, it is easy to see the reason why. We would have very little need for a proactive investigation of the world if nature were an open book—that is, if the causes of natural phenomena were always clear to us and ready to be simply observed with no further work. As one of Heraclitus' famous maxims has more pithily put it, "nature tends to hide."[55] Even so, observation remains a necessary part of natural science, although not a sufficient one.

1.2.2. Measurement

One particular kind of observation that is especially important in scientific investigation is *measurement*. Statements of "pure" observations are qualitative in nature and can encompass all sorts of things using natural language. They are, however, subjective, both in terms of the language we use to express them and, perhaps, how each thing is perceived by different people.[56]

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[52] Feyerabend 1975, 22. The term originally comes from Hanson 1958, 19, but has made it into jargon of the philosophy and history of science.
[53] Hacking 1983, 174–176.
[54] Ibid., 168–169.
[55] DK22 B123.
[56] Colors offer a good example, as noted famously by the sometime Homeric scholar and English Prime Minister William Gladstone (Gladstone 1858, 457–499). An example: for Homer green plants (e.g., *Od.* 16.47: χλωρὰς ῥῶπας) and yellow honey (e.g., *Il.* 6.31: μέλι χλωρόν) are both χλωρός. Does that mean that Greeks saw the

Measurements, by contrast, are neutral observations of relatively few things like time and space, are expressed quantitatively, and can be mathematically manipulated. Although they are less open to personal interpretation, measurements too are subjective, but in an entirely different way than simple observations. Every measurement is based on a compact: they are expressed in terms of units, further measurements that people agree to use as a benchmark. As benchmarks, they can be more or less fixed,[57] and systems of measurements can be more or less conveniently or profitably used.[58] But so long as two units of measurement are measuring the same thing, they are interchangeable, and thus the conventionality and subjectivity behind measurements is not one which seems very harmful to the professed objectivity of science.

As a human activity, measurement has been with us for a very long time. Because measurements were necessary for economic activity, the state took an early interest in setting weights and measures exact enough to aid with commerce. This fact explains why, until quite recently, most units of measurement, like the foot and the cubit, were simply abstracted from everyday experience: there was simply no need for anything else. However, in parallel to the practical use of measurement, scientists began to measure nature quite early on in recorded history too. We still have, for instance, cuneiform tablets containing Babylonian astronomical data, although the sophistication of these measurements (as opposed to the mathematical models contained therein) has been exaggerated.[59] Even so, the use of measurement within certain fields of science—and thus their possible mathematicization—did not progress at an equal pace. Other

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world painted in an entirely different palate from us, or is it simply a question of the semantic range of color words? For a general treatment of the subjectivity of observation in science, cf. Hanson 1958, 4–30.

[57] Compare, for example, the meter, which is defined by its relation to the speed of light in a vacuum, and the foot which is either defined by one's own foot (which has no measurement) or by state fiat. Not only is the former perfectly universal, but it is also perfectly consistent since the speed of light in a vacuum does not change.

[58] If one doubts this, time how long it takes an American (or Liberian) to convert twenty miles into feet and anybody else to convert twenty kilometers into meters. Ease of use also depends on what is being measured and for what reason; we can express interstellar distances in inches (e.g., $\sim 1.63*10^{18}$ to Alpha Centauri) or a paper's margins in light years ($\sim 2.69*10^{-18}$), but it is so cumbersome as to be useless.

[59] Criticizing the exaggeration, see Neugebauer 1969, 97–98.

than astronomy, optics, and mechanics, most fields of science remained mainly qualitative well into the nineteenth century.[60]

One final trait that sets measurement in science apart from simple observation is that measurement is an activity that must be carried out purposefully. An observation can either be the result of active investigation led by some theoretical concern, or it can be passive and then applied to a theory after the fact. Measurement, on the other hand, is never serendipitous. When the scientist measures something in nature it is for a particular reason, such as comparing an actual value to what we expect from a theory.

1.2.3. Testing

Investigation into any topic is rarely easy work. Whereas pure observation and measurement work well when the object in question is right in front of us, they are, in a sense, passive operations; we do not need to intervene in any way in order to apprehend the object. Often, though, some sort of *testing* is required, an action by which we make the reality of a situation clearer.

Testing in this general sense is quite general and found in many different contexts, and not all of them are based on rational principles. For instance, trial by ordeal—a test meant to prove guilt or innocence by invoking divine intervention on the part of the innocent—is a feature found in many ancient legal systems.[61] Lloyd also adduces an interesting parallel called the 'poison oracle' among the Zande people of modern-day Democratic Republic of Congo in his discussion of tests. Poison is fed to a chicken, and series of yes or no questions are posed; if the

[60] Kuhn 1977, 213–221.
[61] E.g., in the Code of Hammurabi (Pritchard 1969, 166); in the Mosaic Law (*Num.* 5:12–28); in the Indian law code of Manu (Olivelle 2005, 173); in Medieval English common law (Hall 1965, 173).

chicken lives the answer is in the affirmative, if it dies, the negative.[62] A similar prognostic yes-or-no test is also found in Ancient Egyptian medical papyri.[63]

But the trial by ordeal is only one context in which testing procedures are found in traditional cultures; it can also be found in much mythology and literature. Indeed, the heroic quest familiar from many mythologies is a "test" of sorts, whereby the hero tests himself and is able to reveal his heroic nature.[64] We find tests throughout Greek mythological material as well. Achilles, unsure whether the gods had turned against him on the battlefield, tested whether they had done so by attacking the river Scamander head-on.[65] Helen tested the Trojan Horse (unsuccessfully) by calling out to the Argives inside it.[66] And in one of the most famous Homeric displays of intelligence, Penelope tests her husband Odysseus by quizzing him about their marriage bed, reasoning that only her husband would truly know such an intimate detail about their life together.[67]

Even from the admittedly limited series of examples above, one can see that testing is a very general concept found in many different contexts. It certainly plays a part in scientific investigation, but there is a need to differentiate a testing procedure from the more precise testing that is driven by theoretical interest in nature: that is, the scientific experiment.

1.2.4. Experimentation

The practice most crucial to our conception of the scientific method is *experimentation*. As we have already noted, science is necessary because causes are not always apparent. We must

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[62] Lloyd 1979, 222.
[63] See pp. 266–267 below.
[64] Campbell 1968/2004, of course, is the best known treatment of the heroic quest as a test, but is problematic in its over-schematization.
[65] ὁσσάκι δ' ὁρμήσειε ποδάρκης δῖος Ἀχιλλεὺς | στῆναι ἐναντίβιον καὶ γνώμεναι εἴ μιν ἅπαντες | ἀθάνατοι φοβέουσι; "as many times as divine Achilles, swift of foot, set out to stand against [Scamander] and to learn whether all the immortal gods would put him to flight" (*Il.* 21.265–70).
[66] *Od.* 4.274–80.
[67] *Od.* 23.141–204.

practice it, as Francis Bacon put it in rhetorical terms, to "shake out the folds of nature" since the "wonders of nature usually lie off the well-worn roads and beaten tracks."[68] Experiments help us do so in a way that we can control.

So what, then, is an experiment? A broad working definition of an experiment might be the design, execution, and observation of an event in order to understand part of nature. Of course, all humans—and even some animals—carry out experimentation in a weak sense (what we have termed testing above) for a variety of reasons.[69] But in a scientific context, we must contrast experimentation from pure observation on the one hand, and a generalized test on the other.

Experimentation on the above definition is distinct from pure observation: it is a dynamic process rather than observing something already existing in nature. In other words, we do not seek to disrupt nature when we want to observe or measure something—indeed we try to avoid it—whereas in experimentation we intervene in order to create a phenomenon. In fact, our intervention is the source of one of the strengths that experiments offer over simple observation: we can create a much wider range of phenomena than happens or is easily observed "in the wild."[70]

Experimentation also helps us understand nature by allowing us to create events tailored to our epistemic needs. When we observe a phenomenon happening in nature, there are many possibly important circumstances that surround it and no way to separate true causes from correlated or simply coincidental phenomena. But we can design experiments to isolate a phenomenon and to manipulate it by means of changing a single variable. Such scenarios—

[68] Bacon 1620/1900, 384: "Magnalia enim naturae fere extra vias tritas et orbitas notas jacent...vero haec res [i.e., experimentum] est ex optimis, et plane sinus naturae excutit."
[69] Mach 1926/1976, 134–136.
[70] Mill 1843/1974a, 382.

designed to be simple and thus easy to understand—happen infrequently in nature, but are of the utmost importance if we are to gain understanding.[71]

Furthermore, experimentation offers the ability to repeat an observation under the same circumstances. This can bolster an experiment's claim to usefulness as the results from the repeated experiment can be compared to the first. The more similar the results of successive iterations of the same experiment are, the more likely it is that the scientist has lit upon a regularity in nature. We should note, though, that not all experimenters throughout history have repeated their experiments or saw any value in doing so.

These, then, are some of the advantages that experimentation offers over pure observation in scientific practice. But how do scientific experiments differ from simply carrying out a *test*? In short, the scientific experiment differs because it is driven by the desire to prove a theoretical point about nature.[72]

But the relationship between a theory about nature and experiment is one of the most heavily debated questions in the philosophy of science. One of the earliest hypotheses is that of Francis Bacon, who placed experimentation among a taxonomy of observations which included simple observation, aided observation, and measurement. He also believed that experimentation (which he called *instantiae crucis,* often translated as "crucial instances") helps us distinguish between two possible explanations for a single phenomenon by creating a situation where either one theory or the other is confirmed.[73] This idea was taken up by the hypothetico-deductive method as formulated by Popper, who believed that instead of confirming a hypothesis,

[71] Ibid., 382–383.
[72] Cf. Lloyd 1979, 223.
[73] Bacon 1620/1900, 436–451. He does note, however, that *instantiae crucis* are one of the most important parts of his taxonomy of *instantiae* and merits extended treatment (Bacon 1620/1900, 451–452).

experiments merely either falsify one or fail or to do so.[74] On the contrary, other, more empirical thinkers believe that theory does not precede experimentation, but that theory is used as a mental guide in designing experiments and that we should concern ourselves with what is observable.[75] But, given our previous point that there have been many scientific methods adopted across time, we should not be surprised if there are just as many historical positions on the relationship of experimentation to theory. We must uncover them from the sources, not seek to deduce an ideal relationship *a priori* nor apply modern positions to historical material.

1.2.5. Thought Experiments

One concept seemingly related to scientific experimentation is the *thought experiment.* The phrase is a translation of the German *Gedankenexperiment* or *Gedankenversuch*, first used by the eighteenth century Danish chemist Hans Christian Ørsted.[76] But as a strategy, thought experimentation far predates the coining of the term. One can find thought experiments used in both philosophy and science stretching back to their earliest days. Archytas, for instance, sought to prove the boundlessness of the universe in the first thought experiment in the Western tradition.[77]

Thought experimentation has been variously defined, and has recently been the subject of intense philosophical discussion.[78] Some define it very expansively as the use of any hypothetical reasoning.[79] However, this definition does not seem to correspond with common usage. We do not call arguments *ad absurdum*, for instance, thought experiments, but think of

[74] Popper 1959/2002, 88–94.
[75] Van Fraasen 1980, 73.
[76] Ørsted 1811/1998, 296.
[77] The thought experiment (DK47 A24) works as follows: the universe is either boundless or bounded. Consider standing at the edge of the universe. If it is boundless, it is impossible to be at an edge. If it is bounded, what is to stop you from sticking your walking stick outside the edge, and repeating the process *ad infinitum*? Thus, the universe must be boundless. On this thought experiment and its ancient reception cf. Ierodiakonou 2011.
[78] Recent monograph studies include Sorensen 1992; Rescher 2005; and Brown 2011.
[79] E.g., Rescher 2005, 61–72.

precisely imagined scenarios like Schrödinger's Cat.[80] In other words, the imagination plays an important role in thought experiments. Others dispense with rigid definitions and simply use examples of what are uncontroversially thought experiments.[81] Without attempting to prove any single definition beyond all doubt, the definition of Nessarian that thought experiments are "the construction of a dynamical model in the mind by the scientist who imagines a sequence of events and processes and infers outcomes" seems close to a common understanding of the term.[82] For present purposes, we should also differentiate between thought experiments in science (i.e., those which deal with the natural world, but in the scientist's mind) and those in philosophy, which can deal with all sorts of ethical and metaphysical matters as well. The former concern nature and the history of science affords us plenty of cases in which they led to real scientific advancements, including some that were then confirmed by performed experiments.[83]

Scientific thought experiments seem to bear some relation to actual, performed experiments, although the nature of this relation is not entirely clear. The physicist Ernst Mach conceived of a thought experiment as the necessary prerequisite to any performed experiment, saying "[e]very experimenter and inventor must have the planned arrangement in his head before translating it into fact."[84] This sentiment is sometimes called the "mental model" view of thought experiments, in which every performed experiment is accompanied by a corresponding thought experiment in the mind of the experimenter, and seems to be a good fit for our usual intuitions

[80] Perhaps the most famous modern thought experiment, meant to show a puzzling conclusion of the 'Copenhagen' interpretation of quantum mechanics wherein a quantum system remains in two states at once ('superposition') until someone observes it. We need not go into the details here, but the thought experiment concerns a system set into motion by the decay of a radioactive atom and concludes that the cat is paradoxically both alive and dead until someone peeks in the box.
[81] E.g., Brown 2011, 1.
[82] Neressian 1992, 292.
[83] Brown 2011, 1–26
[84] Mach 1926/1976, 136.

about thought experimentation.[85] Of course, the converse does not always hold; we can have recourse to thought experiments precisely because performing an actual experiment would be impossible, unethical, or too difficult. The advantage to thought experimentation in these cases is that we are able to "carry them out" in our heads and clarify our intuitions by thinking through each step as if we were carrying out the experimental process. The disadvantage, of course, is that our "results," such as they are, are not checked by observations of what nature actually does, but rest only on our previous knowledge and deductive abilities. Even so, history shows us that scientific thought experiments can lead to genuine scientific advancements, although not equally across all fields.[86]

One final, but important, consideration in speaking about thought experiments as mental models is that it can be very difficult to distinguish descriptions of actual experiments to those of thought experiments, especially as one moves further back in time and deals with science in literary sources, in which form most science was presented until quite recently. There is debate, for instance, about whether we should consider the famous "Tower of Pisa" experiment of Galileo as a performed experiment or merely as an imagined one.[87] As a rule of thumb, if an experiment would be impossible to carry out—either in general or at the time—any description of that experiment will have to be one of a thought experiment. But past this, we must determine the best answer we can for each instance, based on the information given by the sources and the historical context: if an author describes results which are consistent with those if the experiment were performed and if an experiment could be carried out in the period and cultural milieu under

[85] Brown 2011, 113–116 is a good (albeit critical) overview of this view of thought experimentation.
[86] Brown 2011, 31 notes that physics is especially amenable to thought experiments, biology much less so, and chemistry almost not at all.
[87] Koyré 1960 (Galileo performed only thought experiments); Drake 1978 (Galileo was primarily an experimental physicist without any real philosophical leanings); Brown 2011, 122–123 tends toward the former position. It is notable that Galileo is *not* the first to describe such an experiment, which can be found in the 6th century CE philosopher John Philoponus (*in Phys.* 682–84).

discussion, we are more—but perhaps not completely—justified in considering it a physical rather than a mental experiment.

1.2.6. Analogy

Many of the above concepts are widely recognized as indispensable parts of the modern scientific method. However, we less often hear of *analogy* in modern science; indeed, it has sometimes been criticized as unhelpful in today's scientific method.[88] This is perhaps a bit too pessimistic as analogical reasoning can certainly lead to valid insights if the correct comparisons are made. One need only consider a case like Mendel's experiments establishing the classical laws of inheritance; although the experiments were, in the strictest sense, only concerning pea plants, it was obvious even without further testing that the results could be analogically applied to other plants and animals. And even if a scientific analogy is not completely exact, it can also be valuable in communicating scientific insights to laypersons.

Although the value of analogy to modern science has been questioned, we should also cast our glance backwards for a moment. It is well-known that analogy was one of the most important and productive patterns of thought in the ancient world, and one finds it in many fields including philosophy, medicine, historiography, grammar.[89]

However, defining analogy is notoriously difficult and it is best to proceed by making several distinctions rather than attempting a catch-all definition. First, we should differentiate between a formal analogy and analogy as a pattern of thought. The first is a formal and very specific type of argument, called proportional analogy by Lloyd, which is generally expressed

[88] Lloyd 1966, 175.
[89] [89] E.g., Regenbogen 1930/1961; Lloyd 1966, 172–420; Corcella 1984; Langholf 1989. Much of the following discussion has been informed by Schironi 2018, which concerns the use of analogy by Hellenistic grammarians and contains a clear discussion of their theoretical predecessors.

"A is to B as C is to D."[90] This is often symbolically expressed (A:B::C:D) and can be extended indefinitely to any number of terms so long as they are balanced on each side of the analogy. The important thing here is that such arguments are *explicitly* analogical, use specific linguistic cues,[91] and have (preferably one) explicit commonality between terms on each side of the analogy that binds them together. For instance, in the proportional analogy taken from Aristotle "as old age is to life, so evening is to day," the commonality binding the commensurate terms (old age and evening; life and day) on either side of the analogy together is earliness or lateness.[92] One can create analogies using more similarities, but as a general rule, the more complex the analogy, the more comparisons being made within it, and the less we know about the "known" comparandum, the less helpful the analogy becomes.[93]

Although such structurally rigorous analogies are easy to spot, there are also many instances of looser analogies throughout Greek thought. These often lack the explicit linguistic tagging and formality of the proportional analogy; rather, as noted by Lloyd, these weaker analogies consist of the much more general procedure of apprehending something unknown by comparing it to what is known.[94]

Most importantly, however, for the present investigation is the fact that the same passages in Greek authors have been described by "experiments" by some scholars and merely "analogies" by others. One famous example of this disagreement is the *clepsydra* passage of Empedocles, which has been called both "the first recorded experiment of a modern type" and

[90] Lloyd 1966, 175.
[91] For instance, Plato (*Grg.* 465b7–9) tells us that geometers (οἱ γεωμέτραι) expressed analogical proportions in the form: ὅτι Α πρὸς Β, τοῦτο Γ πρὸς Δ; "what A [is] to B, this C [is] to D."
[92] Arist. *Poet.* 1457b16ff.
[93] Mill 1843/1974a, 688–689.
[94] Lloyd 1966, 175

"not an experiment at all," but an analogical inference.[95] But setting up a complete dichotomy between "experimentation" and "analogy," is actually quite misleading. We should make a final, quite important distinction between *how* authors described experiments and *why* they did so. One can describe something that fulfills all the structural aspects of an experiment, but not do so *in order to* falsify or not falsify a hypothesis—that is, in order to carry out the modern scientific method. Put another way, analogy is often the point of an experimental passage, but, as we shall see, there are many features of these empirical descriptions which are interesting outside their purpose as the "known" portion of an analogy.

1.2.7. From the Scientific Method to Scientific Methods

Although we have not defined *the* scientific method in a rigid way, we have pointed to several interrelated features that are important or necessary to *our* scientific method and that of the ancients. First, observation of nature lies at the base of any form of natural science. Despite a high level of mathematicization in many fields of science, and despite attempts to turn natural science into a branch of mathematics[96], we remain stubbornly reliant on what we can sense in front of us. A specific type of observation—measurement—is also especially important, since it allows for a less subjective description of things and aids with the mathematicization of our view of nature.

Observation also figures into experimentation, but experiments are not just a type of observation. Rather, experimentation requires the purposeful design of a situation and our intervention before we observe or measure the results. These situations are tailor-made for our ease of understanding; thus experimentation itself is more complex an enterprise than

[95] On the passage of Empedocles, see pp. 57–63 with citations. For the former statement, see Burnet 1920, 27; the latter Vlastos 1955.
[96] For instance, Plato's attempt to reduce natural science to mathematics as much as possible in the *Republic* (528b–531c) and *Timaeus* (53d–54d and *passim*).

observation, but the observational component is simpler, since there are fewer complexities to take into account in a well-designed experiment. Finally, it seems that not all experiments are ones that could be or were performed, although every performed experiment may coincide with a model of one in the mind of the scientist. Although we do not often think of imagined experiments as part of science, the history of science shows that they can lead to genuine advancements. So in any description of an experiment, we must also pay attention to the context to see whether we can determine whether the author describes an actually performed experiment or a mental one. But above all, we should note that it is experimentation, broadly construed, that is the aspect most characteristic of science today. Measurement and observation are often used for everyday purposes whereas thought experimentation is just as much part of philosophy as it is of science. The design of controlled experiments, however, while not impossible outside natural science, is perhaps its most salient characteristic.

1.3. Greek Categories for Natural Science

Now that we have sketched out some features of the modern understanding of science and the scientific method, we must look backward to ancient categories of thought. To do so accurately, one must pay attention to the intellectual shifts *within* Greek history as well, since speaking about "Greek natural philosophy"—a designation which covers a thousand years from Thales in the sixth century BCE to, say, the Aristotelian commentators in the sixth century CE—is bound to be too simplistic. But, in the earliest period, there were two families of terms that the Greeks used for the study of nature. One conception is that of "natural philosophy," where the study of nature is thought of as part of the broader intellectual endeavor of *philosophia*. Even though there were many early, pre-Platonic natural philosophers practicing philosophy in our (or even a later ancient) sense, they themselves did not have the concept of *philosophia*, much less that they

were practicing a subset of *philosophia* concerning the natural world. Thus, there was another, earlier, conception often called inquiry or *historia*, which was not tightly tied to any single genre like the philosophical treatise. Rather we find its ideas expressed among those who we call philosophers, doctors, historians, and others.

1.3.1. Inquiry into Nature (ἱστορία περὶ φύσεως)

Before the advent of natural philosophy *qua* philosophy, the watch-word for investigation into nature was *inquiry* or ἱστορία. The word itself derives from the agental noun ἵστωρ—which in turn derives from οἶδα, and hence from the very productive Indo-European root *–*u̯(e)id*, alternately signifying seeing and knowing, and the agental suffix *– *tôr*.[97] The ἵστωρ appears in Homer twice in connection with observing or judging, but his exact role is unclear. In the ecphrasis of the shield of Achilles, he is either a witness or a judge for a case of homicide.[98] The second attestation does not clarify matters much either: Agamemnon acts as ἵστωρ for a chariot race, and again either the meaning "witness" or "judge" could work here.[99] The important point, however, is that from Homer onward we find a great deal of semantic overlap among notions of observing, knowledge, and authority derived from that knowledge.[100] In some later sources, the

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[97] Chantraine 1968, 779. The semantic jump from "seeing," "looking," or "watching" to "knowing" must have happened very early as it is a feature of a wide variety of Indo-European languages: Skt. √*vid* 1 "to know" and √*vid* 3 "to find, look out for;" O.E. *wīs* "wise," *witan* 'to know' and *wītan* "to guard, to look after;" OIr. *dr-uí* "druid" (one with religious knowledge, cf. Skt. *veda*)' and *find* "white, shining, visible" (from Celtic *vindo-*); OCS *viděti* "to see" and *věděti* "to know." That is not to say, however, that the connection between vision and thought is peculiarly Indo-European; there is some evidence that it exists in Polynesian and Australian languages as well (Viberg 1983, 157–158).

[98] *Il.* 18.501: ἄμφω δ' ἱέσθην ἐπὶ ἵστορι πεῖραρ ἑλέσθαι; "both [sc. parties] were standing in front of a *histôr* to choose an ending [sc. of the case, i.e., the judgment]." The D Scholia on this passage glosses the ἵστορι as either μάρτυρι ἢ κριτῇ, showing that the confusion already existed in antiquity. Edwards 1991, 216–17 doubts that meaning "witness" works for the trial scene; however it is possible that ἐπὶ ἵστορι could mean "to place the result of the proceedings in the hands of a witness" because the witness' testimony will inform the judgment of the γέροντες presiding over the trial.

[99] *Il.* 23.486.

[100] Snell 1924, 51–73, von Fritz 1945, and Snell 1960, 137 claim, partially on this etymological basis, that knowledge for Homer was sensory. Lesher 2009 has softened this "almost orthodox" position, but still affirms the connection between the two semantic fields in early Greek thought.

(ϝ)ἵστωρ is a witness (either human or divine),[101] whereas in others he is simply one who is knowledgeable.[102]

In the fifth- and fourth centuries, the agent noun was combined with the –ια suffix denoting abstraction and applied it to a wide variety of subjects, including natural philosophy, medicine, geography, ethnography, and history (in the modern sense).[103] We first find the term in Heraclitus, who castigates Pythagoras for practicing ἱστορίη (inquiry) and πολυμαθίη (polymathy, accumulating factual knowledge without understanding);[104] elsewhere he groups a Xenophanes (a poet-philosopher), Hesiod (an epic poet with a strong interest in the natural world), and Hecataeus (a geographer and historian) with Pythagoras as mere purveyors of πολυμαθίη, which hints at the amorphous boundaries of these two terms in both subject matter and genre.[105]

The polyvalent nature of ἱστορία can also be found in later fifth and fourth-century sources. The *locus classicus* for the use of ἱστορία to refer to natural philosophy is Plato's *Phaedo* where Socrates states that as a young man he "desired that wisdom which they call inquiry into nature (ἱστορίαν περὶ φύσεως); for it seemed a magnificent thing to know the causes of each thing, why each thing came to be, why it passed away, and why it is."[106] Euripides also refers to a saying of Anaxagoras in a verse that proclaims that "blessed is he who has

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[101] E.g., *SEG* 21.629, Pol. *Onom.* 8.106. Hp. *Jusj.* 2 calls upon the gods as ἵστορας for the Oath.
[102] Hes. *WD* 792: ἵστορα φῶτα; *h.Hom*. 32.2: κοῦραι Κρονίδεω Διὸς ἵστορες ᾠδῆς; B. *Epin*. 9.43–4: ἐ]γχέων / ἵστορες κοῦραι διωξίπποι' Ἄρηος.
[103] Brunschwig and Lloyd 2000, 223–224. Thomas 2000, 161–167 offers a comprehensive bibliography on the term, focusing, however, on the connection between Herodotus' *Histories* and ἱστορία.
[104] DK22 B129. The exact meaning of ἱστορίη in this fragment is disputed since it is from a contemporary and thus is one of our only clues to the "Pythagorean Question," i.e., what did the historical Pythagoras actually believe. Cf. Burkert 1972, 210 and Huffman 2008.
[105] DK22 B40. Cf. Granger 2004
[106] Pl. *Phd.* 96a6–10.

learning from inquiry...observing the ageless order of immortal nature."[107] We also find "inquiry" among the remains of natural philosophers of the same time period; Democritus, for example, was reported to have written a Περὶ ἱστορίας, suggesting that it was a well-defined enough concept to merit its own treatise.[108]

Writers on medicine, which ancient sources quite naturally connected with natural philosophy, also used the term.[109] The fifth-century author of *On Ancient Medicine* defines the study of human nature as a ἱστορίη, which aims at answering what a human being is and for what reasons it comes to be.[110] The treatise *On the Art*, another late-fifth century work, uses the term contemptuously, as did Heraclitus, when its author castigates those who do not attempt to discover anything new, but merely make a "show of their own ἱστορίη [i.e., the results of others]."[111] Finally, the author of the combined work *On Generation* and *On the Nature of the Child* uses the related term ἱστόριον to refer to observational evidence supporting a previously stated general point.[112] The diminutive suggests that the author of these works considered it a constitutive part of the overall ἱστορίη, a building block from which the entire investigation was created.

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[107] ὄλβιος ὅστις τῆς ἱστορίας ἔσχε μάθησιν / μήτε πολιτῶν ἐπὶ πημοσύνην / μήτ' εἰς ἀδίκους πράξεις ὁρμῶν, / ἀλλ' ἀθανάτου καθορῶν φύσεως / κόσμον ἀγήρων, πῇ τε συνέστη / καὶ ὅπῃ καὶ ὅπως; "blessed is he who has understanding of investigation neither aiming at hostility towards his fellow citizens, nor toward unjust acts, but observing the unageing order of immortal nature, whence it came together, and where and how." Diels (DK59 A30) added these lines next to his teacher Anaxagoras' apothegm that life is worth living in order to θεωρῆσαι τὸν οὐρανὸν καὶ τὴν περὶ τὸν ὅλον κόσμον. The phrase ἀθανάτου...φύσεως ...κόσμον ἀγήρων might also recall Anaximander description of τὸ ἄπειρον as ἀίδιον...καὶ ἀγήρω (DK12 B2), thus harkening back to the very earliest roots of Ionian natural philosophy.

[108] D.L. 9.49.

[109] Cf. Arist. *Resp*. 408b23–26; *Sens*. 436a19–b1.

[110] λέγω δὲ τὴν ἱστορίην ταύτην εἰδέναι ἄνθρωπος τί ἐστι, καὶ δι' οἵας αἰτίας γίνεται, καὶ τἆλλα ἀκριβέως; "I speak of this investigation to know what a human is, and by what cause he comes to be, and other things accurately" (*VM* 20.11–3).

[111] Εἰσί τινες οἳ τέχνην πεποίηνται τὸ τὰς τέχνας αἰσχροεπεῖν... ἀλλ' ἱστορίης οἰκείης ἐπίδειξιν ποιεύμενοι; "There are some who have made an art out of casting aspersion on the arts…but making a display of their own investigation" (*de Arte* 1.1–3).

[112] *Genit.* 1, 8; *Nat. Puer.* 13, 18, 29, 30, 31. The author of *On Diseases* IV often uses the term in the same way too at chapters 54 and 56, which may point to shared authorship (cf. Lonie 1981, 43–50). Also cf. chapter 3, section 3.

Lastly, and most famously, Herodotus begins his historical work by describing it as a ἱστορίης ἀπόδεξις.[113] As noted by Thomas, the difference between history in the modern sense and ἱστορίη in Herodotus is well-known and almost goes without saying, yet always bears repeating to guard against assimilating Herodotus to our understanding of history.[114] Alongside the characters and deeds that constitute his narrative of the Persian Wars, Herodotus' ἱστορίη includes a great deal of information about natural phenomena in specific places (i.e., geography). Even though his interest in nature is localized in this way, he is not altogether outside the mainstream of natural philosophy in this regard. Particularly important natural features—especially the Nile—were part of the usual subject matter of natural philosophy dating all the way back to Thales.[115]

Thus, in the fifth- and fourth centuries we can see ἱστορία connected with various genres concerned with the natural world and human beings as a part of that world. However with the rise of "philosophy" in Plato and others, ἱστορία started to become "history" in our more anthropocentric sense. Aristotle, for instance, famously disputes that Herodotus could have been a poet if only he had composed verse and states that "poetry is more philosophical and more serious a thing than history; for poetry speaks more of the universal, while history of the particular."[116] Although Aristotle's statement could be true concerning the more expansive, Herodotean form of ἱστορία which contained geography, natural history, and ethnography—since they too can deal with particulars (e.g., the Nile rather than rivers; Scythian customs rather than human behavior)—he further defines the universal and particular in terms of "saying and

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[113] Cf. ἱστορίης...ἐπίδειξιν in the opening lines of *De Arte* quoted above in note 110.
[114] Thomas 2000, 9.
[115] DK11 A16.
[116] εἴη γὰρ ἂν τὰ Ἡροδότου εἰς μέτρα τεθῆναι καὶ οὐδὲν ἧττον ἂν εἴη ἱστορία τις μετὰ μέτρου ἢ ἄνευ μέτρων: ἀλλὰ τούτῳ διαφέρει, τῷ τὸν μὲν τὰ γενόμενα λέγειν, τὸν δὲ οἷα ἂν γένοιτο. διὸ καὶ φιλοσοφώτερον καὶ σπουδαιότερον ποίησις ἱστορίας ἐστίν: ἡ μὲν γὰρ ποίησις μᾶλλον τὰ καθόλου, ἡ δ᾽ ἱστορία τὰ καθ᾽ ἕκαστον λέγει; (*Poet.* 1451b).

doing," understandably given the topic of the *Poetics.* The Herodotean streak of expansive historiography never fully dies out in the classical world, but the interconnection among the genres making up ἱστορία surveyed above breaks down as disciplinary boundaries were drawn and intellectual domains were claimed.

1.3.2. Natural Philosophy (φιλοσοφία φυσική or ἡ φυσική)

Yet the study of nature did not continue to be thought of as generalized inquiry, able to be practiced by thinkers with wide array of interests. Rather, it fairly quickly became a subset of *philosophia*, a new word coined for the intellectual endeavor of understanding humanity and nature in fifth and fourth-century Athens. Certainly by the Hellenistic period, it had become commonplace to divide philosophy into three parts, of which natural philosophy was one. Sextus Empiricus relates that Xenocrates was the first to formulate the division explicitly, which was then adopted the Peripatetics and the Stoics.[117] Sextus also states that Plato referred to tripartition "implicitly" (δυνάμει), but only by treating all three subjects philosophically, not by making a methodological point.

But the most important philosopher who claimed the study of the natural world as an explicit part of philosophy was Aristotle, who did more than any other thinker to set disciplinary boundaries in the ancient world. He too divided the propositions and problems of philosophy into the familiar three categories of logical, ethical, and natural.[118] Thus, "natural philosophy" (ἡ φυσικὴ φιλοσοφία or simply ἡ φυσική)—a phrase we meet for the first time in Aristotle—was a specific subset of philosophy. Aristotle was also instrumental in defining the role of the φυσικός or natural philosopher, a concept which predates him, but of which he made extensive use.[119] He

[117] S. E. *M.* 7.16 = Xenocrates fr. 82 Isnardi-Parente. Cf. Sen. *Ep.* 89.9.
[118] Arist. *Top.* 105b19–21.
[119] The first use of φυσικός to refer to a person, and perhaps the first of the adjective altogether (depending on the vexed question of dating the treatises of the Hippocratic Corpus) is [Hp.] *Sterilit.* viii. 444,1 Littré πειρῶ δὲ φυσικὸς

often referred to them in the plural (φυσικοί or φυσιολόγοι), and believed that they represented the first period of philosophy ending with Socrates.[120] Following Aristotle, the *topos* that before Socrates all philosophy was natural philosophy spread to Theophrastus, and thence to the doxographical tradition[121] and the classical world at large.[122] Of course, there is some truth to this commonplace: although they disagreed about much else, both Plato and Xenophon claim that Socrates' disavowal of knowledge was in large part a disavowal of knowledge about nature and natural phenomena.[123]

But considering the Presocratic investigation into the natural world using later ancient criteria has proven problematic. It has long been known that Aristotle is not a "historian" of philosophy in the usual sense, but is interested in earlier thinkers insofar as they approximate his own system of thought, which leads to distortions in his reporting of predecessors.[124] Moreover, the very idea of the philosopher in a technical sense postdates many of the Presocratics. The term φιλοσοφία was (possibly) coined by Pythagoras,[125] and related terms like φιλόσοφος and φιλοσοφεῖν were only used beginning in the fifth century BCE, but then only sparingly by fifth-

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εἶναι, πρὸς τῆς ἀνθρώπου τὴν ἕξιν καὶ τὴν ἰσχὺν ὁρέων; "I shall attempt to be a *physikos*, taking into account the condition and strength of the human female" (I thank Richard Janko for pointing out the usage to me).

[120] Arist. *Met*. 987b1–2, 1078b17–21; *Part. Anim*. 642a28–30.

[121] E.g., [Galen] *Hist. philos*. 1.1 (Diels 1879, 597–8).

[122] S.E. *M.* 8.8; D.L. 2.5.20–1; Sen. *Ep*. 71.7, Cic. *Rep*. 1.10.15. Cicero expresses it in a characteristically memorable turn of phrase at *Tusc*. 5.4.10: *Socrates autem primus philosophiam devocavit e caelo* (obviously alluded to by Bacon 1620/1900, 286: *Socrates philosophiam de coelo in terras deduxisset*).

[123] Pl. *Apol*. 18b, 19c, 23d; X. *Mem*. 1.1.11, 4.7.1–8.

[124] Cherniss 1935 is the classic exploration of this matter, although it is perhaps a bit too pessimistic on Aristotle's value as a source for earlier thinkers. More recent treatments can be found in Guthrie 1957, Stevenson 1974, and Collobert 2002.

[125] E.g., D.L. 1.12; Cic. *Tusc.* 5.8–9; Heraclides of Pontus is the ultimate source (fr. 84 Wehrli). The term seems to have been created to imply the limitations of human knowledge—one cannot hope to be truly σόφος, so one has to settle for being a "lover of σοφία." D.L. states that Pythagoras coined it because "only God is wise." Most scholars consider the attribution to Pythagoras erroneous and anachronistic as it presupposes the Platonic theme that only God is wise (e.g., Burkert 1960 and 1972, 65; Kahn 2001, 68). However, given early musings on the limitation of human knowledge compared with the divine (e.g., Xenophanes DK21 B18; Heraclitus DK22 B78; cf. Snell 1960, 136–152), I do wonder whether the coinage is possibly pre-Platonic "Pythagorean," if not from Pythagoras himself.

century authors.[126] It is only in the early fourth century onward that we see an explosion of debate over φιλοσοφία and how to define it, whether on the Platonic model or as general intellectual cultivation, as argued for by Isocrates (and to a lesser extent by Xenophon).[127] Yet it is precisely the pre-Platonic era in the late sixth- and fifth centuries that is the period dominated by natural philosophers, according to our view harkening back to Aristotle. Without going so far as to deny that philosophy could exist without a corresponding term in the sources, we are justified in using the contemporary description of *historia* for the Presocratic intellectual project in order to guide our investigation into the earliest phase of ancient science, casting our net across genres.

1.4. Inquiry, Science, and Experimentation

Having explored aspects of both our categories for natural science and those in the ancient world, we finally can begin to investigate whether the two are analogues, and if so, how. Of course, doing so in an exhaustive fashion would be a giant undertaking, and so we must break the question into constituent parts in order to achieve the level of detail necessary for a satisfactory answer.

First, I intend to restrict the chronological scope of the material to the broadly Presocratic period of *historia* before natural philosophers saw themselves as philosophers. This period is especially interesting because *historia* is, like our idea of science, a methodological category as much as it is one of subject matter. Furthermore, by focusing on this more open period of Greek intellectual history, we can approach the subject via a number of different genres, and thereby reduce the chance of relying too heavily on the viewpoint of a single ancient author or genre.

[126] Hdt. 1.30.11; Thuc. 2.40.1; Gorgias DK82 11.13; *Dissoi Logoi* 1.1 and 1.9. There are several other, less clearly attributable, citations, including Heraclitus DK22 B35 which would count as the first extant use of φιλόσοφος if genuine.

[127] Cf. Zeller and Mondolfo 1932, 1–9 for an overview of ancient material, and Nightingale 1995, 13–21 for an up-to-date overview of scholarship as well as discussion about the formation of "philosophy."

Second, I also intend to focus on a specific aspect of the various aspects of the scientific method sketched out in section 1.2. More specifically, I intend to focus on experimentation—both performed and thought—in the context of natural investigation, since experimentation is perhaps the aspect most characteristic of modern science. Of course, we will undoubtedly find much to say about other scientific practices, like observation, as well as about theory since experimentation does not take place in a theoretical vacuum.

Within these parameters, I hope to show that *historia* presents an interesting analogue to science today, and a closer one than has previously been thought. All the genres connected to the movement of *historia* utilized an empirical method that made use of observational evidence coming from specifically designed and theoretically informed situations, which we can term experiments in the broadest sense. These "experiments" bore their own relationship to the science of the time, just as all historical periods show different methodological relationships between observation, experimentation, and theory. In particular, the epistemology broadly shared across early Greek thinkers allowed sense-data to be used initially in investigation. Finally, we can also show that *historia* is not only a "spiritual" forerunner of science today, but is also its precursor in a more exact historical sense as later thinkers, including those of the "Scientific Revolution," adopted and performed experiments from these early ancient sources. So, although we cannot give a simple affirmative or negative answer to the question "did early Greek scientists experiment," we can begin to understand the complex relationship between the ancient and modern investigation of the natural world.

CHAPTER TWO: REASON AND THE SENSES IN EARLY NATURAL PHILOSOPHY

2.1. Introduction

The Presocratic philosophers are a heterogeneous collection of thinkers—poets and prose writers, religious thinkers and skeptics, close observers and *a priori* thinkers—conventionally grouped together since antiquity, even though they vary widely in their interests and methods. Despite their differences, however, there are some commonalities which bind them together other than coming before Socrates.[1] One of these commonalities is an interest in the workings of the natural world; indeed, one of the great innovations of the Presocratic period is the conceptualization of "nature" as a whole, governed by constant rules and not by supernatural whim.[2]

This has traditionally been enough for scholars to argue that these early natural philosophers were the first scientists. But, as noted previously, science is not simply the study of nature, but also has a methodological component that is historically contingent. So we must first ask how these thinkers went about studying nature and their methodology for doing so. Here I will argue that the Presocratic philosophers not only used observation, but also were the first to

[1] Democritus, for instance, is contemporary with Socrates. The question of *exact* chronological priority, however, is not a pressing one. Kranz noted this in the preface to the fifth edition of *Die Fragmente der Vorsokratiker* when he noted that the unity of these thinkers truly stems from their practicing "eine Philosophie...die nicht durch die Gedankenschule des Socrates (und des Platons) gegangen ist" (DK, viii). I also restrict my usage of "Presocratic philosophy" here to exclude sophists who, although Presocratic in the strictly chronological sense, belong to another intellectual category. I omit discussion of Pythagoreans like Philolaus—somewhat artificially to be sure—until chapter 4; they too investigated nature philosophically, but on the question of experimentation are better placed in the context of early music and mathematics.

[2] Cf. Naddaf 2005 for the evolution of φύσις until Plato's time. φύσις does not seem to mean "nature" in Homer, although at *Od.* 10.303, Hermes shows Odysseus the φύσιν of the μῶλυ plant, which illustrates the changing semantic field from "growth" into "nature" (cf. *LfgrE* s.v. which states "meaning uncertain.")

conceive of experiments in the sense outlined in the introductory chapter. They did so because they were reacting to a long-standing tradition of doubt concerning the reliability of sense perception, but they had a qualified optimism when it came to more sophisticated use of the senses. Once they began to argue by describing experiments, it spread to other, more specialized, practitioners of *historia*.

2.2 The Debate over Knowledge and the Use of the Senses

Ancient philosophers, quite obviously, did not have the modern scientific method in mind when they sought to explain the natural world. But as we will see, they did point to observations of empirical interventions—the core of the modern experiment—as evidence for their views. Why is this the case? Part of the answer is that they had a view of knowledge where the senses had *some* role to play in the establishment of truth. If they had been totally confident in how the world appeared to them, there would have been no need for a proactive method of investigation. But if they had been entirely pessimistic, any empirical investigation would have been useless. In this, as in much else, the Greeks hewed to the middle path.

In his 1979 work, *Magic, Reason and Experience*, Lloyd surveys empirical research from the earliest Presocratic thinkers to the Hellenistic period. In particular, he rightly singles out an epistemological debate among early thinkers concerning the senses, noting that different thinkers valued sense data to different degrees, and, in short, that no orthodoxy emerged in the Presocratic period.[3] Nevertheless, Lloyd does not find that the Presocratic engagement with empirical evidence very compelling, especially when compared with medical writers and later (i.e., Hellenistic) scientists. While it is certainly true that there was a great deal of debate among Presocratics and that no doctrine in that fractious period rises to the level of orthodoxy, if we

[3] Lloyd 1979, 129–138. Cf. Brunschwig and Lloyd 2000, 220–227, which draws upon Lloyd's original 1979 discussion.

briefly look at the various Presocratic opinions on the reliability of the senses we shall see that there is a bit more room for empirical engagement than Lloyd originally allowed.

To begin, from the earliest philosophers up to the atomists, we do find the theme of imperfect human understanding and the untrustworthiness of appearances. For instance, a later doxographical report in Stobaeus identifies many Presocratic philosophers as skeptics when it comes to sense-perception.[4] But as with all doxographical evidence, a great deal of nuance has been lost, and so we must look to the surviving fragments for the most accurate impression.

Luckily, when it comes to epistemology and the senses, we have more evidence of Presocratic speculation than we do for many other fields. Above all this is due to a single work—the *De Sensibus* of Theophrastus, which has reached us via a direct manuscript tradition.[5] The historical importance of Theophrastus' treatise on his predecessors' opinions concerning the five senses can hardly be overstated, since he gives a detailed account of the *endoxa* concerning sensation up to and including Plato.[6] But we must also keep in mind that Theophrastus—just like his predecessor Aristotle—is not so much trying to present these thinkers in their historical context, as explain them through the lens of Peripatetic philosophy.[7] Thus, when possible, we must first rely on the Presocratics' *ipsissima verba* to build our interpretations.

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[4] Πυθαγόρας Ἐμπεδοκλῆς Ξενοφάνης Παρμενίδης Ζήνων Μέλισσος Ἀναξαγόρας Δημόκριτος Μητρόδωρος Πρωταγόρας Πλάτων ψευδεῖς εἶναι τὰς αἰσθήσεις; "Pythagoras, Empedocles, Xenophanes, Parmenides, Zeno, Melissus, Anaxagoras, Democritus, Metrodorus, Protagoras, [and] Plato [claim] that the senses are deceiving" (Stob. *Ecl*. 1.50.1 = Aët. 4.9.1). Cf. Aristocl. *ap.* Eus. *P.E.* 14.17.1 (=F7 Chiesara), which names only Xenophanes and the Eleatics. ψευδής here must mean not "untrue" or "false"—for the doxography is speaking not of thoughts or statements—but "deceiving," i.e., a source of untruths.

[5] On which cf. Diels 1879, 497–498 and McDiarmid 1962.

[6] The bibliography on Theophrastus and the evidence contained in *De Sensibus* is rather large, but mainly focuses on *how* various thinkers conceived of the senses, rather than their reliability. Beare 1906 treats all five senses (as well as sensation in general) is still useful in some respects. On Alcmaeon, cf. Andriopoulos 2014; on Empedocles, cf. Ierodiakonou 2005 and Kamtekar 2009; and on Democritus, cf. von Fritz 1953, Baldes 1975, and Rudolph 2011. On Theophrastus' account in *De Sensibus* as a whole, see Baltussen 2000.

[7] Cf. McDiarmid 1953, which follows up on Cherniss 1935, a very critical, but fundamental account of Aristotle's trustworthiness as a historian of philosophy.

The earliest natural philosophers—Thales, Anaximander, and Anaximenes—may have dealt with epistemology, since their basic supposition—that the supposed multiplicity of the natural world is actually reducible in some way to a single thing—flies in the face of what we see every day. However, later authors relate nothing about their epistemology or their attitude about the senses, if indeed they said anything at all on these subjects. With such a lack of evidence, then, we must move on to their successors.

Xenophanes, however, is better preserved, and certainly did treat epistemology in several famous fragments.

> οὔτοι ἀπ' ἀρχῆς πάντα θεοὶ θνητοῖσ' ὑπέδειξαν,
> ἀλλὰ χρόνωι ζητοῦντες ἐφευρίσκουσιν ἄμεινον[8]

> The gods have not indicated all things to mortals from the beginning | but, in time, by seeking, they discover better.

> καὶ τὸ μὲν οὖν σαφὲς οὔτις ἀνὴρ ἴδεν οὐδέ τις ἔσται
> εἰδὼς ἀμφὶ θεῶν τε καὶ ἅσσα λέγω περὶ πάντων·
> εἰ γὰρ καὶ τὰ μάλιστα τύχοι τετελεσμένον εἰπών,
> αὐτὸς ὅμως οὐκ οἶδε· δόκος δ' ἐπὶ πᾶσι τέτυκται.[9]

> What is clear, no man has seen, nor will there be anyone | who knows about the gods and what I say about all things; | for if he happened to speak about most things perfectly, | he nevertheless does not know; but belief is set upon all men.

> ταῦτα δεδοξάσθω μὲν ἐοικότα τοῖς ἐτύμοισι[10]

> Let these [teachings] be believed to be like the truth...[11]

> ὁππόσα δὴ θνητοῖσι πεφήνασιν εἰσοράασθαι[12]

> However many things they [i.e., the gods] have revealed for mortals to look upon...

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[8] DK21 B17.
[9] DK21 B34.
[10] DK21 B35.
[11] The translation is that of Bryan 2012, 55–57, after her careful philological study of the fragment. For ἐτύμοισι as "truth" or "true things," rather than "real," cf. Bryan 2012, 25–27 (*contra* Lesher 1992, 171).
[12] DK21 B36. Given the implied contrast with θνητοῖσι, the subject must be understood as οἱ θεοί.

The original order of these fragments in Xenophanes' work is uncertain,[13] and their interpretation debated,[14] but they obviously speak to similar topics and thus a few limited conclusions may be drawn for our purposes. First, just as in epic, we see the dichotomy between divine and human knowledge. Xenophanes believes that the gods have "indicated" and "revealed" certain things to mortals, i.e., that mortals are reliant on the divine for certain knowledge. But in the absence of completely reliable knowledge, humans can and do progress in how much they know by actively seeking out (ζητοῦντες) better understanding, even if it will always be at the level of belief (δόκος). The object of this investigation in this fragment is left open-ended, but in other fragments, Xenophanes deals with a range of natural phenomena like the sea, winds, and rainbows,[15] which flesh out his contention that he speaks περὶ πάντων—that is, he is working directly within the natural philosophical tradition inaugurated by the Milesians. Thus, he represents a bridge between the world of the epic poet and that of the Milesians who directly preceded him. Indeed, perhaps it is *because* he was working within two, somewhat incompatible, traditions that led him to think more carefully and explicitly about what, exactly, humans can know.

This emphasis on active investigation is also mirrored in the fragments of Heraclitus, albeit with many of the tensions that are characteristic of his riddling style. Although he condemns the mere accumulation of facts by means of investigation, which he refers to as mere

[13] Cf. Bryan 2012, 7–8.
[14] Ancient skeptics claimed Xenophanes as one of their own (cf. S.E. *M.* 7.49). Modern scholars usually reject this interpretation, and there have been many attempts at interpreting these fragments. Lesher 1992, 161–167 goes over the main approaches, including, tellingly, seeing Xenophanes both as an empiricist and a rationalist. The *communis opinio* is probably the "fallabilist" position (i.e., that Xenophanes believes that humans can approximate the truth in their beliefs, but, unlike the divine, cannot know the entire truth perfectly); cf. Lesher 1992, 164 and a compelling and recent statement in Bryan 2012, 5–57.
[15] E.g., DK21 B30; 32.

polymathy,[16] he also states in his characteristically riddling style that "men who love wisdom must be inquirers into very many things."[17]

We also see the parallel optimism and pessimism when it comes to the senses. On the one hand, Heraclitus states that "of which things there is seeing, hearing, learning, these I prefer," suggesting that he values what we can directly experience.[18] One case of his apparently empirical mindset, notable for its extreme empiricism, is his assertion that the sun is "in breadth the size of a human foot," that is, exactly the size it appears to us on earth.[19]

On the other hand, however, direct sensory experience is not sufficient, since many people will fall short of knowledge even when they see or hear something directly.[20] Presumably this is due to the fact that the reality of things is not something immediately apparent or, as Heraclitus puts it much more pithily, "nature tends to hide."[21] Or, as in the case with the width of the sun, nature can give us hints, but these are easily missed or misinterpreted without a sound theoretical guide like the *logos* of Heraclitus. As argued by Sider, such a seemingly paradoxical assertion, but one consonant with sensory experience, challenges readers to use their reason, not

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[16] πολυμαθίη νόον ἔχειν οὐ διδάσκει· Ἡσίοδον γὰρ ἂν ἐδίδαξε καὶ Πυθαγόρην αὖτίς τε Ξενοφάνεά τε καὶ Ἑκαταῖον; "polymathy does not teach one to have understanding; for it would have taught Hesiod and Pythagoras, and again Xenophanes and Hecataeus" (DK22 B40). Cf. Granger 2004 on Heraclitus and his attitude toward polymathy and *historia* in general.

[17] χρὴ γὰρ εὖ μάλα πολλῶν ἵστορας φιλοσόφους ἄνδρας εἶναι καθ' Ἡράκλειτον (DK22 B35). It seems plausible that this fragment more or less preserves Heraclitus' wording, since he uses the phrase φιλοσόφους ἄνδρας instead of the more usual and later φιλοσόφους. Thus, we should translate the compound literally, so as not to anachronistically foist the notion of the "philosopher" onto the fragment.

[18] ὅσων ὄψις ἀκοὴ μάθησις, ταῦτα ἐγὼ προτιμέω (DK22 B55). DK22 B101a (ὀφθαλμοὶ τῶν ὤτων ἀκριβέστεροι μάρτυρες) is sometimes also adduced as evidence that Heraclitus considered the eyes to be a more reliable tool for gaining knowledge. But as Kahn 1981, 106 notes, probably correctly, it is proverbial and "expresses not so much an epistemic ranking of the senses as the reliance on direct experience rather than upon hearsay."

[19] περὶ μεγέθους ἡλίου…[sc. Heraclitus says] <u>εὖρος ποδὸς ἀνθρωπείου</u> (DK22 B3).

[20] DK22 B107 says κακοὶ μάρτυρες ἀνθρώποισιν ὀφθαλμοὶ καὶ ὦτα βαρβάρους ψυχὰς ἐχόντων (cf. DK22 B56: ἐξηπάτηνται…οἱ ἄνθρωποι πρὸς τὴν γνῶσιν τῶν φανερῶν…; "humans are fooled regarding their knowledge of what is apparent…"). "Barbarian" here is, of course, pejorative, but also has something of its original linguistic meaning (i.e., non-Greek-speaking): just as barbarians can hear the sounds of Greek and do not understand them, so too can "the many" use their senses and not draw the correct conclusions (especially when they hear Heraclitus!).

[21] DK22 B35: φύσις κρύπτεσθαι φιλεῖ. For φιλέω as "be accustomed to, tend to" rather than "love to," cf. Graham 2003a.

just take sense-data at face value.[22] Yet we should also not that this is by no means a rejection of the senses either, simply an enjoinder to use them rationally.

The qualified acceptance of the senses as found in these earlier thinkers did not go unchallenged, however. Most scholars identify Parmenides as a turning point in the development of Presocratic natural philosophy due to his radical criticism of the earlier project of natural philosophy, and his opinion on inquiry using the senses is no exception.[23] Unlike his predecessors, Parmenides argued that all multiplicity is illusory and our senses completely mislead us as to this truth. Indeed, Parmenides seems to think not merely that the senses are untrustworthy, but, more radically, that the objects of sense perception are themselves unreal. This conclusion was made more explicit by his student Melissus who also clearly rejects the use of senses as well as the phenomenal world itself:

> εἰ γὰρ ἔστι γῆ καὶ ὕδωρ καὶ ἀὴρ καὶ πῦρ καὶ σίδηρος καὶ χρυσός, καὶ τὸ μὲν ζῶον τὸ δὲ τεθνηκός, καὶ μέλαν καὶ λευκὸν καὶ τὰ ἄλλα ... καὶ ἡμεῖς ὀρθῶς ὁρῶμεν καὶ ἀκούομεν, εἶναι χρὴ ἕκαστον τοιοῦτον, οἷόν περ τὸ πρῶτον ἔδοξεν ἡμῖν, καὶ μὴ μεταπίπτειν μηδὲ γίνεσθαι ἑτεροῖον, ἀλλὰ ἀεὶ εἶναι ἕκαστον, οἷόν πέρ ἐστιν. νῦν δέ φαμεν ὀρθῶς ὁρᾶν καὶ ἀκούειν καὶ συνιέναι· δοκεῖ δὲ ἡμῖν τό τε θερμὸν ψυχρὸν γίνεσθαι καὶ τὸ ψυχρὸν θερμὸν καὶ τὸ σκληρὸν μαλθακὸν καὶ τὸ μαλθακὸν σκληρὸν καὶ τὸ ζῶον ἀποθνήισκειν καὶ ἐκ μὴ ζῶντος γίνεσθαι, καὶ ταῦτα πάντα ἑτεροιοῦσθα ... ὥστε συμβαίνει μήτε ὁρᾶν μήτε τὰ ὄντα γινώσκειν. οὐ τοίνυν ταῦτα ἀλλήλοις ὁμολογεῖ. φαμένοις γὰρ εἶναι πολλὰ καὶ ἀίδια καὶ εἴδη τε καὶ ἰσχὺν ἔχοντα, πάντα ἑτεροιοῦσθαι ἡμῖν δοκεῖ καὶ μεταπίπτειν ἐκ τοῦ ἑκάστοτε ὁρωμένου. δῆλον τοίνυν, ὅτι οὐκ ὀρθῶς ἑωρῶμεν οὐδὲ ἐκεῖνα πολλὰ ὀρθῶς δοκεῖ εἶναι.[24]
>
> If there is earth and water, air and fire, iron and gold, the living and the dead, black and white, and the rest ... and we see and hear correctly, each thing should be as it first seemed to us, and not change nor become different, but always be as it is. As it is, we say that we see and hear and understand correctly. But it seems that warm becomes cold, and cold warm; hard becomes soft, and soft hard; the living dies and is born from not living; and all these things change ... and so it comes about that we neither see nor understand that which is. Therefore these things do not agree with one another. Although we say that

[22] Sider 1997, 139–140.
[23] E.g., Guthrie 1969, 1; Barnes 1982a, 122; Coxon 2009, vii, although cf. Palmer 2009 who attempts to show that Parmenides is basically in harmony with both his predecessors and successors. Owen 1960 takes it one step further and places the Eleatics outside the mainstream of Ionian/Italian natural philosophy altogether.
[24] DK30 B8.

> [all things] are many, eternal, [different] kinds, and things having permanence, all things seem to change and differ from what we look at on each occasion. Therefore, it is clear that we do not see correctly nor that those things correctly seem to us to be many.

Despite the force with which Parmenides and his followers pressed their radical monism, it was not widely accepted. However, it was not ignored either. Empedocles, whose poem shows traces of engagement with Parmenides,[25] attempted to resuscitate the natural philosophy of the Ionians, by positing a constant interplay of the familiar four elements, brought together and separated in turn by the forces of Love and Strife. Along with adopting the familiar metaphysical position that all of nature can be reduced to a set number of natural substances, he also retained the non-Parmenidean view on the reliability of the senses and recommended that the readers use every device at their epistemological disposal. In his epic style, he orders the reader to "consider by every device how each thing is evident, not considering a certain sight greater in trustworthiness than something according to hearing, nor a resounding sound over the clarities of the tongue, nor hold back trust from any of the other limbs, howsoever there is a channel (πόρος) to understand, and understand each thing in whatever way it is apparent."[26] Thus, in contrast with Parmenides and his followers, Empedocles called for the use of all resources—including vision and hearing—when studying nature.

This too was the attitude of other post-Parmenidean Presocratic philosophers. Prominent among these, although perhaps not as prominent as he ought to be, is Alcmaeon of Croton, a figure who straddled the border between natural philosophy and medicine;[27] indeed, some

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[25] *KRS*, 283; Inwood 2001, 24–33. There was also some ancient speculation that Empedocles was an admirer of Parmenides (e.g., Theohpr. *ap.* D.L. 8.55; *Suda s.v.* Ἐμπεδοκλῆς), but the discussion is fairly general and usually posits the customary student–teacher relationship found in doxographical passages.

[26] ἀλλ' ἄγ' ἄθρει πάσηι παλάμηι, πῆι δῆλον ἕκαστον, / μήτε τιν' ὄψιν ἔχων πίστει πλέον ἢ κατ' ἀκουήν / ἢ ἀκοὴν ἐρίδουπον ὑπὲρ τρανώματα γλώσσης, / μήτε τι τῶν ἄλλων, ὁπόσηι πόρος ἐστὶ νοῆσαι, / γυίων πίστιν ἔρυκε, νόει δ' ἦι δῆλον ἕκαστον (DK31 B3, 14–18).

[27] The critical study on Alcmaeon's intellectual affinities with both contemporary philosophy and medicine is Mansfeld 1975.

sources state that he was the first to compose a λόγος περὶ φύσεως.[28] From the fragments that we possess, we know that Alcmaeon not only gave physical explanations of all five senses,[29] but perhaps highlighted their importance in the opening of his work:

> Ἀλκμαίων Κροτωνιήτης τάδε ἔλεξε Πειρίθου υἱὸς Βροτίνῳ καὶ Λέοντι καὶ Βαθύλλῳ περὶ τῶν ἀφανέων· περὶ τῶν θνητῶν σαφήνειαν μὲν θεοὶ ἔχοντι, ὡς δὲ ἀνθρώποις τεκμαίρεσθαι.[30]
>
> Alcmaeon of Croton, son of Pirithus, said these things to Brotinus,[31] Leon, and Bathyllus about matters that are unclear; concerning mortal matters the gods have clarity, but [for us] so far as [we are] humans [it is necessary] to judge using signs.

Although he worked within a different intellectual context, Alcmaeon actually recalls earlier Greek thinkers in that he insists that clear knowledge belongs only to the divine, but that humans can begin to level the playing field by using strategies (i.e., by paying attention to signs). What Alcmaeon might have thought these "signs" for studying nature were, he does not say, but given his demonstrated interest in the senses and the implied contrast with τῶν ἀφανέων, it seems most probable that these signs are sensory. One particularly interesting possible strategy used was the dissection of body parts such as the eye, which some ancient sources attribute to Alcmaeon, although scholarly opinion holds that the evidence is quite ambiguous.[32] However, if we look to other, later natural philosophers, we find even clearer room for empirical engagement in their epistemological commitments.

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[28] DK24 A2. Obviously he was not the first to treat natural philosophy, but perhaps the sources mean that his was the first prose writing (λόγος) that the title περὶ φύσεως was attached to. Of course, it is also very possible that this is simply a mistake in the doxography.

[29] The evidence is mostly contained in Theophrastus' *De Sensibus* 25–26 (DK24 A5).

[30] D.L. 8.83. The syntax of this quotation by Diogenes Laertius is strange and very well may not be complete as is. The dative ἀνθρώποις along with the infinitive perhaps suggests an implied ἀνάγκη *vel sim.*, which is how I have construed the passage.

[31] A contemporary Pythagorean about whom we know quite little; the evidence is collected in DK17.

[32] *Demonstranda igitur oculi natura est, de qua…Alcmaeo Crotoniensis, in physicis exercitatus quique primus exsectionem aggredi est ausus, et Callisthenes, Aristotelis auditor, et Herophilus multa et praeclara in lucem protulerunt*; "Therefore the nature of the eye must be demonstrated about which…Alcmaeon of Croton, first among the natural philosophers dared to undertake a cutting [i.e., of the eye], and the student of Aristotle Callisthenes, and Herophilus brought forth many famous matters to light." On this passage (contained in the Platonic commentator Calcidius), see Mansfield 1975; Lloyd 1975.

Chief among these later philosophers interested in nature was Anaxagoras. Anaxagoras is especially important in this debate for many reasons, but especially because he is much better documented than previous thinkers. Thus, a correspondingly fuller picture of his thoughts on the debate about sense perception emerges. Like Empedocles and Alcmaeon, Anaxagoras was interested in a wide variety of biological processes which included the physiological mechanisms by which the various senses worked.[33] Also like Alcmaeon, he believed that sensory knowledge was not uniformly trustworthy. Sextus Empiricus states that Anaxagoras "reproaching the senses as weak, he says, 'due to [the senses'] feebleness, we are not capable of distinguishing the truth."[34] Outside of its original context, that sentiment sounds Parmenidean. However, Sextus may be quoting selectively here in order to portray Anaxagoras in the most skeptic—in the ancient sense—way possible, since skeptics from Pyrrho onward abolished the use of the senses[35] and we have evidence that shows a more nuanced position. In particular, Anaxagoras was celebrated for introducing a famous methodological credo: ὄψις τῶν ἀδήλων τὰ φαινόμενα: "things that are apparent[36] are a sight of what is unseen." Following the studies of Regenbogen, Diller, and Lloyd, it has been widely remarked that this was a statement of an analogical method shared across early philosophers and related disciplines like medicine.[37] While it has been debated whether this maxim alone represents a statement of scientific methodology based on analogical reasoning,[38] we may note that the general sentiment accords well with the previous non-Parmenidean thinkers. There is a realm of appearances that is

[33] The majority of evidence for Anaxagoras' opinions on the senses is again contained in Theophrastus' *De Sensibus* (DK59 A92).
[34] DK59 B21. See also pp. 67–70 below for a thought experiment showing this.
[35] Indeed, these later skeptics were skeptical as to whether the senses could even true or false. Cf. Aristocl. *ap.* Eus. *PE* 14.18.3 (= F7 Chiesara): τὰ μὲν οὖν πράγματά (sc. Pyrrho) φησιν αὐτὸν ἀποφαίνειν ἐπ' ἴσης ἀδιάφορα καὶ ἀστάθμητα καὶ ἀνεπίκριτα, διὰ τοῦτο <u>μήτε τὰς αἰσθήσεις ἡμῶν μήτε τὰς δόξας ἀληθεύειν ἢ ψεύδεσθαι</u>.
[36] Anaxagoras was the first to use the phrase τὰ φαινόμενα here; it did not yet include the meaning of *endoxa* that it gains in Aristotle (cf. Owen 1961) as is evident from the contrast with ἀδήλος.
[37] Regenbogen 1930/1961, Diller 1932, Lloyd 1966, 338–339.
[38] E.g., Barnes 1982a, 428–430 and Wolbergs 2012.

available to humans, but also another one shut off from the human senses; however, we can overcome our limitations by approaching what is apparent carefully and using it as a resource, but not trusting in it outright. We can find close analogues all the way back to Homer, but more closely in Alcmaeon, who counseled the use of signs (τεκμαίρεσθαι) in investigating nature.

Looking forward, we find that the last phases of Presocratic natural philosophy follow Anaxagoras' lead. Often maligned as a simplistic reversion to the material monism of the early Presocratics[39] and as derivative of his more insightful contemporaries[40], Diogenes of Apollonia has undergone a slight reappraisal in recent times.[41] He is the first Presocratic thinker who differentiated between the precision of *different* senses, and attempted an explanation as to why different senses were more acute in different living things (for instance, he mentions that certain animals can smell better than humans). His explanation centers on the nature of "vessels" and "passageways" in the body, which allow air to move around. Such an opinion is understandable as he believed—like Anaximenes—that air was the ἀρχή of all things.[42]

Perhaps most importantly, however, at the end of the Presocratic period we find Democritus and atomism. In the case of Democritus we possess the fullest record of any Presocratic when it comes to his attitude toward the senses and the theory of knowledge. Although we cannot delve into a full reconstruction of Democritus' theory of knowledge here, an overview will show that the last Presocratic natural philosopher also belonged to the mainstream of Presocratic epistemology despite his innovative atomistic metaphysics.

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[39] E.g., Burnet 1920, 356; Barnes 1982a, 567. We find this dismissal in ancient sources as well—Theophrastus thinks that he is too quick to reduce everything to his preferred principle of air (*Sens*. 48.7–9).`

[40] Theophrastus, again, finds Diogenes derivative of Leucippus—Democritus cannot work on chronological grounds presumably—and Anaxagoras (DK64 A5).

[41] Laks' 1983 study of Diogenes has acted as the catalyst for this reevaluation by organizing all the available evidence. Graham 2006, 277–293 is a very positive reinterpretation, but rests on his own, somewhat idiosyncratic, reconstruction of the entire history of Presocratic philosophy.

[42] Theophr. *Sens.* 41–43.

Democritus famously reduced the world into two fundamental entities: atoms and void. As he put it himself, all other things and qualities were merely "by convention." In reality, which Democritus called τὸ ἐτεόν, everything in the world was reducible to atoms moving and interacting in empty space. Of course, just as in the other Presocratic theories, this idea clashes with everyday experience. Therefore, Democritus also posited two levels of knowledge, borrowing language from the vocabulary of domestic affairs. The first level he termed "bastard" (σκότιος) knowing, by which he meant everything we come to know by the use of the senses. The other was "legitimate" (γνησίη) knowing, by which he meant using reason to come to his atomistic conclusion.[43]

Even though we have seen the bifurcation of knowing in other Presocratics—notably Parmenides who divided states of knowing into "knowledge" and "opinion"—Democritus did not take the Parmenidean course of completely disregarding sensory knowledge, despite his calling it "bastard." Rather, he only sometimes abolishes sensory appearances.[44] More particularly, Democritus is quoted by Sextus Empiricus as saying: "when the bastard [knowing] is no longer able to see anything at a smaller [level], nor hear, nor smell, nor taste, nor sense in touching, but ever finer [one must continue with reason, i.e., legitimate knowing]."[45] Therefore, Democritus is also recorded as having approved of Anaxagoras' dictum that ὄψις τῶν ἀδήλων τὰ φαινόμενα,[46] not because he was dedicated to an analogical method, but because the senses

[43] DK68 B11. The term σκοτίος literally means something like "in the dark," and could mean "obscure" (LSJ s.v. A.II.2), but the translation "bastard" is made clear by its comparison to the legitimate (γνησίη) sense of reason. Cf. Pl. *Tim*. 52b, where he refers to λογισμῷ τινι νόθῳ, although for Plato as opposed to Democritus, this "bastard reasoning" is characterized by the *absence* of sense-perception (ἀναισθησία).

[44] Δ. δὲ ὁτὲ μὲν ἀναιρεῖ τὰ φαινόμενα ταῖς αἰσθήσεσι καὶ τούτων λέγει μηδὲν φαίνεσθαι κατ' ἀλήθειαν, ἀλλὰ μόνον κατὰ δόξαν; "Democritus sometimes (ὁτὲ μὲν) does away with what appears to the senses and says that nothing of these things appear to them according to truth, but only according to opinion" (DK68 B9).

[45] For the supplement to Democritus' quote here, cf. Sextus' explanation immediately following the *verbatim* quotation: οὐκοῦν καὶ κατὰ τοῦτον ὁ λόγος ἐστὶ κριτήριον, ὃν γνησίην γνώμην καλεῖ; "therefore also according to him reason is the criterion [of knowledge], which he calls "genuine knowing" (S.E. *M* 7.139–140).

[46] DK59 B21a.

had *some* role to play in the practice of inquiry into nature. Thus, for Democritus, the senses help humans proceed to a certain point in the quest to understand the world, but things at the atomic (and most real) level must be apprehended by reason, especially since the same sense-data is interpreted differently by different people, or, as closer to how he put it himself, the same sense-data is interpreted according to convention.

With Democritus, and indeed even before him, the Presocratic period comes to an end. Although this survey of the various Presocratic opinions on sense-perception is not exhaustive, we may draw several conclusions about the thinkers under consideration here. While there is no unanimity in opinions about the trustworthiness of the senses, there is no contradiction either. Their opinions on the reliability of sense perception existed on a continuum of greater or lesser dependability. Even Parmenides, while taking the strongest stance against sense perception, nevertheless could not credibly do away with the features of the world appearing to the senses, since the majority of his poem was a conventional cosmology.[47] Thus, there was the theoretical room for some use of the senses in understanding the natural world. The question then becomes: did they use them and, if so, how?

2.3. Empirical Practice in Natural Philosophy

Arguing the presence or absence of experimentation in Greek natural philosophy has had a long scholarly history.[48] In large part, this debate is part of the wider debate of whether Greek natural philosophy is scientific in the modern sense—a debate which, as noted in the introductory chapter, runs a great risk of being anachronistic. But relatively little has been done to approach the ancient use of empirical evidence on its own terms. When we do not insist that the ancients'

[47] This gives rise to a major puzzle with which modern scholars still grapple (cf. for instance, Guthrie 1969, 4–6; Curd 1998, 98–104).
[48] Burnet 1920, 25–28; Cornford 1952, 3–11 (and Vlastos' review thereof in Vlastos 1955); Guthrie 1962, 37–38; Lloyd 1979 and Brunschwig and Lloyd 2000, 222–227 (cf. note 3 above). The more general debate of whether Presocratic philosophy was "scientific" has an even longer history, see the introduction.

scientific method be the same as the modern one, we find that—even given the fragmentary evidence—early philosophers generally used empirical evidence of varying complexity, up to and including experiments.

2.3.1. The Milesians

The evidence concerning Thales—the first natural philosopher—is fuller than that concerning many of his successors. This is, however, a mixed blessing since his position as the first philosopher attracted much invention and speculation by later ancient writers. But some reputable sources do attest to an empirical mindset. Besides the famous story of his prediction of the eclipse of 585 BCE contained in Herodotus,[49] many sources attest to Thales' interest in observational astronomy.[50] And, of course, Plato in the *Theaetetus* refers jokingly to Thales' direct observation of the stars in the story where he falls into a well while looking at the night sky, forgetting to notice what was right in front of him.[51]

Nor are the stories of Thales' scientific endeavors limited to just passive observation. Other accounts have Thales measuring large distances using trigonometric demonstrations. Several accounts have him measuring the height of the pyramids by measuring more easily measurable shadows and applying an analogical proportion. One has him waiting for the time of day when his shadow was the same length as his height, and then measuring the shadow cast by the pyramid.[52] Knowing that the shadow cast by any upright object would be the same as its height, and that the height of the pyramid could be visualized as an upright object, he could calculate its height:

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[49] Hdt. 1.74. It has been very widely debated whether Thales could have predicted this eclipse. Cf. Neugebauer 1969, 142–3; Mosshammer 1981; Roller 1983; Panchenko 1994; O'Grady 2002, 126–146.
[50] E.g., D.L. 1.23; Theon Smyrn. 198.14–18; Aristarch. Sam. *ap.* P. Oxy. 3710, col. ii, 36–43. Most of these reports derive ultimately from Eudemus' *History of Astronomy*, which made Thales the first Greek astronomer.
[51] *Theatet.* 174a (= DK11 A9).
[52] D.L. 1.27 (who quotes the Peripatetic Hieronymus), Plin. *Nat. hist.* 36.82.

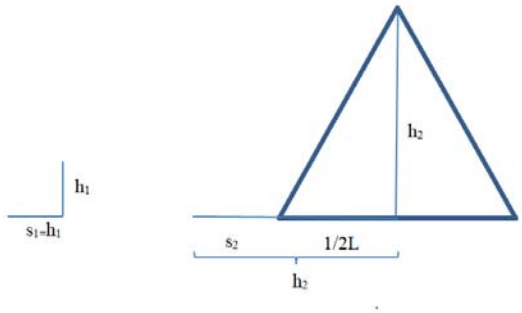

Fig. 2.1: Measuring the pyramids

As with almost everything concerning Thales, the literal truth of this story is debatable. Hahn, in the most current and extensive treatment of the passage, treats it as possible.[53] But several assumptions are necessary to make these demonstrations work; for instance, the sun would have to be exactly due south, east, or west and would have to cast the pyramid's shadow so that it would actually extend onto the ground and not simply onto the pyramid itself (where it could not be easily measured).[54] Hahn has noted that there are only several times on even fewer days of the year where this is possible, and so if Thales did undertake this demonstration he must have either had done quite a bit of preparatory work or had access to Egyptian astronomical records.[55] The sheer rarity of the "perfect" conditions for measurement may lead us to suspect that the story has been invented or imported from another context. For instance, the same tale is told about Archimedes in a later mathematical author.[56] But, on the other hand, we are told that Thales' student Anaximander invented the *gnomon*—the vertical portion of a sundial—and investigated celestial phenomena with it,[57] so it is not outside the realm of possibility that Thales too engaged in this sort of empirical investigation utilizing the position of the sun, even if details of this account are later creations.

[53] Hahn 2017, 97–115.
[54] Ibid., 97–107.
[55] Ibid., 103.
[56] Archimed. fr. 21 Heiberg–Stammatis.
[57] D.L. 2.1; Eus. *PE* 10.14.11; *Suda* s.v. γνώμων. Since the device was known in other cultures for a long time before Anaximander, it is more likely that he simply introduced it to Greece.

Despite his "invention" of the *gnomon*, Anaximander is more renowned as a philosopher than a scientist. This is due to his identification of an indeterminate ἄπειρον or "unlimited" as the principle of all things. The ἄπειρον, whose exact nature was just as mysterious to later authors as it is to modern readers,[58] represented a leap of abstraction from his teacher Thales—who declared that everything is water—and his student Anaximenes—who declared that everything is air. And while his principle may have been an advance for abstract reasoning, it is a retreat from the perspective of natural science, since the principle underlying all things is no longer material and hence the hypothesis is no longer subject to confirmation using the senses.

To put it another way, the theories of Thales and Anaximenes are, potentially, empirically verifiable. It has often been suggested that Thales was inspired to declare that everything is at base water because of water's ability to condense into a solid when cooled and sublimate into a gas when heated[59]—although we should note that Aristotle explains his reasoning differently ("perhaps taking his supposition from seeing that the nourishment of all things is moist.")[60]

Anaximenes, on the other hand, was almost certainly inspired by the ability of air to turn into different forms at different temperatures, as doxographical notices show. In particular, he believed that air changed due to a defined process of either rarefication or condensation; when air is rarefied it warms and becomes fire, and when air is condensed it cools and becomes cloud, water, earth, and then stone.[61] While, of course, Anaximenes could not have seen water becoming earth due to its physical impossibility, he had integrated a valid observation into his system of thought: that temperature and density are inversely correlated.[62] In other words,

[58] E.g., D.L. 2.1–2; Alex. *in Met.* 60.8–10.
[59] E.g., Burnet 1920, 57n1; Guthrie 1962, 61; O'Grady 2002, 59.
[60] DK11 A12.
[61] DK13 A5; A7.
[62] *KRS*, 149.

materials with greater density are cooler whereas more "rarefied" materials are warmer, which is why warmer materials rise when surrounded by cooler ones (i.e., the principle of convection).

Anaximenes' definition of the process by which air changes into other types of matter as condensation and rarefication was also a very important step forward, for it could be empirically investigated. Whereas Anaximander's ἄπειρον turned into other types of matter through a mysterious process of "separating out," (ἀποκεκρίσθαι)[63] one could either observe the compression or rarefication of air either in nature or in an artificial scenario. And, indeed, Plutarch informs us that Anaximenes used empirical evidence to prove his point:

> ἢ, καθάπερ Ἀναξιμένης ὁ παλαιὸς ᾤετο, μήτε τὸ ψυχρὸν ἐν οὐσίᾳ μήτε τὸ θερμὸν ἀπολείπωμεν, ἀλλὰ πάθη κοινὰ τῆς ὕλης ἐπιγινόμενα ταῖς μεταβολαῖς· τὸ γὰρ συστελλόμενον αὐτῆς καὶ πυκνούμενον ψυχρὸν εἶναί φησι, τὸ δ' ἀραιὸν καὶ τὸ χαλαρὸν (οὕτω πως ὀνομάσας καὶ τῷ ῥήματι) θερμόν· ὅθεν οὐκ ἀπεικότως λέγεσθαι τὸ καὶ θερμὰ τὸν ἄνθρωπον ἐκ τοῦ στόματος καὶ ψυχρὰ μεθιέναι· ψύχεται γὰρ ἡ πνοὴ πιεσθεῖσα καὶ πυκνωθεῖσα τοῖς χείλεσιν, ἀνειμένου δὲ τοῦ στόματος ἐκπίπτουσα γίνεται θερμὸν ὑπὸ μανότητος. (τοῦτο μὲν οὖν ἀγνόημα ποιεῖται τοῦ ἀνδρὸς ὁ Ἀριστοτέλης· ἀνειμένου γὰρ τοῦ στόματος ἐκπνεῖσθαι τὸ θερμὸν ἐξ ἡμῶν αὐτῶν, ὅταν δὲ συστρέψαντες τὰ χείλη φυσήσωμεν, οὐ τὸν ἐξ ἡμῶν ἀλλὰ τὸν ἀέρα τὸν πρὸ τοῦ στόματος ὠθεῖσθαι ψυχρὸν ὄντα καὶ προσπίπτειν.)[64]
>
> Just as the ancient Anaximenes thought, let us leave neither the cold nor the hot in substance, but [think that] common states of matter follow upon changes. For he says that the contraction and the condensation of [matter] is cold, and that the warm is looseness and "slackness" (for he calls it by this word). Thence, not implausibly, it is said that a man lets out both warm and cold from the mouth. For breath is cooled when it is pressed and condensed by the lips, but when the mouth is open, the air [blown out] becomes warmth due to the looseness. (Aristotle makes this a sign of the man's ignorance; for [he says that] when the mouth is open, the warmth is blown from ourselves, but whenever we blow with the lips pursed together, the air before our mouth, which is cold, is pushed out and comes forth, not the air from us).

[63] DK12 A10.
[64] Plut. *De Prim. Frig.* 947f1–948a9. Cf. [Arist.] *Prob.* 964a10–18, which discusses the phenomenon under question here, but does not mention Anaximenes by name. The authorship of the *Problems* is debated, but Plutarch, at least, considered them a genuine work of Aristotle (e.g., Plut. *Conv.* 734c).

Although this passage has been characterized as merely analogical reasoning on Anaximenes' part,[65] it is actually quite a poor example of an analogy. Analogical reasoning, as defined by Lloyd in his seminal study of the thought pattern, is not just formal analogy ($a : b :: c : d$), but also a general "mode of reasoning in which one object or complex of objects is likened or assimilated to another."[66] Yet, Anaximenes' point is not to explain the condensation and rarefication of air by relating it to a different phenomenon. Anaximenes meant to simulate artificially the very thing under discussion: the correlation between air temperature and contraction. He changes air by one variable and records the results. In doing so, he has done away with analogical reasoning altogether since there is no comparison of air to anything else, simply a direct observation of the object of investigation before and after an intervention.

Is this, then, an experiment? Some scholars have answered in the negative, some pointing out that, unlike in the modern scientific method, the test is not performed to establish or refute a previously unknown hypothesis.[67] The hypothesis is already stated, and the test is adduced only to confirm the point. That is certainly true; however, in other ways, Anaximenes suggests aspects of experimentation other than its precise role in the modern scientific method. He has posited that varying a single quality—density—directly affects another variable—temperature. He then carries out observations of air under both levels of "density" (simulated by blowing air through pursed lips and then through an open mouth) to be compared. Here we have a very early instance indeed of the independent and dependent variable in experimental design: the independent variable (density) is changed in a controlled way, and a correlated effect in the dependent variable (temperature) is noted.

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[65] Diller 1932, 35–36.
[66] Lloyd 1966, 175. See also Introduction 1.2.6 above.
[67] Cornford 1952, 6; *KRS*, 149–150n1; Wöhrle 1993, 62.

Others have objected that this observation is introduced by λέγεσθαι, and have suggested that Anaximenes is doing nothing more here than referring to a commonly known phenomenon, not an observation motivated by his own theoretical concerns.[68] This objection, however, is less convincing. Surely, the phrase introduced by λέγεσθαι is referring to a proverbial saying for speaking out of both sides of one's mouth, known from the Aesopic corpus: ἐκ τοῦ αὐτοῦ στόματος τὸ θερμὸν καὶ τὸ ψυχρὸν ἐξιεῖς.[69] Furthermore, even if this were a widely-known and widely-remarked upon phenomenon, Anaximenes is the first to have connected it to a theoretical point about nature, as opposed to folk wisdom. Indeed, there is no guarantee that this material is genuinely Anaximenean; it very well could also be a learned allusion to Aesop added by Plutarch.

Thus, Anaximenes'experiment, simple though it is, is an important one in that it anticipates a much later conception. He singles out a relevant variable, modifies it, and records the results that appear to him via his senses (in this case touch). Of course, anticipation of the modern scientific method was not on his mind—how could it have been—but even so, his action here is not a simple analogizing: he is investigating a part of nature (the connection between density and air temperature) directly, not by making a mental equivalency with something else. Thus, even though the ancient sources show no awareness of it as such, we would be justified in call this passage the first description of an experiment in Western science.

2.3.2. Empirical Practice and Philosophical Poets

Today we draw a line between a poetic temperament and a scientific one, yet such a distinction was foreign to antiquity—Aristotle, for instance, considered whether an author composed poetry

[68] *KRS*, 149–150, n. 1.
[69] Perry 1952, 335.

or prose incidental to his status as a φυσικός.[70] And there is a rich tradition of scientific poetry reaching back to the earliest period of Greek natural philosophy under investigation here.

For instance, Xenophanes, the earliest poet to deal with the new physical cosmology introduced by the Milesians, straddled generic boundaries. Within his elegiac poetry, he combined symposiastic verse, theological speculation, and, as we have seen, thoughts on epistemology. His poetry also engaged in scientific inquiry in the Milesian mold, including keen observations. For instance, in order to support his contention that the earth was originally covered in water, Xenophanes is reported to have noticed many cases of fossils of marine animals in locations far removed from any water.[71] Interestingly, the notice contains the exact locations of these fossil finds in the Greek world, a fact which, coupled with Xenophanes' self-reported wanderings around Greece,[72] may point to direct observation on the poet's part rather than collecting reports from elsewhere.

While Xenophanes shows traces of empirical engagement, it is in the remains of Empedocles, one of the most important and puzzling thinkers of this period, where we find the most complete record of ancient Presocratic philosophical poetry. Because our knowledge of Empedocles is better supported by his own words, it is significant that we find an extended description of a test using a special apparatus—the *clepsydra*. The exact interpretation of this

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[70] Ar. *Poet.* 1447b16–20.

[71] ὁ δὲ Ξενοφάνης μίξιν τῆς γῆς πρὸς τὴν θάλασσαν γίνεσθαι δοκεῖ καὶ τῷ χρόνῳ ὑπὸ τοῦ ὑγροῦ λύεσθαι, φάσκων τοιαύτας ἔχειν ἀποδείξεις, ὅτι ἐν μέσῃ γῇ καὶ ὄρεσιν εὑρίσκονται κόγχαι, καὶ ἐν Συρακούσαις δὲ ἐν ταῖς λατομίαις λέγει εὑρῆσθαι τύπον ἰχθύος καὶ φωκῶν, ἐν δὲ Πάρῳ τύπον δάφνης ἐν τῶι Βάθει τοῦ λίθου, ἐν δὲ Μελίτῃ πλάκας συμπάντων τῶν θαλασσίων; "Xenophanes...saying that [he] has the following demonstrations: that seashells are found in the middle of the ground and on mountains, and in Syracuse he says that the impression of fish and seals are found in quarries, and in Paros the impression of coral (LSJ s.v. IV) in depths of stone, and on Malta [there are] flat stones of all types of sea creatures" (DK21 A33).

[72] ἤδη δ᾽ ἑπτά τ᾽ ἔασι καὶ ἑξήκοντ᾽ ἐνιαυτοὶ | βληστρίζοντες ἐμὴν φροντίδ᾽ ἀν᾽ Ἑλλάδα γῆν; "Already there have been seven and sixty years, tossing my thought up and down the land of Greece" (DK21 B8).

fragment, however, has generated a great deal of debate and so it is worth dealing with it in depth.[73]

Empedocles' *clepsydra* fragment appears in Aristotle's *De Respiratione*. Aristotle introduces the fragment by explaining Empedocles' view of respiration. Empedocles believed that respiration worked through the skin. Blood exists in channels extending to the surface of the skin. When we inhale, however, the blood moves down the channels away from the surface and air enters where the blood was. The air stays in these channels until we again exhale and the blood rushes up again to the surface of the skin. The entire process can be illustrated as follows:

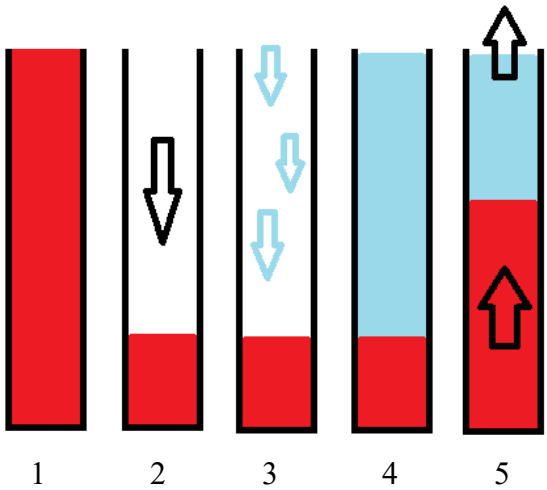


Fig 2.2: Empedocles' model of respiration[74]

Aristotle then introduces Empedocles' own words, where he compares (Aristotle's word is παρεικάζων) the process of respiration to the *clepsydra*:

> ὧδε δ' ἀναπνεῖ πάντα καὶ ἐκπνεῖ· πᾶσι λίφαιμοι
> σαρκῶν σύριγγες πύματον κατὰ σῶμα τέτανται,
> καί σφιν ἐπὶ στομίοις πυκιναῖς τέτρηνται ἄλοξιν
> ῥινῶν ἔσχατα τέρθρα διαμπερές, ὥστε φόνον μέν
> κεύθειν, αἰθέρι δ' εὐπορίην διόδοισι τετμῆσθαι.
> ἔνθεν ἔπειθ' ὁπόταν μὲν ἀπαΐξῃ τέρεν αἷμα,

[73] There is some ancient discussion on this passage (Aët. 4.22.2 and Mich. *in PN* 123, 20–127, 8), although it is not very helpful. Much larger is the modern, somewhat inconclusive debate about its interpretation: Last 1924; Furley 1957; Booth 1960; Regenbogen 1930/1961, 192–194; Lloyd 1966, 328–33; Worthen 1970; O'Brien 1970; Arata 1995.

[74] 1.) At rest, blood extends to surface of skin in "channels;" 2.) inhalation, blood recedes; 3.) air moves into empty space left by blood; 4.) air extends through channels, held in equilibrium until 5.) exhalation, air leaves and blood follows.

αἰθὴρ παφλάζων καταΐσσεται οἴδματι μάργῳ,
εὖτε δ' ἀναθρῴσκῃ, πάλιν ἐκπνέει, ὥσπερ ὅταν παῖς
κλεψύδρῃ παίζῃσι διειπετέος χαλκοῖο—
εὖτε μὲν αὐλοῦ πορθμὸν ἐπ' εὐειδεῖ χερὶ θεῖσα
εἰς ὕδατος βάπτῃσι τέρεν δέμας ἀργυφέοιο,
οὐδεὶς ἄγγοσδ' ὄμβρος ἐσέρχεται, ἀλλά μιν εἴργει
ἀέρος ὄγκος ἔσωθε πεσὼν ἐπὶ τρήματα πυκνά,
εἰσόκ' ἀποστεγάσῃ πυκινὸν ῥόον· αὐτὰρ ἔπειτα
πνεύματος ἐλλείποντος ἐσέρχεται αἴσιμον ὕδωρ.
ὡς δ' αὔτως, ὅθ' ὕδωρ μὲν ἔχῃ κάτα βένθεα χαλκοῦ
πορθμοῦ χωσθέντος βροτέῳ χροῖ ἠδὲ πόροιο,
αἰθὴρ δ' ἐκτὸς ἔσω λελιημένος ὄμβρον ἐρύκῃ
ἀμφὶ πύλας ἠθμοῖο δυσηχέος ἄκρα κρατύνων,
εἰσόκε χειρὶ μεθῇ, τότε δ' αὖ πάλιν, ἔμπαλιν ἢ πρίν,
πνεύματος ἐμπίπτοντος ὑπεκθέει αἴσιμον ὕδωρ.
ὡς δ' αὔτως τέρεν αἷμα κλαδασσόμενον διὰ γυίων
ὁππότε μὲν παλίνορσον ἀπαΐξειε μυχόνδε,
αἰθέρος εὐθὺς ῥεῦμα κατέρχεται οἴδματι θῦον,
εὖτε δ' ἀναθρῴσκῃ, πάλιν ἐκπνέει ἶσον ὀπίσσω.[75]

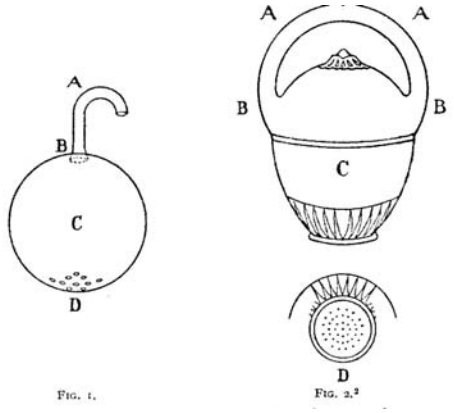
Thus all [living] things breathe in and out. In all things, bloodless channels of flesh stretch into the depths of the body, and at their densely [placed] mouths, the surfaces of the skin[76] are pierced right through, so that the blood is hidden, and good passage for air is cut by these passages. Then, whenever the soft blood rushes away from here, the blustering air rushes down with a furious swell; but when it rushes up, [the air] exhales again, just as when a child plays with a *clepsydra* of radiant bronze—when, placing the opening of the pipe against her beautiful hand and she dips the delicate frame into the silvery water, no water rushes into the vessel, but the mass of air inside falling [down] against the dense perforations, until she uncovers the dense stream. Right then, as the air leaves, a measure of water comes in. Just as when she holds the water in the depths of a bronze pipe, the channel, blocked up by mortal flesh, the air outside struggling [to get] inside, blocks the water, ruling the extremities around the gates of ill-sounding strainer, until she lets go with her hand, then again just as before does the wind fall in and the measure of water run off—just as this, so too does soft blood surging through the limbs, when it rushes back inwards, straightaway the flow of air rushing in a swell comes in; and when [the blood] leaps up, again equal air breathes back out.

[75] Arist. *Resp.* 473a7–474a6.

[76] The translation of ῥινῶν is one crux in this puzzling passage. Aristotle took this—quite understandably enough—to be the genitive plural of ῥίς 'nostril.' Yet, the fragment itself makes it seems like the plural of ῥινός 'skin' and many scholars since Diels have preferred this reading (Furley 1957, 31) given a similar theory found in Plato's *Timaeus* 77c–79e. Booth 1960 and O'Brien 1970, however, have also argued for 'nostrils' on philological grounds. In this case, the exact translation matters less since we are interested in the *clepsydra* itself, not the exact working of the analogy (see below).

Many points are unclear so it is best to start with what is uncontroversial about the passage. Empedocles presents a simile here of the Homeric type; small details like the girl playing with the *clepsydra* add more of an epic feeling than a simple description. But the simile is not simply literary ornament—Empedocles means to make an analogy between the interchange of blood and air in the living body and the interchange of water and air in the *clepsydra*.

The *clepsydra* itself is *not* the better-known water clock, but rather a contrivance (bronze in this case) for picking up and moving water (thus the name *water-stealer*, also called a *hydrarpax* in some sources).[77]



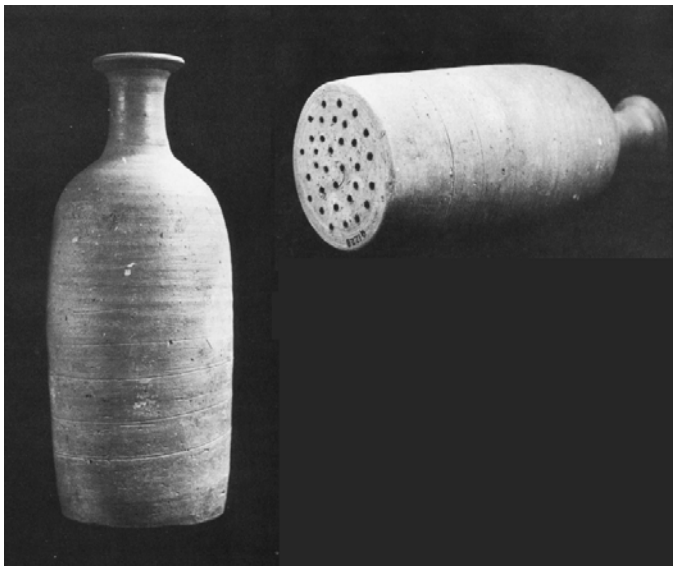


Fig. 2.3: A diagram of a clepsydra[78] **Fig. 2.4: Photograph of clepsydra found in Meroë[79]**

It was a hollow vessel with a single hole at the top and a perforated surface at the bottom. By dipping the bottom into water, the vessel would fill up. If the user then plugged the top hole, he or she could remove the entire *clepsydra* without having the water fall out through the perforated bottom again. And by opening up the hole at the top, the water would come out in a shower

[77] As established by Last 1924, who also presents the ancient material on the device (as well as helpful illustrations, reproduced here as Fig. 2.3).
[78] Reproduced from Last 1924, 170.
[79] Reproduced from Devries 1973, 63–64. This specimen is held in the Egyptian Museum in Cairo.

through the perforated bottom once again.[80] One can observe the same principle at work with the scientists' pipette or with a child (or an adult for that matter) dipping a straw into water and removing the liquid by keeping their finger over the open end of the straw.

While the identification of the *clepsydra* is not controversial, how Empedocles meant it to illustrate respiration is very much so. Some scholars hold that blood in the body corresponds to water in the *clepsydra*; others have argued the exact converse (that water in the *clepsydra* corresponds to air in the body).[81] It has also been argued, perhaps more plausibly, that Empedocles is not insisting on rigid correspondences between elements of the simile, but seeking only to illustrate the invisible process.[82]

For our purposes, it is not as important to reconstruct the exact correspondences Empedocles had in mind, since we are primarily interested in the illustration itself rather than what is being illustrated. The analogy is not a fanciful one—the simile is supposed to elucidate an invisible process, and so it is a good choice to make the other part of the simile a well-known observation or easily observable. This passage also resembles an experiment in that it describes observations before and after changing a single variable (i.e., blocking the spout of the *clepsydra*). Thus, there is every reason to suspect that the empirical demonstration, that is the experiment, was undertaken *in order to* supply material for an analogy.

The use of controlled observation has prompted some scholars to remark that Empedocles is describing an experiment here.[83] On the other hand, however, there are facets of this passage that point away from simple scientific experimentation. Empedocles introduces a subject—the girl—carrying out the test; the use of such a subject is reminiscent more of a Homeric simile than

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[80] Archaeological specimens of this type of *clepsydra* have also been found around the Mediterranean (Devries 1973, which includes plates of finds from Meroë)
[81] For the former, cf. Furley 1957; O'Brien 1970. For the latter, cf. Booth 1960.
[82] Worthen 1970, 521.
[83] Burnet 1920, 27; Farrington 1961, 58–61.

similar passages from Empedocles' contemporaries where the subject is unexpressed or simply τις. More importantly, however, Empedocles' motivation for introducing the *clepsydra* is *not* to prove a point about air or water, or something else that is being directly observed or measured within the test, but to introduce an analogical argument.[84] This, of course, is true, and certainly would preclude us from seeing Empedocles as a modern experimentalist, with the modern scientific method in mind. But, we should still note that Empedocles is speaking about the controlled observation of an intervention, which is certainly a necessary part of a scientific experiment, even if the results were not used in a modern way.

Furthermore, we have evidence that similar experiments *were* being undertaken at this time, not as part of analogical reasoning, but to directly investigate the nature of air. Aristotle, again, is our source:

> οἱ μὲν οὖν δεικνύναι πειρώμενοι ὅτι οὐκ ἔστιν, οὐχ ὃ βούλονται λέγειν οἱ ἄνθρωποι κενόν, τοῦτ' ἐξελέγχουσιν, ἀλλ' <ὃ> ἁμαρτάνοντες λέγουσιν. ὥσπερ Ἀναξαγόρας καὶ οἱ τοῦτον τὸν τρόπον ἐλέγχοντες. ἐπιδεικνύουσι γὰρ ὅτι ἐστίν τι ὁ ἀήρ, στρεβλοῦντες τοὺς ἀσκοὺς καὶ δεικνύντες ὡς ἰσχυρὸς ὁ ἀήρ, καὶ ἐναπολαμβάνοντες ἐν ταῖς κλεψύδραις.[85]
>
> Some attempting to show that [empty space] does not exist, refute not what people wish to call void, but speak in error, just like Anaxagoras and those who refute it in this way. For they show that air is something by twisting wine skins and showing that air has strength, and by cutting it off in *clepsydras*.

Other ancient authors like the commentator Simplicius expand on this passage in Aristotle; in his treatment, Simplicius (who had access to Anaxagoras' writings) makes it clear that Anaxagoras' test with the *clepsydra* utilized the same mechanism described by Empedocles.[86] By dipping the *clepsydra* into water and bringing it back up while "cutting off" the air by the hole at the top, it is demonstrated that something corporeal offers resistance (σῶμά ἐστι καὶ ἀντίτυπον, in

[84] As noted, for instance, by Furley 1957, 34; O'Brien 1970, 168–9; Barnes 1982a, 313.
[85] DK59 A68.
[86] Simpl. *in Phys.* pp. 647–648. Cf. Simpl. *in Cael.* pp. 524–525.

Simplicius' words) to the downward inclination of the water, which would otherwise fall through the holes at the bottom of the *clepsydra*. Anaxagoras and others seem to have taken this as proof that air is everywhere, leaving no room for truly empty space in the world—if there were just empty space below the *clepsydra*, the water would simply fall out.

Thus it is worth asking about priority of these two thinkers: which is the original context for the *clepsydra* test? Of course, a definitive answer remains beyond our reach, since the thinkers are nearly contemporaries. However, there are some clues that Anaxagoras may have predated and influenced Empedocles.[87] Aristotle, for instance, says that "Anaxagoras of Clazomenae was prior in age [sc. to Empedocles], but later in his works" (Ἀναξαγόρας δὲ ὁ Κλαζομένιος τῇ μὲν ἡλικίᾳ πρότερος ὢν τούτου, τοῖς δ' ἔργοις ὕστερος).[88] While the meaning of the phrase "later in his works" is debatable, it seems best to take it to mean "more advanced," or even "more contemporary," given Aristotle's well known tendency to evaluate his predecessors by how closely they approximated his own system of thought.[89] Furthermore, the fourth-century BCE sophist Alcidamas corroborates Aristotle's account and informs us that Empedocles "listened to" (i.e., was a student of) Anaxagoras. Given Alcidamas' closeness in date, this seems to be a fairly reliable testimonium.[90]

If this is the case, then the main criticism against the use of the *clepsydra* as an "experiment"—namely that it does not directly investigate a topic but is merely an analogy—loses a bit of its force. For even though Empedocles uses it in an extended simile, it seems to

[87] For the most part, I follow O'Brien 1969 here, which gathers and evaluates the evidence and scholarly discussion on this question. Some scholars after O'Brien have argued against for the priority of Empedocles, but most agree with his assessment (cf. Curd 1998, 17n37).
[88] Arist. *Met.* 984a11–13.
[89] Cf. p. 35, n. 123. O'Brien 1969, 99 argues that "more up-to-date" does not work on linguistic grounds, but he does not take into account Aristotle's teleological view of the history of philosophy.
[90] D.L. 8.56.

have been a direct empirical test, and Empedocles may have originally come across the use of the *clepsydra* when it was used by Anaxagoras in an empirical test of the corporeality of air.

2.3.3. Thought Experimentation among the Presocratics

Although the empirical tests surveyed thus far are relatively simple and easily performable, there is another class of "experiments" described which by their very nature cannot be physically carried out. These are thought experiments: an imagined sequence of events and the inference of outcomes. Although a thought experiment is not empirical in a sense, it has been plausibly argued that a physical experiment has a corresponding thought experiment working as a "mental model."[91] In any case, as we shall see, there are certain structural similarities between thought experiments and "real" experiments in the ancient material as well.

Perhaps the most well-known thought experiments of early Greek antiquity are Zeno's paradoxes. Ancient sources inform us that Zeno wrote forty λόγοι or arguments in defense of his teacher Parmenides' various unorthodox beliefs including that there is no plurality in the world, no motion, and no such thing as place.[92] Some of these involved the description of imagined scenarios, which can be understood as thought experiments. In the famous "Achilles argument," for instance, Zeno asks us to imagine a scenario where Achilles—the fastest of all the Achaeans at Troy—contends in a footrace with a slower competitor—commonly a tortoise.[93] Achilles gives the tortoise a head start of, say, 100 feet. Achilles easily makes up the distance, but in the

[91] Cf. p. 19.
[92] DK29 A15. The sources, which are late antique commentators on Plato and Aristotle, are uncertain on exactly how many arguments Zeno wrote and how they relate to one another.
[93] Aristotle in DK29 A26 (*Ph.* 239b) does not specify whom Achilles is racing. Later commentators (Them. *in Ph.* 199–200; Simpl. *in Ph.* 1014–1015) say that Achilles is racing Hector or a tortoise "the slowest of them all." Since the image of Achilles racing a tortoise is much more striking than him racing Hector (Achilles does catch Hector after running around Troy three times after all), it is this version that has become best known. See, for instance, Lewis Carroll's dialogue between Achilles and the Tortoise (Carroll 1895).

meantime the tortoise has moved forward, say, ten feet. Achilles makes up the ten feet, but in the meantime, the tortoise has moved forward a foot *ad infinitum*.[94]

This has been called a thought experiment,[95] but not because it could be turned into a physical experiment. Indeed, the entire point of the paradox is that the race *would not* work like this in the physical world. At first, this seems to mediate against the definition of a thought experiment as an experiment—how can one use an empirical test for the empirically impossible? However, thought experiments in common usage are often paradoxical, even though they exhibit the structure of performed experiments. Zeno's paradox, then, is a thought experiment because it is imagined scenario where there are certain quantifiable, mental "controls" on the variables (like the head start the tortoise has, the ratio between the tortoise and Achilles' speeds, etc.) The exact value of these variables is not important; rather, they allow us to tease out the logical and mathematical issues at play in an otherwise very abstract scenario.

One less celebrated, but intriguing paradox of Zeno's—called the "millet seed"—is even more of a thought experiment in the sense defined in the introduction. Aristotle, again, is our earliest authority here[96], but only alludes to the content of the argument. The most complete account is contained in the late antique Aristotelian commentator Simplicius:

> διὰ τοῦτο λύει καὶ τὸν Ζήνωνος τοῦ Ἐλεάτου λόγον, ὃν ἤρετο Πρωταγόραν τὸν σοφιστήν. "εἰπὲ γάρ μοι, ἔφη, ὦ Πρωταγόρα, ἆρα ὁ εἷς κέγχρος καταπεσὼν ψόφον ποιεῖ ἢ τὸ μυριοστὸν τοῦ κέγχρου;" τοῦ δὲ εἰπόντος μὴ ποιεῖν "ὁ δὲ μέδιμνος, ἔφη, τῶν κέγχρων καταπεσὼν ποιεῖ ψόφον ἢ οὔ;" τοῦ δὲ ψοφεῖν εἰπόντος τὸν μέδιμνον "τί οὖν, ἔφη ὁ Ζήνων, οὐκ ἔστι λόγος τοῦ μεδίμνου τῶν κέγχρων πρὸς τὸν ἕνα καὶ τὸ μυριοστὸν τὸ τοῦ ἑνός;" τοῦ δὲ φήσαντος εἶναι "τί οὖν, ἔφη ὁ Ζήνων, οὐ καὶ τῶν ψόφων ἔσονται λόγοι πρὸς ἀλλήλους οἱ αὐτοί; ὡς γὰρ τὰ ψοφοῦντα, καὶ οἱ ψόφοι· τούτου δὲ οὕτως ἔχοντος, εἰ ὁ μέδιμνος τοῦ κέγχρου ψοφεῖ, ψοφήσει καὶ ὁ εἷς

[94] The "paradox" was not really reckoned with until the 17th century with the invention of calculus. Although there is an infinite number of times Achilles has to "catch up," the sum of this series is not itself infinite: it has a finite value as its limit. With the values here ($100 + 10 + 1 + \frac{1}{10} + \ldots$), Achilles overtakes the tortoise at $111.1111\ldots = 111\frac{1}{9}$ feet.
[95] E.g., Cohen 2008, 97–99.
[96] Arist. *Ph.* 250a19–24.

κέγχρος καὶ τὸ μυριοστὸν τοῦ κέγχρου.” ὁ μὲν οὖν Ζήνων οὕτως ἠρώτα τὸν λόγον.[97]

> In this way [Aristotle] solves the argument of Zeno of Elea, which he put to Protagoras the sophist. “Tell me,” he said, “Protagoras, does one grain of millet make a sound when it falls or the ten thousandth part of it?” When he said that it did not make [a sound, Zeno] said, “And the bushel of millet grains, does that make a sound when dropped or not?” When he said that the bushel did resound, Zeno said, “Why then, surely is there not some ratio between the bushel of grains and the one grain and the ten thousandth part of the one?” When he affirmed this, Zeno said, “Why then, will the ratios that the sounds have to one another also be the same? For as [is the case for] the things making the sounds, also [is the case for] the sounds. And this being the case, if the bushel of millet makes a sound, so too will one grain make a sound and the ten thousandth of the grain.” Zeno put his argument in this way.

Several questions arise with this passage. First, is Simplicius quoting directly from a work of Zeno? We know that Zeno was connected with the dialogue form, as Diogenes Laertius informs us that “they say that Zeno of Elea was the first to write dialogues.”[98] Furthermore, so far as we can trust our sources when it comes to chronology, it seems as if Zeno was a contemporary of the sophist Protagoras at Athens.[99] Yet some scholars have claimed that it would have been an odd choice for Zeno to have featured himself in a dialogue since the author-as-character is a trait found mainly in later dialogues.[100] In any case, putting aside the matter of exact attribution, there is no reason to question the material of the passage, even if it did not reach Simplicius and us in Zeno’s exact words, since it does not conflict with Aristotle’s highly abbreviated account.

Presuming, then, that the material Simplicius presents in genuine, the other pressing issue is: what is Zeno’s point here? Surely he did not mean to argue simply about the sound that millet

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[97] Simpl. *in Ph.* 1108.12–28.

[98] διαλόγους τοίνυν φασὶ πρῶτον γράψαι Ζήνωνα τὸν Ἐλεάτην; “they say that Zeno of Elea was the first to write dialogues” (D.L. 3.47).

[99] Apollodor. *ap.* D.L. 9.56 and Eus. *Chron.* 113, 20 put Protagoras’ *floruit* in the 84th Olympiad [444–440]; Several sources (DK29 A1 and A2, which includes Apollodorus and Eusebius as well) put Zeno’s *floruit* between the 78th and the first year of the 81st Olympiad [464–456]. Putting aside exact chronology from later sources, Plato informs us that Zeno was around forty years old when Socrates was a young man (*Parm.* 127b), while Protagoras told a middle-aged Socrates that he was old enough to be his father (*Protag.* 317c).

[100] Burnet 1920, 312; Lee 1936, 110; Guthrie 1969, 81. Yet, the notable absence of the author within his own dialogues is above all characteristic of Plato (he mentions himself in passing only in two works, at *Ap.* 34a and 38b and *Phd.* 59b); On the contrary, Aristotle and Cicero make themselves characters. Cf. Hirzel 1895, 55–56 for Zeno’s role in developing the literary form.

seeds make. Here the character of Protagoras provides a clue, as Sedley has noted.[101] Protagoras was well known for holding that everything in the world is as we sense it and Zeno is concerned here with turning that contention on its head. This line of argument would absolutely be in keeping with Zeno's position as Parmenides' disciple since the Parmenidean thesis that the senses—in this case hearing—are unreliable is also directly opposed to Protagoras' radical acceptance of the senses.

If we understand the passage in this way, Zeno's reasoning makes better sense. One can hear a bushel of, say, 10,000 grains fall on the floor easily. A ten thousandth part of a bushel is a grain and one can barely hear the single grain fall, if at all. A ten thousandth part of the one grain is entirely inaudible. Yet, there are simple proportional relationships between the part of the grain, the grain, and the bushel. It stands to reason that the same proportions hold for the sounds that the falling grains make—the type of falling body, the fact that it is falling, and the fact that impact creates sound are all the same, only the amount changes. This in turn implies that the ten thousandth of the grain makes a minute sound, *contra* our sense of hearing. Thus, our hearing is unreliable.

In a sense, this is a scenario that could be experimentally performed, unlike the "Achilles paradox" above. A single action is performed, a single variable is changed in a numerically measurable way, and the results are noted. The results confute a working hypothesis that we can trust our hearing in all cases. Yet, in another sense this would be a very unsatisfactory empirical test since the entire point is to force us to draw a conclusion against the evidence of our senses. Thus, again, it is best to see it as having some structural similarities to an experiment in *our* sense of the term, yet with an entirely different agenda.

[101] Sedley 1977, 112n85.

Furthermore, there is evidence that other thinkers used similar thought experiments to prove the limitations of our other senses, such as sight. Anaxagoras is quoted by Sextus Empiricus as positing a similar experiment:

> ἔνθεν ὁ μὲν φυσικώτατος Ἀναξαγόρας ὡς ἀσθενεῖς διαβάλλων τὰς αἰσθήσεις "ὑπὸ ἀφαυρότητος αὐτῶν" φησὶν "οὐ δυνατοί ἐσμεν κρίνειν τἀληθές." τίθησί τε πίστιν αὐτῶν τῆς ἀπιστίας τὴν παρὰ μικρὸν τῶν χρωμάτων ἐξαλλαγήν· εἰ γὰρ δύο λάβοιμεν χρώματα, μέλαν καὶ λευκόν, εἶτα ἐκ θατέρου εἰς θάτερον κατὰ σταγόνα παρεκχέοιμεν, οὐ δυνήσεται ἡ ὄψις διακρίνειν τὰς παρὰ μικρὸν μεταβολὰς καίπερ πρὸς τὴν φύσιν ὑποκειμένας.[102]
>
> Hence, Anaxagoras, the consummate natural philosopher, attacking the senses as weak, says "we are not able to discern the truth by their feebleness," and he puts forth as proof of their untrustworthiness the gradual change of colors. For if we should take two colors, black and white, and then poured one into the other a drop at a time, our sight would not be able to discern the gradual changes, although [the changes] exist in nature.

This line of reasoning, while related to Zeno's millet paradox, is different in a significant way. Rather than changing what is being observed by a large amount, the point here is that the changes are so minute that they are impossible to see. We know that something in the nature of the first color has changed, because we have added something different—indeed its exact opposite.[103]

Such minute changes also raise a disturbing implication as to the identification of color itself. Common sense tells us that there is a point at which the original color ceases to be white or black and becomes something else: grey. But where is this point? We proceed drop-by-drop, but because we are changing the color so slowly, there does not seem to be a natural cutoff point. We can always ask: why is this color grey, or white, or black, but the color right before it is not? And because color exists on a continuum, we can decrease the amount of the change *ad infinitum*, but without any answer to our conundrum.

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[102] S.E. *M.* 7.90.

[103] This is presuming that the colors can "blend" together seamlessly. A similar image of mixing a single drop of wine with the ocean, and then, paradoxically, claiming that the ocean is both entirely water and entirely wine (although not to the same degree), was later utilized by Chrysippus (D.L. 7.151).

Although Anaxagoras does not draw out the implication here, later skeptical philosophers did so and formulated this line of reasoning as the *sôrites* or 'heap' paradox.[104] This paradox proceeds in a similar manner. We ask ourselves whether one grain makes a "heap." We of course answer "no," and so add another grain. Any reasonable person must also agree that the addition of a single grain does not create a "heap" either. This, however, proceeds *ad infinitum* until, at some indeterminate point, we have a "heap." But where is this numerical boundary, where we have a heap if we add a grain, but do not if we take it away? The boundary is a "fuzzy" one, and has led to an enormous amount of speculation, both ancient and modern.[105] But here the paradox has undergone a fundamental shift from its Presocratic roots. While Anaxagoras' doubt is centered on the senses, Hellenistic thinkers felt that the question was one of logic and language: how can we use predicates (like "is a heap," "is few," etc.) in a way that avoids vagueness when it comes to marginal cases?

As many interesting philosophical issues as Anaxagoras raises here, one question is especially important for our purposes: is this a truly performed experiment, or a thought experiment? Nothing would have prevented Anaxagoras from undertaking the experiment described, perhaps with different hues of paint. Indeed, Empedocles used the mixing of paint in an extended metaphor and Anaxagoras himself is said to have written a treatise on scene-painting for the stage.[106] Yet, the context in which the description is given does not include enough detail for us to draw a firm conclusion and the experiment is as effective imagined as it would have

[104] The paradox in this form seems to have been invented by the post-Socratic philosopher Eubulides of Megara (D.L. 2.108), and was famously used against Chrysippus by Arcesilaus and the skeptical Academy (Cic. *Ac.* 2.92–96). Much has been written about the Hellenistic *sôrites* paradox (cf. Barnes 1982b and Burnyeat 1982 for two famous treatments), but to my knowledge, no treatment remarks upon the proto-"soritical" reasoning of Anaxagoras' thought experiment with colors.
[105] Barnes 1982b, 65–66 lists the ancient citations. On post-antique and modern treatment of the paradox see Williamson 1994, 31–35; Sainsbury 2009, 40–66.
[106] DK59 A39.

been performed.[107] Perhaps it is safest to say that it at least describes a thought experiment, but one which could have easily been performed in practice.

Indeed, even though Zeno and Anaxagoras offer us several interesting examples that are reminiscent of empirical tests of nature found in other authors, there is ample evidence that these were never meant to be performed. For one, the entire point of these thinkers was to prove paradoxical conclusions, including about the unreliability of sense data. If they were to be performed, then, they would be self-defeating: if one proves the unreliability of the senses by experiment, one also proves the unreliability of the experiment's results. Thus, these passages are better interpreted as thought experiments which have the structure of a performed experiment, but are not scientific in that they do not test nature directly. Rather they are used to hone our reasoning, even when that reasoning flies in the face of what our senses tell us. If anything about the ancient use of experimentation (broadly construed to contain thought experiments) conflicts with the modern scientific method, it is exactly this.

2.4. A Presocratic Model of Investigation

Although we have only scattered remains from the Presocratic philosophers, we can draw two main conclusions. First, the epistemology of the various Presocratics, which differed in particulars, nevertheless allowed room for empirical investigation. Except for the Eleatics, who were in many ways removed from the mainstream of the time,[108] the Presocratic philosophers saw sense perception as a necessary, but imperfect, tool in their mission of understanding nature.

Nor were these philosophers simply acute collectors of passive observations, although they were often that. They also directly intervened into this or that physical phenomenon in a controlled way and observed the results. Some of these instances (like Anaximenes' test) accord

[107] One is reminded of the "missing shade of blue" thought experiment of Hume in his *Enquiry*, which also deals with sensory perception of color, but was not performed.
[108] See note 21 above.

with the actual phenomena and were simple enough to have been performed. Others (like Anaxagoras' gradual mixture of color) gernally expressed and are perhaps should be interpreted as thought experiments. Thought experimentation would have appealed especially to the Eleatic Zeno, since it presumed no sensory input. Yet, all the tests we find in the philosophers are notable for being precisely designed to change only a single variable and to observe—whether actually or mentally—the results.

As the investigation into nature grew in popularity with these thinkers, we shall see that this strategy of understanding the world migrated into other topics. The idea that one can set up a precise scenario, intervene into it, and record the results also spread into various contexts, including music, mathematics, history, and, medicine—all the topics which made up the broader *historia peri phuseôs*.

CHAPTER THREE: EMPIRICAL ENGAGEMENT IN ON GENERATION/ON THE NATURE OF THE CHILD/DISEASES IV

3.1. Introduction

An especially important body of sources for scientific work in the Classical period is the Hippocratic Corpus. Although we now usually call them a set of medical treatises, they are not simply medical, even if most were originally composed by physicians.[1] They also include much biology, geography and ethnography, and even sometimes mathematics and numerological speculation. Thus, they are an important source for reconstructing the methods and content of early Greek science, especially since the Hippocratic corpus is closely related to contemporary work by philosophers interested in human biology.[2]

Even though we are fortunate enough to have plenty of complete treatises to study, the pseudonymous Hippocratic Corpus is not without its own interpretative difficulties. First, I will introduce the Corpus and the history of its creation. Because texts from many different sources and with many different methodologies were collected together with little regard for consistency, it follows that the most fruitful approach is to focus on a specific treatise, or set of treatises, which belongs to the period under consideration. Second, I will argue that a collection of treatises—*On Generation*/*On the Nature of the Child* and *Diseases* IV—is perfectly suited to the question of the use of empirical testing in early Greek science. To do so, I will investigate the

[1] Although not necessarily just *for* physicians: there is ample evidence that some Hippocratic treatises were originally intended for consumption by a lay public (cf. Jouanna 1999, 57–58).
[2] E.g., Alcmaeon, who inhabited the borderlands between natural philosophy and medicine. Cf. Aristotle's contention at *Resp.* 408b and *Sens.* 436a that medicine and natural philosophy are coterminous (σύνορος) disciplines.

body of treatises, its authorship, its date and its general method, which is emblematic of the intellectual milieu of *historia*. Then we shall take an in-depth look at the empirical evidence that frames the treatises, placing them in their historical and intellectual context and seeing how the empirical tests contained therein related to the author's theoretical commitments.

3.2. Hippocrates and the Hippocratic Corpus

The Hippocratic Corpus is comprised of around sixty treatises of varying date, authorship and subject matter. Over time, however, they all were pseudonymously attached to the name of Hippocrates—the famous fifth-century physician whose skill was well-known even in his lifetime. Plato is our earliest extant source concerning Hippocrates, mentioning something both of his Asclepiad lineage and his doctrines.[3] A generation later, Aristotle used Hippocrates' name as a by-word for physician.[4] Such references, with little else in the way of explanation as to which Hippocrates—a common name in Athens at the time[5]—they were referring to, help to show that Hippocrates was already an eminent personage in late fifth- and fourth-century Athens.[6] But little else in the way of reliable biography has made its way to us from such an early period, much less from contemporary sources. Most biographical information instead comes from Roman and Byzantine sources, which may, however, date back to earlier authorities.[7]

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[3] Pl. *Prt.* 311bc; *Phdr.* 270c. Ar. *Thesm.* 272 (ὄμνυμι τοίνυν πάντας ἄρδην τοὺς θεούς; "I swear by all the gods together") has sometimes been interpreted as an allusion to the beginning of the Hippocratic *Oath* (ὄμνυμι Ἀπόλλωνα ἰητρὸν, καὶ Ἀσκληπιὸν…καὶ θεοὺς πάντας τε καὶ πάσας; "I swear by Apollo the doctor, and Asclepius…and all the gods and all the goddesses"), although many commentators either reject the allusion or are agnostic (for the former, cf. Jouanna 1999, 7, Austin and Olson 2004, 142; for the latter, cf. Kudlien 1971).
[4] Arist. *Pol.* 1326a 15–16.
[5] In addition to other Hippocrates known from literary sources (e.g., the mathematician Hippocrates of Chios, who worked in Athens, or the *strategos* mentioned first at Thuc. 4.66 and then *passim*), there are twenty-six instances of the name in fifth- and fourth-century Attica (Austin and Olson 2004, 142).
[6] We should not, however, place his *acme* too early in the fifth-century: Herodotus states that Democedes of Croton was the foremost doctor of the day and that the best doctors in Greece came from Croton and Cyrene, without mention of Hippocrates' home of Cos (Hdt. 3.125 and 3.131–132).
[7] Jouanna 1999, 9 goes over the fullest, later sources for Hippocrates' biography. Soranus' *Vita Hippocratis* is especially useful since he names his sources throughout (which include Eratosthenes, Pherecydes of Athens, and

The collection of around sixty works now attributed to Hippocrates, then, surely is a later construction. Aristotle, for instance, imputes doctrines found in the Hippocratic Corpus not to Hippocrates himself, but to his student Polybus.[8] On the other hand, the *Anonymus Londoniensis*, which probably draws upon the work of Aristotle's student Meno, gives a précis of Hippocrates' views, which agrees only with the treatise *On Breaths*, and does not show any awareness of other 'Hippocratic' works.[9] In short, using the apt phrase of Jouanna, the Hippocratic Corpus was made up by "writings in search of an author,"[10] and Hippocrates was an excellent candidate given the logic that attribution should go to the most famous name possible. We can imagine both anonymous treatises and those by lesser known authors being reattributed in order to ensure the widest possible interest in their contents.

By the first centuries BCE and CE it is clear that a collection had formed around Hippocrates' name, since the works we know now as Hippocratic were well known by ancient authors. Philo most likely knew of the work *On Sevens*, which now, apart from a few Greek fragments, survives only in Latin and Arabic translation.[11] Apollonius of Citium, a first century BCE physician, wrote a commentary[12] on the Hippocratic *On Joints*.[13] Authors of the next century, like Soranus and Plutarch, show an acquaintance with a greater number of works in our

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several later physicians). The inclusion of Pherecydes – a fifth-century logographer who traced divine genealogies down to his day – may seem strange, but is probably explained by Hippocrates' status as an Asclepiad (and, therefore, his relation to Apollo). It has been debated, however, whether a writer as early as Pherecydes could have written about Hippocrates himself (cf. *FGrHist* 3 F59, 409 and Thomas 1989, 159, n. 6).

[8] Arist. *HA* 512b12–513a7 = Hp. *Nat. Hom.* 11.

[9] Jouanna 1999, 59–61; Smith 2002, 36–8.

[10] Jouanna 1999, 56.

[11] *Op.* 105; 124. Mansfeld 1971 dated this treatise quite late (1st century CE, which would make it contemporaneous with Philo) on various grounds, but others have left open the possibility of or opted for an earlier date (e.g., West 1971, 383–385; Craik 2015, 128). *Vit. Cont.* 16 also quotes Hippocrates' famous first aphorism "life is short, but the art is long," but since sayings are easily memorized, there is no reason to conclude that he had the written collection of Hippocratic aphorisms that we have today.

[12] It has been debated whether this work by Apollonius is a commentary in the true sense and most scholars now see it as an interpreative introduction rather than a true ancient *hypomnema*, cf. Potter 1993; Roselli 1998; Smith 2002, 212–215.

[13] *CMG* 11.1.1. The preface to his work allows dating him to the first century BCE since the dedication to King Ptolemy (either Ptolemy Auletes or Ptolemy of Cyprus) provides a *terminus ante quem* of 51 BCE.

Hippocratic Corpus than most earlier writers.[14] But the most important source is the grammarian Erotian, who compiled a lexicon of difficult words contained in "Hippocrates" in the first century CE. In the introduction to his work, he lists all the writings in *his* Hippocratic Corpus and divides them into categories, thus showing not only the existence of a Hippocratic Corpus substantially similar to ours, but also its scholarly reception at the time.[15]

Whether the gathering of these texts happened over a long period of time or in a short burst of critical activity, we do not know. But perhaps we should note that there *is* evidence of work on Hippocrates by scholars before Erotian. In his preface, Erotian, very helpfully for us, names many of his predecessors who wrote about difficult words in Hippocrates. These include students of the Alexandrian doctor Herophilus (Bacchius[16]) as well as doctors from certain sects (Philinus, the founder of 'empiricism'), philosophers (the Peripatetic Aristonicus of Rhodes), and literary scholars (e.g., Aristarchus and Didymus[17]). As one would expect from ancient writers hailing from different disciplines, and especially from different schools within a single discipline, Erotian informs us that much of the work was polemical in nature.

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[14] Plut. *De coh. ira* 455e (= Hp. *Prog.* 2); *Aet. Rom.* 291c (= Hp. *Flat.* 1); *De Garrul.* and *De Cap. ex Inim.* 90d (= Hp. *Ep.* 3.2.6). Sor. 1.60 (= Hp. *Nat. Pueri* 13 and *Oath* 15, on which see section 3.6.1 below).

[15] Erotian divides the Corpus into headings (semiotic, physical and aetiological, those on the art, therapeutic, and mixed) and sub-headings (the therapeutic works were divided into dietetic, surgical, and entirely mixed – presumably so much that classification was made impossible). It is unclear whether Erotian adapted this scheme from elsewhere, although similar divisions were made of the Platonic corpus (D.L. 3.49–50).

[16] Bacchius (latter half of the 3rd century BCE) was an extremely important source for Erotian and the first scholar whom we know focused on Hippocrates specifically (Smith 2002, 202). Erotian also mentions an otherwise anonymous Xenocritus of Cos, as the first to explain 'these sorts of utterances' (τὰς τοιαύτας…φωνάς) by which he may simply mean the first to compile a lexicon of Ionic (cf. the only citation at Erot. 4, 24–26 Nachmanson: Ξενόκριτος δὲ ὁ Κῷός φησι παρὰ τοῖς Ἴωσι λέγεσθαι τὸ ἀλλοφάσσειν ἐπὶ τοῦ τῆς διανοίας παραφόρου; "Xenocritus of Cos says that 'deleriousness' is said among the Ionians for delusion of thought"). For more on Bacchius, cf. von Staden 1989, 484–500, von Staden 1992b, and Smith 2002, 202–204.

[17] τῶν δὲ γραμματικῶν οὐκ ἔστιν ὅστις ἐλλόγιμος φανεὶς παρῆλθε τὸν ἄνδρα [sc. Ἱπποκράτην]…ἔτι δὲ Ἀρίσταρχος καὶ μετὰ πάντας Ἀντίγονος καὶ Δίδυμος οἱ Ἀλεξανδρεῖς; "Of the grammarians, there is not one who was clearly held in regard and passed over the man [sc. Hippocrates]…Aristarchus, and after all them, Antigonus and Didymus, the Alexandrians" (Erot. 5, 14–19 Nachmanson). Manetti 2015, 1143–1145, however, counsels caution about Aristarchus here, for whom there is no other evidence of interest in Hippocrates. Yet, as she also notes, before the discovery of *P.Amherst* 2.12, there was also no evidence that Aristarchus was interested in Herodotus, another Ionian prose writer.

But the very popularity of the works gives rise to a major interpretive danger in studying the Hippocratic Corpus. Because of the attraction that the name of Hippocrates exerted, many works from different times and intellectual contexts were gathered into a single collection. Thus, it is not a straightforward proposition to compare one Hippocratic work to another; indeed, sometimes they even contradict each other.[18] The problem was acute enough in ancient times that medical writers began to try to separate the genuine Hippocrates from spurious writings. Galen wrote a now lost *Commentary on the Genuine and Spurious Writings of Hippocrates*.[19] Erotian also may have called into question two treatises—the *Embassy* and *Oration from the Altar*—by saying that they belonged more to a "patriot than a doctor."[20] We do not pay as much attention to Hippocratic authorship *sensu stricto* today—mainly because in most cases it is nearly impossible to establish[21]—but we must attend to the dating and contextualizing of these pseudonymous works or risk anachronism.

Yet dating itself is a vexed task since we must often rely on internal evidence. Sometimes the undertaking is made easier by references contained in the text; for example, *On Ancient Medicine* mentions Empedocles, and so must have been written after his *floruit* in the mid-fifth century BCE.[22] Other times, we must surmise a date based on intellectual affinities with other works. This procedure need not be, but often is, circular. An example of the non-circular type of this sort of reasoning would be the treatise *On the Heart.* It can be reliably dated to the

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[18] A very obvious contradiction is between *Nat. Pueri* 13 which describes an abortion carried out at the behest of 'Hippocrates' (according to the ancients, or course) and the Hippocratic *Oath* which famously forbids abortive pessaries; see section 3.6.1 below.
[19] Gal. *in Hip. Nat. Hom.* 19, 15 (all references to Galen hereafter refer to Kühn's standard edition).
[20] Πρεσβευτικὸς γὰρ καὶ Ἐπιβώμιος φιλόπατριν μᾶλλον ἢ ἰατρὸν ἐμφαίνουσι τὸν ἄνδρα; "For the *Embassy and Oration from the Altar* show a patriotic man rather than one of medicine" (Erot. 9, 20–1 Nachmanson). Although, as Smith 2002, 222 notes, this is not a decisive statement that Erotian considered these works spurious.
[21] As with other such 'questions,' especially the Homeric question, modern scholarship has by and large moved past the 'Hippocratic question' as originally formulated. Lloyd 1991, 194–223 sums up both the staggering amount of work done on the question and the very little we have to show for it, and recently Craik 2015, 89 has opined: "such a quest is now generally viewed as chimerical and somewhat discredited." Some scholars hold out more hope for attributing particular treatises (as, for instance, Smith 2002, 44–61 does for *On Regimen*), but they are the outliers.
[22] Schiefsky 2005, 63–65; Craik 2015, 285.

Hellenistic period because its description of the organ is accurate enough that it must have relied on the dissection of a cadaver, and we know from external sources that the third century BCE physician Herophilus was the first to perform such an operation.[23] Yet more often we must compare material to what is said in other Hippocratic treatises also of uncertain date, and this undoubtedly runs the risk of circular reasoning as one debatable text bolsters the dating of another. But it must be noted that *precise* dates, while desirable, are not always needed when studying and comparing the content of a treatise. Intellectual change is not instantaneous; often authors continue on contributing to debates when, in hindsight, it is clear that the debate has run its course. More specifically, in the case of the Corpus, one can continue to do Presocratic natural philosophy well into the fourth century. In this sense, we need only to place a treatise within its wider intellectual context, which still requires dating, but to a less exact degree.

With these problems of dating and the creation of the Corpus in mind, it seems best to focus on a single text or a small group of texts as an exemplum, in order to avoid the pitfalls of interpreting across incompatible texts and in order to restrict the focus to a manageable scope. Two considerations, then, seem to come to the fore in choosing the text for this study: 1). that it belong to the date under consideration (i.e., to the Presocratic period, again observing that this does not mean it is *precisely* dated to before Socrates or even Plato), and 2). that its methodology belong to the same period. Although several treatises fit this description, the collection of treatises *On Generation*/*On the Nature of the Child* and *On Diseases* IV fits both criteria easily.

[23] Duminil 1998, 164–169 and 175–181. On Herophilus' dissection cf. Von Staden 1989, 139–153, Von Staden 1992a for more on the pre-Hellenistic taboo on dissection, leaving analogy as one of the only ways to proceed.

3.3. The Treatises On Generation/On the Nature of the Child and Diseases IV: Date and Author

The treatise—or rather, part of a treatise, as we will see—*On the Nature of the Child* was a well-known part of the Hippocratic Corpus in antiquity. Erotian includes it under the heading of "aetiological and physical treatises," i.e., treatises dealing with the usual (healthy) workings of the human body.[24] The definition of the work as physical or 'natural' seems to have been generally adopted later, as the sixth century Hippocratic commentator Palladius placed it before treatises dealing with sickness, reasoning that 'what is natural is more worthy than what is unnatural'.[25] Galen also refers to it several times. Alongside casual references to the title of the treatise and more in-depth discussion based on its contents,[26] Galen also quotes several extensive passages from the treatise *verbatim*.[27] Elsewhere he tells us that he is quoting the beginning of the treatise and again gives the same opening as contained in our Hippocratic Corpus, which suggests that Galen had access to a version of the text with roughly the same structure as ours.[28]

If we can surmise, as seems plausible, that the text available to Erotian in the first century BCE is the same as the one quoted by Galen in the second century CE, then we can confidently date *On the Nature of the Child* at least that far. But can we date it further back as an example of *historia* in the Classical period? Ancient sources almost uniformly identify Hippocrates as the

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[24] Erot. 9, 10 Nachmanson.

[25] ταῦτα [sc. τὰ κατὰ φύσιν] γὰρ τῶν παρὰ φύσιν τιμιώτερά εἰσιν. διὸ πάλιν δεῖ προλαμβάνειν τό τε Περὶ παιδίου φύσεως; "Things [that are according to nature] are more honorable than that which is outside of nature. For this reason, it is right to take up *On the Nature of the Child* beforehand"… (Pall. *in Hp. Fract.* 18, 19–21 Irmer). Another version of this Hippocratic reading order passed down under the name of the seventh century commentator Stephanus can be found Steph. *in Hip. Fract.* 19, 18–20 Irmer.

[26] E.g., Gal. *De fac. nat.* 86, 13; *In Hp. Epid. VI comment.* 1006, 9.

[27] E.g., Gal. *In Hp. Epid. VII comment.* 828, 7; *Foet. form.* 653, 14–15. In both passages he explicitly states that he is quoting Hippocrates 'to the very word' (κατὰ τήνδε τὴν ῥῆσιν).

[28] [sc. Ἱπποκράτης] φησὶ γοῦν ἀρχόμενος τοῦ περὶ φύσεως παιδίου…; "Hippocrates says in the beginning of *On the Nature of the Child*…" (Gal. *De sem.* 595, 16–7); μὴ τοίνυν ἔτι πρὸς Ἱπποκράτην ζυγομαχείτωσαν εἰπόντα κατὰ τὴν ἀρχὴν τοῦ περὶ φύσεως παιδίου γράμματος…; "Therefore, let them not quarrel with Hippocrates who said at the beginning of his writing *On the Nature of the Child*…"(Gal. *De sem.* 600, 10–11).

author, except for Galen who in one passage is unsure whether to attribute the treatises to Hippocrates or his student Polybus.[29] Yet, as we have noted, the authorial presence of Hippocrates is not well-attested until quite late. So we must rely on internal evidence and see whether *On the Nature of the Child* takes part in the debates current in the late fifth and early fourth centuries.

Luckily, an authorial connection between *On the Nature of the Child* and two other treatises—*On Generation* and *On Diseases* IV—makes dating an easier task, for, taken together, they all offer evidence of a late fifth-century date. Littré in his landmark 1851 edition, was the first to hypothesize that these three treatises were originally a single work: he noted that the treatises all referred to one another and seemed to stop abruptly and start just as abruptly from the same thought.[30] Most modern scholars follow Littré and accept that they all are the work of the same author, given the similarities in thought and expression[31], but hold that only *On Generation* and *On the Nature of the Child* belong together as a single treatise, since *Diseases* IV deals with topics concerning disease that the other treatises do not.[32] The author also probably wrote the treatise *On the Diseases of Women*, given his statement that he will pass over certain topics, but "they will be described in *On the Diseases of Women*."[33] Even so, the safest approach

[29] ὁ γράψας τὸ περὶ φύσεως παιδίου βιβλίον, εἴτ' αὐτὸς Ἱπποκράτης ἐστὶν εἴθ' ὁ μαθητὴς αὐτοῦ Πόλυβος; "The author of the book *On the Nature of the Child*, whether it is Hippocrates himself or his student Polybus" (Gal. *Foet. form.* 653, 14–5). Galen may be just be, reasonably, passing over the question of actual authorship here and rightly noticing that the treatise is 'Hippocratic' in a looser sense.
[30] Littré 1851, 462–463; 486, n. 1; 542, n. 1.
[31] Regenbogen 1930/1961, 169–176.
[32] E.g., Lonie 1981, 43–51; Craik 2015, 117. Giorgianni 2006, 16–30 gives the most up-to-date and fullest overview of the *status quaestionis* about the author. Cf. the ancient definition of "physical" treatises dealing with the healthy working of the human body as opposed to disease in Palladius above.
[33] Ἀλλὰ τί δεῖ λέγειν αὐτὰ ἐνθάδε; εἰρήσεται γὰρ ἐν τοῖσι Γυναικείοισι νοσήμασιν· ἀλλ' ὅθεν ἀπέλιπον περανέω τὸν λόγον; But why is it necessary to speak of these things here? For they will be spoken of in the *Diseases of Women*. I will finish the remainder of the account there" (*Nat. Pueri* 15). Although the construction is passive and makes no personal claim to the work on women's diseases, the author of *On the Diseases of Women* states that he wrote a book about the nature of the child in the womb (1.1 cf. 1.44, 1.73). It is probable, but by no means certain, that by this the author of *On Diseases of Women* means the treatise we now call *Genit./Nat. Pueri*.

seems to be to stick to these three treatises (while cross referencing others when appropriate) from the pen of the same author with the same habits of speech and thought.

Once we look at these three treatises together, there are other points that suggest a date of the late fifth or early fourth century BCE. In *On Generation* 3, the author adopts two positions representative of fifth-century thought. First, he states that the seed comes from "the entire body, from both solid and soft parts, and from its entire moisture."[34] This doctrine, called pangenesis, is also found in Democritus and other Hippocratic treatises, although the question of Democritus' direct influence, as opposed to both having a generally similar theory, is a vexed one.[35] The second position is a variant of the humoral theory famously described in the more or less securely datable *On the Nature of Man*.[36] There is also an experiment contained at *Nat. Pueri* 25 (see section 4 below) seeks to confirm the Presocratic philosophical principal of like-to-like and echoes a similar demonstration described by Democritus.[37]

Finally, Aristotle replicates an experiment found in *On the Nature of the Child* (dealt with below in section 5.2)[38], and, given the pre-Aristotelian context of the work and the fact that Aristotle often borrowed from Hippocratic treatises, we may assume that Aristotle borrowed the experiment from *Nat. Pueri* as well. Thus, he may act as a *terminus ante quem*, although not one placing the treatise in the fifth century (for we cannot exclude a date of the early fourth century). It is clear, then, that no one piece of evidence decisively places this treatise in the fifth century

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[34] Τὴν δὲ γονήν φημι ἀποκρίνεσθαι ἀπὸ παντὸς τοῦ σώματος, καὶ ἀπὸ τῶν στερεῶν καὶ ἀπὸ τῶν μαλθακῶν, καὶ ἀπὸ τοῦ ὑγροῦ παντός; "I claim that the seed is separated out from the entire body, both from the solid parts and soft, and from the entire moisture [sc. of the body]" (*Genit.* 3).
[35] Democritus DK68 A141; Hp. *Aër*. 14, *Morb. Sacr*. 5. Cf. De Ley 1981; Lonie 1981, 64–67; Giorgianni 2006, 52–55 on the connection between the philosophical and medical uses of the doctrine of pangenesis.
[36] We can date *Nat. Hom.* securely as *Nat. Hom.* 1 mentions Melissus whereas Arist. *HA* 512b12–513a7 summarizes *Nat. Hom.* 11 as the work of Polybus. Though this is the *locus classicus* of humoral theory for us, there were many variations of humoral theory around this time, although the author of *Nat. Pueri* is notable for not connecting his humors with natural elements (e.g., fire, water) or abstract qualities (e.g., hot, dry) like philosophically minded doctors such as Alcmaeon (Lonie 1981, 56–57). Also cf. *Morb.* IV 38.
[37] DK68 B164.
[38] *Nat. Pueri* 29 = Arist. *HA* 6.3, *GA* 3.2.

(or perhaps very early fourth century), but an accumulation of evidence makes it the most probable dating.

3.4. The Method of *Genit.*/*Nat. Pueri*/*Morb.* IV: Analogy and Observation

As one would expect from a collection of works with numerous authors, topics, and dates of composition, there is wide variation in how an author of any Hippocratic treatise goes about his work and the sorts of arguments he uses (if indeed there is any argument at all). For us, an important fault line is the extent to which authors relied upon empirical research since the Hippocratic Corpus can vary quite widely in this regard. For example, the author of the treatise *On the Nature of Man* adopts the theory of the four humors, adapted from Empedocles' theory of the four elements, to explain health and disease. There is no attempt to support the overarching theory based on empirical evidence; rather, the invisible processes posited by the theory are used to explain all the perceptible phenomena of disease, and scientific research in our sense is otiose. At the other extreme, however, one may consider the case studies contained in *Epidemics* I and III, where the writers (since they are actually notes from several hands[39]) compile case studies of individuals but make no explicit attempt to generalize them into a theory.[40] At this early point, the methodological dichotomy is an implicit one, but, as the theoretical study of medicine became institutionalized at Alexandria, we see intellectual orientations turned into formal "schools" of medical thought.[41]

The collection of treatises *On Generation*/*On the Nature of the Child* and *On Diseases* IV, on the other hand, do not seem to adhere to either extreme—being either too theoretical or a

[39] *Epidemics* I and III, however, are usually treated as parts of the same 'group' of notes (cf. Deichgräber 1933, 9–23; Craik 2015, 89).

[40] The insistence on counting the days before a 'crisis' may also have some theoretical (in this case numerological) underpinning (cf. Giorgianni 2014). But nowhere in the *Epidemics* do the authors give an explicit formulation of these principles, if indeed they were led by them.

[41] The empiricists were founded by Philinus of Cos (ca. 250 BCE); later authors called Hippocrates the founder of the rationalists, but the idea of a methodological group called the λογική αἵρεσις is a later one (the term οἱ λογικοί referring to doctors is first found in Plb. 12.25e.4).

bare accumulation of facts.[42] Rather, it attempts to give a theoretically informed embryology, but at the same time marshals many observations and often applies them as analogies to invisible, biological processes.

In general, the theoretical reliance on analogy is a characteristic method of fifth century thought.[43] But in these treatises, the analogical reasoning is empirically engaged: it is connected with observation, and sometimes observations of deliberately designed and controlled scenarios. The inclusion of both analogy and empirical evidence is mainly explained by the fact that the author was hampered, as were all physicians before the Hellenistic physician Herophilus, from actually observing the interior of the human body due to a widely shared taboo against death and handling the dead.[44] This meant that the author could not engage in dissection, which forms the basis of accurate anatomical knowledge, both ancient and modern. The tenacity of the prohibition—and thus its short-lived abandonment in Hellenistic Alexandria—was remarkable.[45] We know of no dissection of cadavers before and for nearly a millennium and a half after Herophilus and Erasistratus, even though there is plenty of evidence of dissecting (and vivisecting) animals, and human-like animals in particular, showing that later ancient doctors

[42] Cf. Preus 1983, 188: "The gynaecological works of the Hippocratic Corpus have both "empiricist" and "rationalist" sections; their authors are not committed to one approach or the other."
[43] Lloyd 1966 lays the essential groundwork for the study of analogy in fifth-century thought. On analogy in Hippocratic medicine and this collection of treatises in particular, cf. Regenbogen 1930/1961; Lloyd 1966, 345–360; Lonie 1981, 77–86; Fausti 2010.
[44] On the ritual uncleanliness of the dead in a Greek context cf. Parker 1986, 32–48, Bendlin 2007. Although no Hippocratic work explicitly speaks to ritual pollution in relation to dissection, works in the Corpus seem to recognize the concept of the pure and the polluted (e.g., *Morb. Sacr.* 6). But the importance of this taboo can be overstated as well for it is first and foremost a religious doctrine (especially one regarding priests), then a societal one (Bendlin 2007, 180–181).
[45] It is not immediately clear what precipitated the change in the Hellenistic period, and why it changed so quickly. Various solutions have been assayed: changes in ideas about the soul, the authoritarianism of the Ptolemies, the influence of Egyptian culture and mummification practices (Edelstein 1967, 273–285; von Staden 1992a, 231–4). One should note, however, that these explanations do not exclude one another.

believed in the importance of the procedure.[46] So, like his contemporaries, our author proceeded with applying his own observations of what was visible to the invisible.

Indeed, the author shows some explicit awareness of his method by marking his observations with repeated and unique language. He explicitly states that it is possible to draw his conclusions from "what happens to be visible," implying that his observations can be repeated by anybody else.[47] This phrase also recalls the famous dictum of Anaxagoras and Democritus that ὄψις τῶν ἀδήλων τὰ φαινόμενα[48], another fact which helps to date this author to the late fifth century. Elsewhere, he refers to his observations of what is visible as "evidence for my account."[49] His word for evidence, ἱστορίον, is only found in this work and is a diminutive form of ἱστορία, perhaps connoting the pieces from which his entire investigation is composed.

In addition, there are further linguistic tags, first catalogued by Regenbogen, which the author uses to signal his observational evidence. Many of his descriptions of such evidence are regularly introduced with ὥσπερ εἴ τις, "it is as if someone…," followed by the present

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[46] Galen famously gives the endorsement: ἔκλεξαι δὲ εἰς τοῦτο τῶν πιθήκων τοὺς ὁμοιοτάτους ἀνθρώπῳ; "choose for this [i.e., dissection] the most similar of monkeys to a human" (*Anat. Admin.* 222, 5–6). Also cf. Celsus *Proem.* 23: *cum in interioribus partibus et dolores et morborum varia genera nascantur…ergo necessarium esse incidere corpora mortuorum*; "since in the inner parts pains and different types of diseases come about…therefore it is necessary to cut into the bodies of the dead," and *Proem.* 74 which offers a more full-throated statement in support of human dissection: *Incidere autem vivorum corpora et crudele et supervacuum est, mortuorum discentibus necessarium: nam positum et ordinem nosse debent, quae cadaver melius quam vivus et vulneratus homo repraesentat*; "To cut into the bodies of the living is both cruel and unnecessary, but it is necessary for learners to [cut into the bodies] of the dead. For they ought to have become familiar with its arrangement and order, which a cadaver better represents than a living or wounded human." Yet, Celsus' methodological assertion seems hollow in the absence of any genuine advance in the knowledge of human anatomy (cf. Scarborough 1976).

[47] Ξυμβάλλεσθαι δὲ παρέχει...τοῖσιν ἐμφανέσι γινομένοισι (*Genit.* 7).

[48] Lonie 1981, 133. Cf. chapter 2 section 2 on the principle.

[49] *Genit.* 1, 8; *Nat. Pueri* 13 (cf. Lonie 1981, 74 for more citations). Potter 2012 translates ἱστορίον as proof, which highlights what role the author believes the observations are playing in his account, although it has connotations (mainly from mathematics) of a single, irrefutable argument. That sort of proving by rigorous argumentation is not what the author has in mind here as he often uses several ἱστόρια to back up a single point (e.g., *Genit.* 8; *Morb.* IV 56).

optative.[50] The regular use of the conditional and the indefinite pronoun, perhaps, is a way for the author again to shift the burden of believability. Instead of relying on the audience's trust in his own credibility, he argues from what is universally observable. And even in the cases which one presumably would not run into on a daily basis, the conditional nature of the introduction again suggests that he believes *anyone* could confirm the experiment if so desired. It is also a way of speaking which is at variance with the claims of divine authority for making an assertion, most famously from early epic, but also in philosophical poetry where it exists side-by-side with explicit argumentation.[51]

Thus it is clear that the author has a fairly developed conception of and vocabulary for empirical evidence. This was in fact also Regenbogen's conclusion: that there was an isomorphism between the author's language and thought, and that the analogies were not simply literary dressing, but an important part of the author's thought process.[52] All these considerations place the collection of treatises squarely into the tradition of fifth-century natural philosophy as widely conceived. But it still remains to be seen how these observations and tests work: what sorts of things caught the author's eye and how his tests operate. And, in addition to evaluating the analogical reasoning behind such tests, we must consider whether different kinds of empirical evidence are used by the author.

3.5. Empirical Evidence in On Generation/On the Nature of the Child/On Diseases IV

Overall, there is no single type of observational evidence for the author; rather, his conception of empirical evidence runs the gamut from simple observations to purposeful and quite sophisticated tests.

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[50] Regenbogen 1930/1961, 190–1.
[51] As in Empedocles (DK31 B131) or Parmenides (DK28 B1 24–32); the former has an invocation to a Muse, whereas the latter meets with a mysterious goddess who sets him on the path to truth. It is debatable how much of this is genuine religious feeling and how much is the expectation of genre.
[52] Regenbogen 1930/1961, 143.

The simplest observations are, as noted above, used as the visible part of a "visible to invisible" analogy and are taken from everyday life. For instance, at *Nat. Pueri* 12, the author wishes to prove that warmth causes the embryo to let off 'breath'; he believes that warmth causes things to 'inhale' and the breath subsequently forces its way out by tearing the surface which contains it. As warm breath escapes, cold breath is taken in to 'feed' the process of combustion.[53] He then observes the same phenomenon in wood, and especially green wood (which he correctly notes does create more smoke when burned). When wood is burned, smoke escapes and rises, spiraling as cold "breath" is drawn in to take its place.[54] At first glance the author's general theory, and thus his analogical reasoning, seems to be completely mistaken: smoke is simply the evaporation of moisture in the wood. Yet later he states that breath is the result of moisture being warmed (i.e., evaporation), which brings his theory closer to a modern understanding. Thus the author's reasoning here is partly speculative and partly sound from the modern perspective, but, more importantly for us, the observation, simple though it is, in itself is accurate.

In addition to simple observational analogies, there are those which belong to a specific craft. This especially included horticulture, which, if not a craft, certainly qualifies as a specialized body of knowledge with its own technical texts in the ancient world.[55] At *Nat. Pueri* 22–27, the author goes on an extended excursus on the visible generation and growth of plants and how that can illustrate the invisible growth of humans in the womb.[56] Indeed, he sums up his entire position on the matter by saying with great methodological clarity that "if anybody wishes

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[53] The idea that "cold feeds the warm" is a theory found in other Hippocratic treatises as well, as in *Carn*. 6: καὶ τροφή ἐστι τῷ θερμῷ τὸ ψυχρόν; "And the cold is nourishment for the warm" (cf. *Vict.* III 62 for a substantially similar theory). See also Lloyd 1964, 100.

[54] The author's observation that a rising plume of smoke can sometimes curl around (ἐλίσσεται) is accurate, but the cause is not differing temperatures of air. Rather, the transition from 'laminar' to 'turbulent flow' is responsible (Gerhart et al. 1992, 130–131).

[55] From the scientific standpoint the first surviving botanic text is Theophrastus' *De Plantis*. However, from the standpoint of agricultural works, there is a longer history whose roots stretch back to Hesiod.

[56] Nor is his interest in plants contained to this passage: cf. *Nat. Pueri* 33–4 and the demonstration at *Genit.* 9 treated below. Cf. Lonie 1969 and 1981, 211–216.

to consider what I have said about these things, from beginning to end, he will discover that all growth (φύσις) is similar, both that of things growing from the ground and that of humans."[57] The interest in plants and the connection of their growth to that of humans is indicative of early Greek natural philosophy, and one can find many parallels.[58]

One noteworthy experiment utilizing plants is contained in *Genit.* 9. The author believes that the embryo will grow to the space available to it. Thus, large parents have large children and, vice versa, small parents will have small children. As he believes that vegetable growth and human growth are similar, he uses a horticultural demonstration to explain why:

> Ἔχει δὲ οὕτως, ὥσπερ εἴ τις σίκυον ἤδη ἀπηνθηκότα, ἐόντα δὲ νεογνὸν καὶ προσεόντα τῷ σικυηλάτῳ, θείη ἐς ἀρυστῆρα, ἔσται τοῦ ἀρυστῆρος τῷ κοίλῳ ἴσος καὶ ὅμοιος· ἢν δέ τις ἐς ἄγγος θῇ μέγα, ὅ τι ἐπιεικές ἐστι σίκυον χαδέειν, ἀλλὰ μὴ πολλῷ κάρτα μέζον τῆς φύσιος τοῦ σικύου, ἴσος ἔσται ὁ σίκυος τοῦ ἄγγεος τῷ κοίλῳ καὶ ὅμοιος· ἐρίζει γὰρ ἐν τῇ αὔξῃ τῷ κοίλῳ τοῦ ἄγγεος. Σχεδὸν δὲ εἰπεῖν καὶ πάντα τὰ φυόμενα οὕτως ἔχει, ὅκως ἄν τις καταναγκάσῃ αὐτά.[59]
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> It is just as if someone should place a cucumber which has already started to bloom, but is new and next to the cucumber bed into a cup, and it will be equal and similar to the cup. But if one places it into a great vessel, which is suitable to contain a cucumber, but is not very much bigger than the cucumber's nature,[60] the cucumber will be equal and similar to the vessel. For it strives in its growth toward the hollow space of the vessel. Suffice it to say also that nearly all things that grow behave however one forces them to.

Indeed, the general point that the author makes here (as opposed to his analogical application of it to growth in the womb) is quite valid. If one artificially restricts the space available for a fruit

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[57] Ἢν δέ τις βούληται ἐννοεῖν τὰ ῥηθέντα ἀμφὶ τούτων, ἐξ ἀρχῆς ἐς τέλος, εὑρήσει τὴν φύσιν πᾶσαν παραπλησίην ἐοῦσαν τῶν τε ἐκ τῆς γῆς φυομένων καὶ τὴν ἀνθρωπίνην (*Nat. Pueri* 27).

[58] E.g., Anaxagoras: ζῷον γὰρ ἔγγαιον τὸ φυτὸν εἶναι (DK59 A116), which explicitly ties together plant and animal biology on the basis of a definition.

[59] The text of *Genit./Nat. Pueri* and *Morb.* IV used here and below is that of Littré 1851, along with consultation of Joly 2003 and Giorgianni 2006. The main textual concern is the extent to which we should restore Ionic readings, a problem which we shall pass over here as it usually does not affect the text's meaning (cf. Giorgianni 2006, 128–134).

[60] The word for 'nature' here (φύσις) is usual, but clearly shows the overlap between the original meaning 'growth' and the later, but more common meaning 'nature' or 'essence.' LSJ s.v. II ("the natural form or constitution of a person or thing as the result of growth") is both a good definition and explanation of the usage.

or vegetable to grow, it will grow into the shape and size desired.[61] This is probably what the author wishes to distinguish when he twice uses the phrase ἴσος καὶ ὅμοιος. The latter is more qualitative similarity (in this case, shape) whereas the former is used for size (which can be measured quantitatively). Indeed, 'cup' (ἀρυστήρ or ἀρυτήρ) can act as both as the measuring device itself and the amount measured, as usual with these words.[62] This is, perhaps, a step toward quantitative measurement, especially given the author's use of the standardized 'Attic *cotyle*' elsewhere.[63] Less reassuringly, however, he seems to have misconceived of his general principle that the cucumber "strives in growth toward the hollow space of the vessel," and so a vessel "not very much bigger than the cucumber's nature" is needed. Of course, any vessel bigger than the natural size of a cucumber, as well as growing it out in the open, will result in generally the same sized cucumber. Given that he thinks that the cucumber has a "natural" size, one would expect him to understand that this test only works for *restricting* the size and shape of the cucumber. Perhaps, then, he was impelled to stipulate that the jar be not much bigger than a cucumber because it is an analogy to the embryo in the womb as well and the womb does not offer such 'extra' space. Thus, the motivation would be to keep both parts of the analogy as close as possible.

Still closer to our conception of an experiment are those tests which require some sort of specialized apparatus to carry out, and several tests of this type appear too, including a notable

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[61] The principle can be seen in action with the famous square watermelons found in Japan.

[62] An ἀρυ(σ)τήρ was not one of the canonical Greek measurements of volume; Hesych. s.v. glosses it as a κοτυλή, but there is no other evidence equating the two measures. However cf. the pharaoh's daily provision to his guards in Herodotus where it does seem to be somewhat standardized along with the *mina*: ἐπ᾽ ἡμέρῃ ἑκάστῃ, ὀπτοῦ σίτου σταθμὸς πέντε μνέαι ἑκάστῳ, κρεῶν βοέων δύο μνέαι, οἴνου τέσσερες ἀρυστῆρες. ταῦτα τοῖσι αἰεὶ δορυφορέουσι ἐδίδοτο; "Every day, a weight of five minas of roast grain, two minas of beef, and four cups of wine. These were always given to the bodyguards" (Hdt. 2.168).

[63] χωρέει ἡ κάθαρσις, ἕως τοῦ εἰρημένου χρόνου, πλῆθος ἀττικὴ κοτύλη ὅλη καὶ ἡμίσεια τὸ πρῶτον, ἢ ὀλίγῳ πλεῖον ἢ ὀλίγῳ ἔλασσον, κατὰ λόγον τουτέου μέχρις ἂν λήξῃ; "the purgation flows, until the stated time, an entire Attic *cotyle* in amount and half at first, or a little more or less, in proportion until this [point] it ceases" (*Nat. Pueri* 18).

example at *Nat. Pueri* 17. Like many early Greek thinkers, the author believed in the explanatory potential of attraction, that is the idea that like is attracted to like or, conversely, that dissimilar things are attracted together. The idea, of course, is proverbial and predates any thinker's systematic application of it to the physical world. We know of several proverbs, well-known by the time of Plato and Aristotle, to the effect of "birds of a feather flock together."[64]

But with the naturalizing tendency of the fifth-century natural philosophers, it was generalized and took the status of a 'natural law.' Indeed Aristotle himself remarks on this transformation from proverbial wisdom to philosophical principle. After mentioning several proverbs for like-to-like, he states that "the natural philosophers organize the entirety of nature by taking the fact that like goes towards like as their principle."[65] This was hypostasized as the principle of love (*philia* or *philotês*) by Empedocles, but can also be found in, for example, Anaxagoras and Democritus.[66]

Doctors also adopted and elaborated on this principle. The physician Eryximachus in Plato's *Symposium* seems to adopt this sort of theory where he calls the attraction of 'unlike' elements in the body to each other in the body 'love'.[67] We find it in the Hippocratic Corpus as well, including in *On Generation*/*On the Nature of the Child*.[68] In particular, the author is interested in the process by which the undifferentiated flesh of the fetus is differentiated into

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[64] E.g., αἰεὶ τὸν ὅμοιον ἄγει θεὸς ὡς τὸν ὅμοιον; "the god always brings like to like" (*Od.* 17.218; Arist. *EE* 1235a; *CPG*, 253); ἀεὶ κολοιὸς ποτὶ κολοιὸν ἱζάνει; "jackdaw always sits next to jackdaw" (Arist. *Rhet.* 1371b17; *EN* 1115a33–4; *CPG*, 44); ἥλιξ ἥλικα τέρπει; "age delights in the same age" (Arist. *Rhet.* 1371b16; *CPG*, 253).
[65] οἱ δὲ φυσιολόγοι καὶ τὴν ὅλην φύσιν διακοσμοῦσιν ἀρχὴν λαβόντες τὸ τὸ ὅμοιον ἰέναι πρὸς τὸ ὅμοιον (Arist. *EE* 1235a10–11).
[66] E.g., DK31 B37, B90; DK59 A41, 24–26; and DK68 A63, A135 and p. 90, for each thinker respectively. On the natural philosophers and their use of the principle, cf. Müller 1965, 26–108.
[67] Pl. *Symp.* 185c–188e. There has traditionally been some debate as to whether to read the speech as a serious reflection of contemporary medical theory or parody. I am inclined to see it as a more or less accurate specimen of medical thought of the time: Edelstein 1945 and and Rowe 1999, 56 gives a good synopsis of how the argument could actually work (cf. Levin 2014, 73–108 for a recent in-depth discussion along with much bibliography). But even if the passage is parodic, it still informs us that the use of attraction belonged to contemporary medical discourse; otherwise, the parody would have no bite.
[68] See Müller 1965, 112–45 for its use in the Hippocratic Corpus (and esp. 113–21 on this very passage).

different parts (e.g., limbs, eyes, ears) and tissues (e.g., bones, viscera). To explain this he applies the law of like to like *and* uses an analogy to an apparatus which he has constructed:

> Ἡ δὲ σὰρξ αὐξομένη ὑπὸ τοῦ πνεύματος ἀρθροῦται, καὶ ἔρχεται ἐν αὐτῇ ἕκαστον τὸ ὅμοιον ὡς τὸ ὅμοιον, τὸ πυκνὸν ὡς τὸ πυκνὸν, τὸ ἀραιὸν ὡς τὸ ἀραιὸν, τὸ ὑγρὸν ὡς τὸ ὑγρόν […] Τουτέων δὲ διαρθροῦται ὑπὸ τῆς πνοῆς ἕκαστα· φυσώμενα γὰρ διίσταται ξύμπαντα κατὰ συγγένειαν. Καὶ γὰρ εἰ θέλοις αὐλίσκον προσδῆσαι πρὸς κύστιν, καὶ διὰ τοῦ αὐλίσκου ἐμβαλεῖν ἐς τὴν κύστιν γῆν τε καὶ ψάμμον καὶ μολίβδου κνήσματα λεπτὰ, καὶ ὕδωρ ἐπιχέας φυσῇν διὰ τοῦ αὐλίσκου, πρῶτον μὲν ἐκεῖνα ἀναμεμ⟨ε⟩ίξεται τῷ ὕδατι, ἔπειτα δὲ χρόνῳ φυσώμενα ἐλεύσεται ὅ τε μόλιβδος ὡς τὸν μόλιβδον καὶ ἡ ψάμμος ὡς τὴν ψάμμον καὶ ἡ γῆ ὡς τὴν γῆν· καὶ ἤν τις αὐτὰ αὐανθῆναι ἐάσῃ καὶ περιῤῥήξας τὴν κύστιν σκέψηται, εὑρήσει αὐτέων τὸ ὅμοιον ἐς τὸ ὅμοιον ἐληλυθός· οὕτω δὴ καὶ ἡ γονὴ καὶ ἡ σὰρξ διαρθροῦται, καὶ ἔρχεται ἕκαστον ἐν αὐτῇ τὸ ὅμοιον ὡς τὸ ὅμοιον. Ταῦτα δέ μοι ἐς τοῦτο εἴρηται.
>
> The growing flesh is articulated by breath, and each [part] in it goes 'like to like,' the dense to the dense, the loose to the loose, the wet to the wet […a description of the creation of various body parts and tissues follows…] Each of these things is articulated apart by breath; for everything, as it grows, is separated according to similarity. For if you should also wish to attach a tube to a bladder, and through the pipe place into the bladder earth, sand, and fine shavings of lead, and, pouring water in, to blow through the pipe, at first those things will be mixed up in the water, but then after being suspended for a while, the lead will be drawn to the lead, the sand to the sand, and the earth to the earth. And if someone allows for these things to be dried and, breaking the bladder from around it, looks [inside], he will discover that among these [things in the bladder] the like has gone to the like. So too is both seed and flesh articulated, and each [part] in it goes 'like to like'. This is what I have to say on this [matter].

The use of an apparatus which the author has constructed in carrying out a test is an innovation here. That is not to suggest, however, that the apparatus has no practical antecedents; Lonie cites a passage (*Mul.* II 131), where the author constructs a very similar device from a tube and a bladder, but for medical purposes.[69] Indeed, we find the exact same instructions elsewhere in the Corpus as well. At *Mul.* II 222, the author again describes "fitting a tube to a sow's bladder." And at *Nat. Mul.* 14, although this treatise may be later than *Nat. Pueri*,[70] the author uses a

[69] Lonie 1981, 184.
[70] Craik 2015, 217. Jouanna 1999, 400–401 notes that the treatise seems to be an epitomized version of pre-existing gynecological material.

bladder and tube bellows in order to blow air on a 'wandering uterus'.[71] Finally, in a more general sense, the term αὐλίσκος also could denote a catheter for the removal of stones—a procedure which probably gave the original idea for constructing the above therapeutic instruments.[72]

Regardless of these practical antecedents, however, the comment made by Lonie in his commentary is important, that "what is surprising, and admirable, is the insight which saw the *theoretic* possibilities of such apparatus" (emphasis mine).[73] We do find observations of this phenomenon in occurring in nature or everyday activity made by the natural philosophers. Democritus, for example, noted that pebbles coming up on the seashore are all of one shape and that winnowing baskets separate beans from barley.[74] Yet, these are simply passive observations marshalled in support of the general principle, rather than an actively designed test with a novel use of an apparatus.

Nor is the Hippocratic author (or his sources) entirely deluded with the principle being demonstrated here either. The sedimentation within the bladder happens because each material has a single density different than the other materials. Thus, it is not a question of the author applying a fundamentally false principle to explain the inner workings of the bladder contraption. Rather, the principle as formulated is too general—the sedimentation *does* happen because the materials are 'like' each other, but it happens specifically because each type of material has the same density, and a different density from the other materials. A piece of earth will be about as

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[71] Some Greeks—both Hippocratic writers and others (e.g., Pl. *Tim.* 91b-d)—held the absolutely bizarre, and surprisingly long-lasting, notion that the uterus can move around a woman's body and cause mental illness ('hysteria'). On hysteria and the 'wandering womb' during the period under consideration see Dean-Jones 1994, 69–77 and King 2002, 205–225.
[72] *Morb.* I 6,
[73] Lonie 1981, 184.
[74] <ὡς> δὲ καὶ ἐπὶ τῶν ἀψύχων, καθάπερ ὁρᾶν πάρεστιν ἐπί τε τῶν κοσκινευομένων σπερμάτων καὶ ἐπὶ τῶν παρὰ ταῖς κυματωγαῖς ψηφίδων; "so too in the case of lifeless things [do they go like to like], just as is possible to see in the case of seeds being sifted and pebbles on the seashore" (DK68 B164).

dense as another piece, and the same with sand. A piece of lead, on the other hand, if it is pure, will have the exact same density as another piece. So, the author misses *how* they are alike, even though he is correct in a general way. Of course, the validity of analogically applying this insight to development of the fetus is another matter entirely.

Another important difference among the various observations and tests in the work, is, as Lloyd first noted, the use of *purpose-made* apparatus.[75] The construction of a unique apparatus is important for it implies two things. First, the evidence is not gleaned incidentally, either from everyday life or a specific craft, but is the result of a purely investigatory motive. Even with everyday apparatus used in a novel way, there is a chance that the result was obtained by the normal (i.e., non-investigative) use of the device. Secondly, the construction of a purposeful apparatus also implies that the tests were actually carried out, if the device plausibly could be created and the results accord to what would happen with a given device.

Both considerations can be illustrated in the other work by the same author as *Genit./Nat. Pueri*: *Diseases* IV. In chapter 39, the author states that there are many 'cavities' in the body, and that once moisture from food and drink enters them, the moisture is transferred among the cavities equally. In these terms, the author's meaning is somewhat opaque, so once again he introduces an experiment:

> Ἔχει γὰρ οὕτως ὥσπερ εἴ τις ἐς χαλκεῖα τρία καὶ πλείονα ὕδωρ ἐγχέας καὶ συνθεὶς ὡς ἐπὶ ὁμαλωτάτου χωρίου καὶ συναρμόσας ὡς κάλλιστα διαθείη, αὐλοὺς ἐναρμόσας ἐς τὰ τρυπήματα, καὶ ἐγχέοι ἡσυχῇ ἐς ἓν τῶν χαλκείων ὕδωρ μέχρις οὗ ἐμπλησθῇ ἀπὸ τοῦ ὕδατος πάντα· ἀπὸ γὰρ τοῦ ἑνὸς ῥεύσεται ἐς τὰ ἕτερα χαλκεῖα μέχρις ὅτου καὶ τὰ ἄλλα ἐμπλησθῇ· ἐπὴν δὲ πλήρεα γένηται τὰ χαλκεῖα, ἤν τις ἀπὸ τοῦ ἑνὸς ἀπαρύσῃ τοῦ ὕδατος, ἀνταποδώσειεν ὀπίσω ῥέον τὸ ὕδωρ ἐς τὸ ἓν χαλκεῖον, καὶ κενεὰ ἔσται τὰ χαλκεῖα πάλιν ὥσπερ καὶ ἐδέξατο. Οὕτω δὴ καὶ ἐν τῷ σώματι ἔχει…

[75] Lloyd 1966, 351.

> It is just as if someone, pouring water into three or more bronze vessels and placing them together on the most level surface possible, should arrange and fit them together as well as possible, and by fitting tubes into holes bored into them, and gently pour water into the bronze vessels until the point when they all are filled with water. For [water] will flow from the one to the other bronze vessels up until the others too are filled. When the bronze vessels are filled, if anyone should draw water out from one, the water will flow backward in return into the one bronze vessel, and the vessels will again be empty just as they received [the water].

The description now makes it clear exactly what the author means: equilibrium as shown in the now-famous communicating vessels type of experiment. Presuming that the tubes connecting the vessels do so at the bottom (which would be necessary for it to work), any given quantity of water will eventually equalize over all the vessels, since the greater weight of the water in the first vessel will push down and through the tube until halted by an equal and countervailing amount of water in the other vessels. The same will happen with the removal with water (again presuming that it is done by removing water from the bottom). Thus, he uses the bronze vessels as a visible model of the invisible vessels in the body.

We should also note that these vessels serve no use other than as an experimental apparatus. Indeed, with holes bored in the bottom, they are useless for any practical purpose.[76] Thus, unlike elsewhere in the treatise, where the author uses unmodified bronze cauldrons to make a point,[77] the above test is exceptional in that it requires construction of the apparatus.

This fact, along with other details, certainly seems to suggest that the author did in fact carry out this demonstration.[78] For example, we should note that the author stipulates that the surface should be "the most level surface possible," that the water be poured carefully, and that there should be "three or more bronze vessels." The insistence on a level surface is readily

[76] *Contra* Lonie 1981, 299, who states that "no-one is going to ruin a good bronze cauldron by boring holes in it," it seems that ancient scientists did have sufficient access to purposely-made bronze instruments for purely investigative purposes (cf. Hippasus' bronze discs to demonstrate the harmonic intervals in chapter 4, section 3). If anything, this demonstration tells us something about the economic status of the author, that he can afford such an impractical pursuit.
[77] *Morb.* IV 48, 55.
[78] Cf. Lloyd 1966, 351, Lonie 1981, 296–7.

explicable: if one vessel is above or below another, the water will not flow into each evenly—and thus will defeat his general point. Also understandable is his insistence that the water be poured "gently," so that one can see the process happening at a constant rate. The stipulation of "three or more" vessels is less clear. Perhaps it is meant to serve a didactic purpose: it is easier to see the process working across multiple vessels than in just two. The number three, then, simply acts as a suggested minimum, but, as the author also notes, one could extend the number of vessels indefinitely.

Overall, the impression is that the author conceived of empirical evidence as an indispensable part of his method. This evidence could be as simple as applying an everyday observation or as complicated as building an apparatus to demonstrate his point. Furthermore, although he did not base his theories purely on experimental data, he used empirical evidence, including tests, as the "visible" part of analogical reasoning. This is understandable given his interests; there would be no way for him to directly observe the growth of the fetus—his main interest—without recourse to dissection. Nor is analogical reasoning a completely fallacious procedure, as we especially shall see below.

3.6.Two ἱστόρια on Human Growth

The preceding descriptions are well-integrated into the text—that is to say that they are not singled out in any way by the author as special pieces of evidence. And even though we have distinguished them in certain ways, these classifications (e.g., observation vs. test vs. experiment; use of an apparatus vs. not) are not ancient themselves. One two occasions, however, the author makes a point to flag a piece of evidence as especially important. In fact, in the first passage he promises to return to the point later, which he does with his second proof, and it seems as if he

conceives of both these pieces of evidence as different, but equally valid demonstrations of the same point.

3.6.1. The "Six-Day Seed"

The first of these passages begins at *Nat. Pueri* 12–13. The author begins by asserting that the seed—the author's term for the fetus—develops a membrane when it is "heated" in the womb. He even compares this membrane resulting from heating to the crust that develops on a loaf of bread when being baked.[79] Perhaps sensing that his audience might find this claim hard to believe, he introduces a notable anecdote:

> Καὶ μὴν ἓξ ἡμέρας μείνασαν ἐν τῇ μήτρῃ[80] γονὴν καὶ ἔξω πεσοῦσαν αὐτὸς εἶδον· καὶ ὁκοίη μοι ἐφαίνετο ἐν τῇ γνώμῃ τότε, ἀπ' ἐκείνων τὰ λοιπὰ τεκμήρια ποιεῦμαι· ὡς δὲ εἶδον τὴν γονὴν ἑκταίην ἐοῦσαν ἐγὼ διηγήσομαι. Γυναικὸς οἰκείης μουσοεργὸς ἦν πολύτιμος, παρ' ἄνδρας φοιτέουσα, ἣν οὐκ ἔδει λαβεῖν ἐν γαστρὶ, ὅκως μὴ ἀτιμοτέρη ἔῃ· […] καί κως ᾔσθετο οὐκ ἐξιοῦσαν τὴν γονὴν, καὶ ἔφρασε τῇ δεσποίνῃ, καὶ ὁ λόγος ἦλθεν ἕως ἐμέ· καὶ ἐγὼ ἀκούσας ἐκελευσάμην αὐτὴν πρὸς πυγὴν πηδῆσαι, καὶ ἑπτάκις ἤδη ἐπεπήδητο, καὶ ἡ γονὴ κατεῤῥύη ἐπὶ τὴν γῆν, καὶ ψόφος ἐγένετο, κἀκείνη δὲ ἰδοῦσα ἐθεῆτο καὶ ἐθαύμασεν. Ὁκοῖον δὲ ἦν ἐγὼ ἐρέω, οἷον εἴ τις ᾠοῦ ᾠμοῦ τὸ ἔξω λεπύριον περιέλοι, ἐν δὲ τῷ ἔνδον ὑμένι τὸ ἔνδον ὑγρὸν διαφαίνοιτο· ὁ τρόπος μέν τις ἦν τοιοῦτος ἅλις εἰπεῖν· ἦν δὲ καὶ ἐρυθρὸν καὶ στρογγύλον· ἐν δὲ τῷ ὑμένι ἐφαίνοντο ἐνεοῦσαι ἶνες λευκαὶ καὶ παχεῖαι, εἰλημμέναι ξὺν ἰχῶρι παχέϊ καὶ ἐρυθρῷ, καὶ ἀμφὶ τὸν ὑμένα ἔξωθεν αἱμάλωπες· κατὰ δὲ τὸ μέσον τοῦ ὑμένος ἀπεῖχε λεπτὸν ὅ τί μοι ἐδόκεεν εἶναι ὀμφαλὸς, κἀκείνῳ τὴν πνοὴν καὶ εἴσω καὶ ἔξω ποιέεσθαι τὸ πρῶτον· καὶ ὁ ὑμὴν ἐξ ἐκείνου ἐτέτατο ἅπας περιέχων τὴν γονήν. Τοιαύτην μὲν ἐγὼ εἶδον ἑκταίην οὖσαν τὴν γονήν. Ἐρέω δὲ καὶ ἄλλην διάγνωσιν ὀλίγον ἐπὶ τούτῳ ὕστερον, ἐμφανέα παντὶ τῷ βουλομένῳ εἰδέναι τούτου πέρι, καὶ ἱστόριον παντὶ τῷ ἐμῷ λόγῳ, ὅτι ἐστὶν ἀληθὴς, ὡς εἰπεῖν ἄνθρωπον περὶ τοιούτου πράγματος. Καὶ ταῦτα μὲν ἐς τοῦτό μοι εἴρηται.

[79] Καὶ ἡ γονὴ ὑμενοῦται φυσωμένη· περιτέταται γὰρ ἀμφ' αὐτὴν τὸ ἔξωθεν, συνεχὲς γινόμενον, ἅτε γλίσχρον ἐὸν, ὥσπερ ἐπ' ἄρτῳ ὀπτωμένῳ, λεπτὸν ἐξίσταται ἐπιπολῆς ὑμενοειδές· θερμαινόμενος γὰρ καὶ φυσώμενος ὁ ἄρτος αἴρεται· ᾗ δ' ἂν φυσᾶται, κείνῃ τὸ ὑμενοειδὲς γίνεται; "The seed grows a membrane when it touches the air. For the outside portion is stretched around it, becoming continuous, since it is sticky, just as in the case of baking bread a slight membrane-like [crust] arises upon the surface. For as the bread touching the air is warmed, it rises, and where it touches the air, a membrane-like [crust] forms" (*Nat. Pueri* 12).

[80] So manuscripts MV (cf. Joly 2003, 55), although the quotation by Gal. *Foet. Form.* 654 gives the plural μήτρῃσι. The reading ἐν τῇ γαστρὶ found in the *recentiores* is an obviously mistaken correction from the idiomatic phrase λαβεῖν ἐν γαστρὶ ('to conceive, to become pregnant') found below, since the author does not figuratively use γαστήρ to mean 'womb' (*LSJ* s.v. II) outside this phrase; he adopts a more precise vocabulary.

> And I myself saw a seed which remained for six days in the womb and fell out. From how it then appeared to me in my understanding, and from these [observations], I will make the rest of my proofs. I will describe how I saw a seed which was six days old. My female relative had a very valuable singing girl, who frequented men and [for] whom it was necessary that she not conceive, lest she become less valuable […] and when she realized that the seed was not coming out, she told her mistress, and the account came to me. I, hearing [this], bade her to jump [lifting her legs] to her buttocks. And she jumped seven times, and the seed came out upon the earth and made a noise; she gazed at it and was amazed. What it was like, I will say: it was like if someone were to remove the shell of a raw egg, and the fluid inside could be seen in the membrane inside. Its manner was something like the following, to say enough [to describe it]. It was red and round. In the membrane there appeared to be broad, white strands inside, pressed together with thick, red liquid[81], and there were blood clots outside around the membrane. In the middle of the membrane there extended [something] white which seemed to me to be an umbilical cord and through that respiration in and out is first made. And the membrane spread from that entirely containing the seed. This is the sort of thing which I saw the six day seed [to be]. I will also speak of another means of knowing this (διάγνωσιν) a little later in this [book], for everyone who wishes to clearly know about this, and a proof for my entire account, that it is true, as much as [it is possible for] a human to speak on such a matter. These things are what I have to say on this matter.

This is a remarkable passage. One is tempted to call it a case study like those found in the *Epidemics*. At the very least, the author relates a personal anecdote: his kinswoman owns a 'singing girl' who 'frequented men'—an obvious euphemism for prostitution[82]—whose pregnancy threatens to bring her value as a slave down. In order to solve the problem, he supposedly induces abortion by having her vigorously jump up and down seven times. He then takes the occasion to observe the partially developed fetus directly, which shows a point in the developmental process otherwise hidden to him. However, there are many controversies—ancient and modern—about the reliability of this passage which must be addressed to clarify exactly what the author was reporting, and whether the report itself is reliable.

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[81] The word translated 'liquid' here – ἰχῶρι – can mean 'blood-serum' (the watery liquid which separates from blood upon coagulation) in the Corpus as well as, originally, the immortal blood of the gods in Homer (although Jouanna and Demont 1981 argue that 'serum' is the original meaning). Neither meaning can work here: the latter for obvious reasons, and the former since blood serum is neither red nor thick (it is clear/yellowish and watery). Given that the word can refer to other liquids (e.g., bile at Philolaus DK44 A27, whey at Arist. *HA* 521b27), a more general translation seems best. Cf. *Nat. Pueri* 18, 502, 1 Littré.

[82] The mere mention of a female musical performer was probably enough to make his point because the association with female musical performers at symposia and prostitution was well-known. Cf. Davidson 1997, 81–82; Goldman 2015.

Ancient controversies mainly centered around the propriety of the passage and, by extension, its reliability; in order to save 'Hippocrates' from charges of immorality, then, ancient readers either engaged in belabored interpretation or even changed the text. A case in point is the identity of the γυνὴ οἰκείη. Many ancient readers found it unacceptable that the author should implicate his own female relative in pandering; thus some adopted the definition of οἰκείης as slave (οἰκέτις). The Hippocratic lexicographer Erotian glossed οἰκείη, as "a slave, [or] some say a female relative" and informs us that "the term appears in *On the Nature of the Child*."[83] Galen also quotes this passage several times with the variant οἰκέτις. But this reading lacks any manuscript support and contradicts quotations in other ancient authors; it is also suspicious that what is a definition in Erotian has turned into a reading in Galen.[84] Even some modern emendations, like Wiliamowitz' Κείης 'Ceian', are also products of this moralizing impulse.[85] But without importing notions—modern or ancient—of what is deemed 'proper', and given the fact that the text is supported by the manuscript evidence and perfectly understandable as is, we are justified in keeping the reading and understanding that his female relative was indeed somehow involved in prostitution. Perhaps the entire point of introducing his female relative in the story is to establish greater credibility: from the Greek point of view, a woman would not have gone to a stranger with such a delicate matter.

Other ancient commentators (mainly other medical writers) had very different concerns. Since they uniformly believed that *Nat. Pueri* was the work of Hippocrates (with the partial

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[83] οἰκείης· δούλης, οἱ δὲ ἰδίας. κεῖται ἐν τῷ Περὶ φύσεως παιδίου ἡ λέξις; "*oikeiês*: a slave, or some say a relative. The term is contained in *On the Nature of the Child*." (Erot. 101, 4–5 Nachmanson).

[84] γυναικὸς οἰκέτις μουσουργὸς πολύτιμος ἦν (= Gal. *De Sem.* 525, 9 and *Foet. Form.* 654, 4–5). Ps.-Iambl. *Theol.Ar.* 61, 15–6 De Falco (quoted directly from Nicomachus, a second century CE Neopythagorean author) has γυναικὸς οἰκείης ἡμῖν μουσουργὸς.

[85] "Da ist οἰκείης unmöglich; une femme de ma connaissance kann es nicht heißen, und daß eine Bordellmutter zu seiner Familie gehörte, wird der Verfasser nicht sagen wollen" (von Wilamowitz-Möllendorff 1923, 79–80).

exception of Galen, who also considered Hippocrates' student Polybus a candidate[86]), they were concerned with the passage from the standpoint of consistency. Because the Hippocratic *Oath* famously contained the statement that "I will not give an abortive pessary to a woman," later medical writers had to square the seemingly contradictory positions of 'Hippocrates' on abortion. The second century doctor Soranus solves the problem by making the problem into a terminological one: Hippocrates recognized a difference between a pharmaceutically induced abortion and one induced physically or by a procedure, and only bans the former.[87] But this possible objection to the reliability of the passage also takes on much less importance once we lay the question of Hippocratic authorship (in the literal sense of 'actually written by Hippocrates') aside, as most modern commentators do.

But, in what is perhaps the most striking contrast to modern debates, not many ancient commentators were concerned with the passage from the standpoint of the permissibility of the abortion itself or even from that of the ancient prohibition against contact with the dead.[88] Indeed, even though this passage from *Nat. Pueri* was well-known to later authors, it is only in the seventh century CE—i.e., well into the Christian period—that the Byzantine commentator John of Alexandria addresses this passage from a moral standpoint.[89] Thus it seems that there are

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[86] Cf. note 29 above.

[87] τὸ δὲ 'ἐκβόλιον' οἱ μὲν συνωνυμεῖν τῷ φθορίῳ λέγουσιν, οἱ δὲ διαφέρειν τῷ μὴ ἐν φαρμάκοις νοεῖσθαι, κατασεισμοῖς δὲ καὶ πηδήμασιν, εἰ τύχοι· διὸ καὶ τὸν Ἱπποκράτην παραιτησάμενον τὰ φθόρια παραλαβεῖν ἐν τῷ Περὶ παιδίου φύσεως ἐκβολῆς χάριν τὸ πρὸς πυγὰς πηδᾶν; "Some say that the 'expellant' is synonymous with an abortifacient, others say that it differs in that it is not considered to be among drugs, but shaking and leaping…wherefore, [they say that] Hippocrates, although he forbids abortifacients, utilizes jumping to the buttocks for the sake of expelling [sc. the fetus] in the *Nature of the Child*" (Sor. *Gyn.*1.60).

[88] On the Classical Greek attitudes toward the permissibility of abortion (insofar as we can reconstruct them), cf. Crahay 1941; Nardi 1971, chapter 2; Riddle 1992, 7–8 and 62–63; Kapparis 2002, 169–193. On abortion as a 'polluting' act, cf. Parker 1986, 354–356.

[89] 11.1.4.146. Since John does not wish to impugn 'Hippocrates', he suggests that he did so only to save the life of the mother: καὶ γὰρ εἰ εἴασεν Ἱπποκράτης τὴν γονὴν, ἔμελλεν ἡ γυνὴ, τοῦ κάλλους ἀπομαραινομένου, ἀγχόνῃ χρήσασθαι· αἱροῦνται γὰρ αἱ ἑταιρίδες θάνατον ἢ ἀμορφίαν; "For if Hippocrates allowed the seed [sc. to be aborted], the woman must have been about to have recourse to hanging since her beauty was withering away. For courtesans choose death over ugliness." The suspect psychologizing aside, John may have misunderstood his

no grounds to doubt or change the author's testimony on the basis of ancient concerns about the propriety of this passage.

Modern commentators have usually approached this passage with a different set of questions concerning the reliability of the passage. First and foremost, at six days, the author's description does not correspond to actual human development. Indeed, for some weeks after conception, the fetus would barely be visible;[90] it certainly would not impel the author to say that "it was like if someone were to remove the shell of a raw egg." There are three possible responses to this objection: 1.) the author was confused about the date of conception and saw a more developed fetus, 2.) the 'fetus' was not a fetus at all, but something else entirely which the author then misinterpreted given his own theoretical interests,[91] or 3.) the author fabricated the entire account.

The third option seems unlikely not only because it is uncharitable, but also the author's description of whatever he saw, as opposed to his explanation, does exhibit a certain believability. We may compare it to a parallel passage in the contemporary Hippocratic work *On Fleshes*, where the author describes a very similar experiment purporting to prove that the fetus is fully formed after only seven days. The author of *On Fleshes* states that "public prostitutes ... know whenever they become pregnant, and then destroy [the fetus]. After it is destroyed, it falls out like flesh. And by placing this in water and looking at it in water, you will discover [that it] has all its parts, spaces for eyes, the ears and the limbs; the fingers and legs and feet and toes, and the genitals and the entire rest of the body is clear."[92] It is obvious that the author has based

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sources here, since 'hanging' (ἀγχόνη) was also a name for mandrake (Dsc. *Mat. Med.* 4.75), whose root was used in at least one ancient recipe for an abortifacient (Scrib. *Comp*. 121).

[90] Ellinger and Guttmacher 1952, 117.

[91] These first two possibilities are addressed by Lonie 1981, 161.

[92] αἱ ἑταῖραι αἱ δημόσιαι […] γινώσκουσιν ὁκόταν λάβωσιν ἐν γαστρί· κἄπειτ' ἐνδιαφθείρουσιν· ἐπειδὰν δὲ ἤδη διαφθαρῇ, ἐκπίπτει ὥσπερ σάρξ· ταύτην τὴν σάρκα ἐς ὕδωρ ἐμβαλὼν, σκεπτόμενος ἐν τῷ ὕδατι,

his more removed account on the personal description in *On the Nature of the Child*. But instead of the sober description found there, the author of *On Fleshes* has embellished his account beyond credibility—he is describing a homunculus. Since he offers no information past that which anybody who has ever seen a human could provide, it is obvious that he has no personal experience with the situation which he is describing. Perhaps, this is a show of one-upmanship, an attempt to embellish an already memorable passage in a professional rival's work. In any case, our author's more clinical description does not engage in such exaggeration.

It is harder to choose between the remaining two options. It is, of course, possible that all the parties in the story, including the author, were confused about the date of conception, and that the fetus was much further along in development. But another suggestion made in Guttamcher's medical commentary on the work is that the author observed a mole—a type of tumor which sometimes develops during pregnancy in lieu of a viable fetus.[93] This suggestion may present a slight benefit since it is unlikely that all concerned should be incorrect in their reckoning of conception by several months. It also explains the presence of blood vessels on the outside of the membrane and why the 'fetus' should be so easily dislodged (i.e., since it was never viably implanted).[94] But, without any more information, the question must remain open. The important fact is that the author did observe *something*, and attempted to describe it more or less faithfully, even if his description was influenced by what he was looking for in the first place.[95]

εὑρήσεις ἔχειν πάντα μέλεα καὶ τῶν ὀφθαλμῶν τὰς χώρας καὶ τὰ οὔατα καὶ τὰ γυῖα· καὶ τῶν χειρῶν οἱ δάκτυλοι καὶ τὰ σκέλεα καὶ οἱ πόδες καὶ οἱ δάκτυλοι τῶν ποδῶν, καὶ τὸ αἰδοῖον καὶ τὸ ἄλλο πᾶν σῶμα δῆλον (*Carn.* 19).

[93] Ellinger and Guttmacher 1952 115–17. Guttmacher was a practicing gynecologist, which not only presents a (regrettably) rare case of collaboration across the "two cultures," but also makes this suggestion more plausible.

[94] Ibid. p. 116.

[95] Lonie 1981, 161 makes a similar point.

Indeed, the author's impossible insistence that only seven days had elapsed since conception provides the best example of how his theoretical interests shaped his account. Even though the seed is six days old, it is seven days out from conception.[96] In addition, it is on the seventh jump that the seed is expelled. Of course, the number seven was very numerologically significant both in Greek thought in general and in the Hippocratic Corpus in particular. It was connected to the periods of life at least as early as Solon[97] and we find it explicitly connected to the development of the fetus elsewhere in the Hippocratic Corpus. Notably, as mentioned above, the fifth century author of *On Fleshes* is convinced that the fetus has all of its "parts," i.e., the body parts of a fully grown human, within seven days of conception.[98] This seems to have been a specific instance of a wider Hippocratic interaction with numerology too: even though the date is disputed, a cosmological treatise *On Sevens* is included in the Corpus as well.[99]

But, even though there were non-scientific factors at work, the passage is remarkable for its direct and empirical investigation of a topic. We have previously noted that empirical evidence for this author existed along a continuum of complexity from simple observations to controlled experiment. Where, then, should we place this description? On the one hand, it is not much more than an acute observation; his intervention in the situation was motivated not by any investigative motive, but by a personal factor—his relative had asked him for help. But, on the other hand, the personal connection gave him the opportunity to observe directly based on his

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[96] Cf. Macrob. *Somn. Scip.* 1.64: *hoc cum a physicis deprehensum sit, Hippocrates quoque ipse qui tam fallere quam falli nescit experimenti certus adseruit, referens in libro qui De natura pueri inscribitur tale seminis receptaculum de utero eius eiectum quam septimo post conceptum die intellexerat*; "Although this [i.e., that the universe is governed by the number seven] was recognized by natural philosophers, Hippocrates himself, who does not know how to deceive nor be deceived, was sure to make his claim by an experiment; testifying in his book which is entitled *On the Nature of the Child*, he understood that such a receptacle of the seed was ejected from the uterus on the seventh day after conception."

[97] Solon fr. 27 West.

[98] ὁ δὲ αἰών ἐστι τοῦ ἀνθρώπου ἑπταήμερος. πρῶτον μὲν ἐπὴν ἐς τὰς ὑστέρας ἔλθῃ ὁ γόνος, ἐν ἑπτὰ ἡμέρῃσιν ἔχει ὁκόσα περ ἔστιν τοῦ σώματος; "the time of a human is seven days. First when the seed goes into the uterus, it has in seven days as many [parts] as there are of the body" (*Carn.* 19).

[99] Cf. note 11 above.

scientific interest. Furthermore, he did in fact intervene in the situation—by producing the abortion—and attempted (however poorly) to record relevant details such as the time from conception. Thus, we would be justified in saying that, even though this description is neither a test nor free from the author's theoretical biases, the passage still represents an impressive specimen of direct research in early Greek science, made possible by a remarkable set of circumstances.

3.6.2. The Egg Experiment

As we have previously noted, the author does not think that his observation of the "six-day seed" is enough, since he promises to return with another way of knowing (διάγνωσις) what the fetus looks like when it is developing. At chapter 29 of *On the Nature of the Child*, he fulfills this promise:

> Νῦν δὲ ἐρῶ τὴν διάγνωσιν, ἣν ἔφην ἀποφανέειν ὀλίγῳ πρότερον, ὡς ἀνυστὸν ἀνθρωπίνῃ γνώμῃ ἐμφανέα ἐοῦσαν παντὶ τῷ θέλοντι εἰδέναι τούτου πέρι, ὅτι ἥ τε γονὴ ἐν ὑμένι ἐστὶ, καὶ κατὰ μέσον αὐτῆς ὁ ὀμφαλός ἐστι, κἀκείνη πρῶτον τὴν πνοὴν ἕλκει ἐς ἑωυτὴν καὶ μεθίησιν ἔξω, καὶ ἐκ τοῦ ὀμφαλοῦ ὑμένες εἰσί· καὶ τὴν ἄλλην φύσιν τοῦ παιδίου, ἣν εἴρηκα, ὧδε ἔχουσαν εὑρήσεις πᾶσαν μέχρις ἐς τέλος, ὅκως μοι ἐν τοῖσι λόγοισιν ἀποπέφανται, εἰ βούλεταί τις τοῖσιν ἱστορίοισιν, ὁκόσοισι μέλλω λέγειν, χρῆσθαι. Εἰ γάρ τις ἐθέλει ὠὰ εἴκοσιν ἢ πλείονα, ὅκως ἐκλεπίσηται, ὑποθεῖναι ἀλεκτορίσιν εἴτε δυσὶν εἴτε πλείοσι, καὶ ἑκάστης ἡμέρης ἀπὸ τῆς δευτέρης ἀρξάμενος μέχρι τῆς ὑστάτης ᾗ ἐκλέψει τὸ ὠὸν, ὑφαιρέων, καταγνύων, σκοπῶν εὑρήσει ἔχοντα πάντα κατὰ τὸν ἐμὸν λόγον, ὡς χρὴ ὄρνιθος φύσιν ξυμβάλλειν ἀνθρώπου φύσει. Ὅτι γὰρ ὑμένες εἰσὶν ἐκ τοῦ ὀμφαλοῦ τεταμένοι, καὶ τἄλλα ὁκόσα εἴρηται περὶ τοῦ παιδίου, οὕτως ἔχοντα ἐν τῷ ὠῷ τῷ ὀρνιθείῳ εὑρήσεις ἐξ ἀρχῆς ἐς τέλος· καίτοι ἤν τις μηδέπω εἶδε, θαυμάσει ἐν ὀρνιθείῳ ὠῷ ἐνεόντα ὀμφαλόν. Ἔχει δὲ ὧδε τάδε, καὶ ταῦτα δέ μοι ὧδε εἴρηται.
>
> Now I will speak of the way of knowing (διάγνωσιν) which I said I would reveal a little while ago, so that it will be as clear as possible for human judgment to everyone who wishes to know concerning the following, that the seed is inside a membrane, and in its middle is a navel, and this first draws breath into itself and again releases it, and that there are membranes [coming] from the navel. And one will discover that the entire rest of the growth of the child to its end is just as has been described by me in my writings, if anyone wishes to use these proofs of which I am about to speak. For if someone wishes to place twenty or more eggs under hens, either two or more, so that they hatch, and each day beginning from the second [day] up until the last [day] at which point the egg

> hatches, taking one from underneath, breaking it open, and observing it, one will find everything is according to my account, inasmuch as it is right for the growth of a bird to coincide with human growth. That there are membranes stretching from the navel, and the other things which have been said concerning the child, you will discover that they are the same in the bird's egg, from beginning to end, although, if someone had not yet seen [this], he would be amazed that there is a navel in a bird's egg. And this is how these matters are, and this is what I have said on them.

Although the previous passage focused on direct observation made possible in special circumstances, here the author reverts to his usual method and reasons by analogy. This time, the analogy is between two actually analogous types of growth: human and animal. Such an analogy (and demonstration reliant on that analogy) corresponds with his analogy between animal (including human) and plant growth discussed above (i.e., the cucumber 'experiment'), although this time the analogy is much more informative.[100]

Putting aside the author's analogical thought process, however, we should note that, even more than the observation at chapter 13, this passage shows the author's methodological sophistication. He describes a systematic test of a single point (i.e., that both the developing chick and developing human show a structural similarity with the presence of the membrane, navel, etc.). The experiment is carried out over a set period of time—very close to the average incubation period of a chick[101]—rather than 'performed' only once as in previous tests, and is carried out systematically (i.e., an egg from the clutch is checked daily). This way, the tester can watch the regular progression from "beginning to end," and compare those findings with the author's observation earlier in chapter 13. Indeed, since the earlier observation was done in entirely special circumstances, this passage acts as a test that the reader could conceivably carry out to verify the author's conclusions if so inclined. The verbal echoes to chapter 13 also help to remind the audience of what has been said before, which is typical of this author as he often

[100] Arata 1998, 347.
[101] 21 days according to the 2017 *Old Farmer's Almanac*, 296, although of course there is natural variation.

places cross-references into his work.[102] Finally, and importantly, he also notes that this is a *partial* analogy and valid insofar as human growth and animal growth are similar; such a concession is a rare example of a Greek author acknowledging the provisional nature of a proof. More often the attitude on display is an unalloyed confidence.

Although this experiment was novel, there is some evidence that the author was at least inspired by the oölogical interests of earlier philosophers. Empedocles, perhaps, drew an analogy between the seed of a tree and an egg, but, since we have only one line on the matter, this also could be poetic license.[103] Both the medical theorist Alcmaeon[104] and the philosopher Anaxagoras[105] debated whether the egg white or the yolk acted as 'milk', i.e., as nourishment, for the developing chick. Democritus also had some interest in the matter, seemingly coming up with a theory as to why chicken eggs vary in color.[106]

Whatever its theoretical antecedents, however, the experiment certainly impressed and inspired later authors. Aristotle undertook the exact procedure described above and described the results in his works on animal biology. In the sixth book of his *Historia Animalium*, Aristotle gives a complete description of the development of the chick at different points in the process.[107] At three days, the yolk appears along with a speck of blood which will turn into the heart (561a10–11); a little later the body starts to become differentiated and, agreeing with our author,

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[102] Fausti 2010, 316.

[103] Aristotle, at any rate, takes the equation seriously: καὶ τοῦτο καλῶς λέγει Ἐμπεδοκλῆς ποιήσας· 'οὕτω δ' ᾠοτοκεῖ μακρὰ δένδρα πρῶτον ἐλαίας'. τό τε γὰρ ᾠὸν κύημά ἐστι; Empedocles speaks rightly when he writes the verses: 'thus the tall trees first lay their egg, the olive-tree.' For the egg is the embryo…" (DK 31 B79 = Arist. *GA* 731a4–5).

[104] DK 25 A16.

[105] DK 49 B22.

[106] DK 68 A146.

[107] Aristotle also discusses some relevant details of the development of the chick in the fifth book of his *Generation of Animals*, but refers the reader back to his more complete discussion in the *History of Animals*: δι' ἀκριβείας μὲν οὖν, ὃν τρόπον ἔχουσι ταῦτα πρὸς ἄλληλα κατ' ἀρχάς τε τῆς γενέσεως καὶ συνισταμένων τῶν ζῴων, ἔτι δὲ περί τε ὑμένων καὶ περὶ ὀμφαλῶν ἐκ τῶν ἐκ ταῖς ἱστορίαις γεγραμμένων δεῖ θεωρεῖν·; "Therefore, in what way these [parts] relate to one another in their beginnings of generation and the forming of animals, and furthermore about membranes and umbelicial cords, one must understand from what has been written in the *Histories* with accuracy" (*GA* 753b14–17).

the umbilical cord comes from the 'navel' (561a24). At ten days, the parts become clearly visible and, again corroborating our author, there is a membrane around the yolk (561a26–b10). Finally, on the twentieth, the chick is totally formed and will even chirp "if you open the egg." (561b27–30). And even though Aristotle is interested in many more physiological features than our author was, we should also note that Aristotle mentions the development of a cord coming from the 'navel' and a 'membrane' around the yolk, both of which features are central to the Hippocratic author's interests. Thus, although one cannot prove it beyond all doubt, it is probable that Aristotle knew of and was influenced by the author of *On the Nature of the Child*.

In conclusion, these two pieces of evidence rely on one another. The circumstance behind the first observation is unique and therefore could not be replicated easily; the details that the author reports, however, despite both ancient and modern concerns, seem to be more or less accurate (with the possible exception of the numerological coloring). The second piece of evidence corroborates the first observation using a very sophisticated test that anybody could, and some did, replicate. And even though this test still relied on analogical reasoning, it also illustrates that this is not necessarily a scientific failure: the author's methodology was quite sophisticated and explicitly formulated, and he stressed the need for regular observation of a controlled situation.

3.7. Conclusion

As we have seen, the author of these treatises used many different observations and tests in his work. Yet there were many different types of evidence used for different reasons. Sometimes he simply adduced observations from everyday life to make his point. Other times, he uses observations from specialized fields like medicine or horticulture. There is also a difference between more or less passive observation of a phenomenon and an active test where, e.g., an

instrument is built or the author describes an artificially controlled situation. Thus we may call some of his evidence observational and some experimental, although for him, the evidence all was of a kind. This is especially clear in his account of human growth, where he ties together both a direct observation and an experiment.

Overall in these descriptions one feels the presence of an intellect that is home in many fields, that shows a trust both in the senses and in similarity between parts of nature, and who approaches his readers, even when attempting to impress and convince them, with an admirable clarity. For all these reasons, and even though the author's reasoning is sometimes suspect to modern readers, his work still represents a high point of empirical engagement in pre-Hellenistic science.

CHAPTER FOUR: EARLY HARMONIC RESEARCH AND EXPERIMENTATION

Perhaps the most intriguing material regarding experimentation in early Greek science concerns harmonic theory, which, for the ancients, primarily concerned the study of tuning. In terms of scientific practice, even scholars generally pessimistic on the empirical content of early Greek science have claimed that the ancient study of sound represents a case for cautious optimism.[1] Although thinkers like Philolaus and Archytas constructed complex harmonic theories, three early figures also were associated with experiments: Pythagoras, Hippasus, and Lasus. Their achievement is all the more impressive since they all date from the late sixth to early fifth century, and so are quite early compared to the thinkers that we have treated thus far. Yet, the reliability of the ancient evidence and these figures' place in contemporary theoretical debates must be assessed carefully if we are to have an accurate picture of the advances of the time.

To that end, we will begin by surveying the later ancient evidence for harmonic theory to situate the three thinkers and their harmonic experiments. Then we will take in each in turn. Pythagoras presents a special challenge, as the constantly productive tradition around his person, theories, and exploits grew larger and larger throughout antiquity. It is therefore no surprise that he is one of the earliest figures to whose name harmonic experiments are attached. These harmonic experiments reflect the Pythagorean tradition's growth throughout the Hellenistic and Roman eras, and we must doubt the attribution of these experiments to Pythagoras. Nevertheless,

[1] E.g., Lloyd 2000, 222–223.

the reports are accurate insofar as they portray various tests which were undertaken by other investigators and which (at least in part) might date to the time period under consideration.

On the other hand, the other two early harmonic experimenters for whom we have evidence—Hippasus and Lasus—present the opposite problem: they are quite poorly-attested figures. Even so, the little information that we do possess suggests that Hippasus played a very large role in the early study of music and sound. On the contrary, the evidence concerning Lasus often used to portray him as a theoretical investigator into music, is actually much *less* compelling than usually thought.

4.1. Early Harmonic Theory: Theoreticians and Empiricists

The early history of the harmonic theory among the Greeks is quite shadowy in its details, but the overall state of the field is clear. Ancient authors interested in musical theory are almost unanimous in dividing the early history of harmonic theory into two generally opposed theoretical camps. First were the "Pythagoreans," who reduced harmonics to mathematics by insisting that the all musical intervals were, in some way, mathematical ratios. Opposed to them were a group of later authors called the "empiricists" or "harmonicists" (ἐμπειρικοί or ἁρμονικοί), who relied on their senses to distinguish tones from one another.

The first author to speak of this theoretical division at length is Plato.[2] Indeed, the first we hear of "harmonic study" at all is in the *Phaedrus*, where Plato speaks of a self-appointed "harmonicist" who knows how to play the highest and lowest notes (of a scale perhaps), and that this knowledge belongs to "studies necessary to understand before harmony, but not harmonics itself."[3]

[2] Cf. *P.Hibeh* 13 (most likely Alcidamas) and its speaking of ἁρμονικοί below on p. 129.
[3] τὰ γὰρ πρὸ ἁρμονίας ἀναγκαῖα μαθήματα ἐπίστασαι ἀλλ᾽ οὐ τὰ ἁρμονικά (*Phd.* 268de).

Further detail about Plato's view of earlier harmonics can be gleaned from the guardians' educational program in the *Republic*, which consists of an ascent through arithmetic, geometry, stereometry[4] (the study of static three-dimensional bodies), astronomy (stereometry in motion), and harmonics, before moving to dialectic. Concerning the final two courses of study before dialectic, astronomy and harmonics, Socrates agrees with "the Pythagoreans" that they are "sister sciences."[5]

Several sentences later, at *Rep.* 531a, Socrates then specifies that the relevant type of harmonic study is not the practice of those who "measure heard harmonies and sounds against one another" and strain to hear the smallest possible intervals. If there seems to be a smaller interval possible than the one they have already tuned, these investigators, ironically called χρηστοί, "persecute and torture the strings, and stretch them out on the pegs," i.e., they tune their instruments to ever smaller intervals.[6] These are a different group from the Pythagoreans and in Plato's mind their dedication to the sensible world is suspect. But Plato even dismisses as insufficient the method of the Pythagoreans, who "seek out numbers in heard harmonies, but do not ascend to problems."[7] By the somewhat cryptic phrase "they do not ascend to problems," (οὐκ εἰς προβλήματα ἀνίασιν) Plato seems to mean that even the Pythagoreans did not make

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[4] The word is not Plato's, as he notes that the study has no term and is "neglected" (*Rep.* 528bc). The pseudo-Platonic author of the *Epinomis*—probably an early Academic—is the first to call it στερεομετρία (*Epinom.* 990d).

[5] *Rep.* 530d. The phrase ἀδελφαί τινες αἱ ἐπιστῆμαι is taken almost directly from the work of Archytas (DK47 B1, where he calls arithmetic, astronomy and acoustics τὰ μαθήματα...ἀδελφεά), and it is overwhelmingly likely that Archytas' work heavily influenced Plato's thinking in this passage (cf. Huffman 2005, 114).

[6] The language of the passage is obviously ironic and borders on the macabre. Obviously χρηστοί is no compliment, but means that the investigators are good at what they do, but what they do is useless for the understanding which they seek. Plato continues on to develop the image of a law-court: instead of slaves being tortured as witnesses, strings are, and there are accusations and denials (κατηγορίας πέρι καὶ ἐξαρνήσεως) over what intervals are heard. The image, although soon abandoned by Plato, underscores what is objectionable to him about this type of investigation: its subjectivity. Cf. the metaphorical connection of scientific investigation and torture famously made by Francis Bacon (Pesic 1999).

[7] τοὺς γὰρ ἐν ταύταις ταῖς συμφωνίαις ταῖς ἀκουομέναις ἀριθμοὺς ζητοῦσιν, ἀλλ᾽ οὐκ εἰς προβλήματα ἀνίασιν, ἐπισκοπεῖν τίνες σύμφωνοι ἀριθμοὶ καὶ τίνες οὔ, καὶ διὰ τί ἑκάτεροι. (*Rep.* 531c). Plato does not name the Pythagoreans here, but it is clear that he means Pythagoreans by this unnamed second group.

the leap into purely abstract (that is, purely mathematical) investigation; they still are concerned with the object (sound) that they model with mathematics.[8]

We find later philosophers and musical theorists making the same division more explicitly. For Aristotle, harmonics is primarily mathematical because it is a type of arithmetic,[9] but he disagrees with Plato that harmonics can be completely separated from its subject matter sound and should be reduced to pure mathematics.[10] Rather, Aristotle's conception of harmonics contains both a description of the phenomena gained from observation *and* the mathematical explanation of the phenomena, without necessarily privileging the latter. He attempts to bridge both sides of the methodological divide: whereas empiricists collect the data, the more mathematically inclined give the reason why the data are the case.[11] He does not explicitly identify the mathematician with Pythagoreans, but, given Plato's testimony and that of later authors, the identifications are secure.

Aristotle's vision of the scientific study of sound, stemming from the divide between mathematical Pythagoreans and empiricists, was adopted by other Peripatetics as well. The most important source for early Greek musical theory is the Peripatetic Aristoxenus, since later technical writers on musical theory accessed the Platonic and Peripatetic notion of two schools of harmonic study through him.[12] He gives more information about the divide between

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[8] Burkert 1972, 372 takes Plato's description of the Pythagoreans not "ascending to problems," in this way, which seems correct given the fact that πρόβλημα was a technical term for a purely abstract, and often mathematical, problem (cf. Oenopides DK49 A12, Pl. *Tht.* 180c, Arist. *Top.* 104b).
[9] *APo.* 75b16, 76a10; *Met.* 1194a8.
[10] *Met.* 997b21, 1077a5.
[11] *APo.* 79a1, 87a34. At 79a1, Aristotle also names these sub-types of harmonics ("mathematical harmonics" (ἁρμονικὴ… μαθηματικὴ) and "harmonics by ear" (ἡ [sc. ἁρμονικὴ] κατὰ τὴν ἀκοήν)). The division of sciences into practical data-collection and mathematical explanation also holds for other parts of natural philosophy, like astronomy (divided into "mathematical" and "nautical" parts). Aristotle also notes here, quite rightly, that adherents of one methodology often miss the insights of another.
[12] Barker 1976, 1.

Pythagoreans and the *harmonikoi*, a name used by Theophrastus for empiricists.[13] In his *Harmonica*, he divides his predecessors (οἱ ἔμπροσθεν) into the familiar two groups:

> καὶ τούτων ἀποδείξεις πειρώμεθα λέγειν ὁμολογουμένας τοῖς φαινομένοις, οὐ καθάπερ οἱ ἔμπροσθεν, οἱ μὲν ἀλλοτριολογοῦντες καὶ τὴν μὲν αἴσθησιν ἐκκλίνοντες ὡς οὖσαν οὐκ ἀκριβῆ, νοητὰς δὲ κατασκευάζοντες αἰτίας καὶ φάσκοντες λόγους τε τινας ἀριθμῶν εἶναι καὶ τάχη πρὸς ἄλληλα, ἐν οἷς τό τε ὀξὺ καὶ τὸ βαρὺ γίγνεται, πάντων ἀλλοτριωτάτους λόγους λέγοντες καὶ ἐναντιωτάτους τοῖς φαινομένοις· οἱ δ' ἀποθεσπίζοντες ἕκαστα ἄνευ αἰτίας καὶ ἀποδείξεως οὐδ' αὐτὰ τὰ φαινόμενα καλῶς ἐξηριθμηκότες.[14]
>
> And of these things we attempt to state proofs which agree with appearances, not like our predecessors, some who state what is irrelevant and shun sense perception as something which is not accurate, but create intellectual reasons, and say that there are certain ratios of numbers and speeds relative to one another in which high and low [tones] happen—giving an account most at odds with everything and completely opposed to appearances. But others give oracular utterances on each thing without explanation or demonstration, nor do they enumerate the appearances themselves well.

With Aristoxenus' account we can identify the first group even more securely as the Pythagoreans. Aristoxenus speaks not only of numerical ratios, but explains that these ratios are of relative speeds. The further specification is important since it calls to mind Archytas' theory that pitch is dependent on the speed of moving air.[15] Also notable is Aristoxenus' insistence that the Pythagoreans' method of investigation is entirely irrelevant to serious harmonic study along his own lines.[16] This is because, like the *harmonikoi*, a name which he attached to those he considered closer to his method, Aristoxenus sought to give reasons that agreed with the phenomena.[17] To be sure, Aristoxenus also dismisses the non-Pythagorean *harmonikoi* as

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[13] Theophr. fr. 716 62.1–3 Fortenbaugh.
[14] Aristox. *Harm.* 41, 17–42, 5.
[15] DK47 B1 speaks about the necessity of an impact moving air at various speeds for there to be sound. Cf. Huffman 2005, 129–148.
[16] Cf. Aristox. *Harm.* 12, 4–6: μὴ ταραττέτωσαν δ' ἡμᾶς αἱ τῶν εἰς κινήσεις ἀγόντων τοὺς φθόγγους δόξαι καὶ καθόλου τὴν φωνὴν κίνησιν εἶναι φασκόντων; "Let the opinions of those refer sounds to movements and, in general, those who say that sound is motion, not trouble us." Again Archytas, and the anonymous predecessors to whom he refers, must be the ultimate target here (Barker 2007, 28–9).
[17] Barker 1976, esp. 1–8 and Barker 2007, 37. Although in the passage they fall under the umbrella of οἱ ἔμπροσθεν, Aristoxenus is equally as concerned to stress that they were ἀλλοτριωτάτους, pursuing matters outside the ambit of harmonic theory (again, on his definition).

insufficiently theoretical, as they do not give "reasons or accounts" (ἄνευ αἰτίας καὶ ἀποδείξεως). Furthermore, he states that they too were careless in reporting how things appear. By this complaint, however, he implies that the non-Pythagoreans at least *tried* to gather sense-data. Because of the emphasis he placed upon gathering sensory data, later authors tended to see Aristoxenus as the empiricist *par excellence* and empirical investigators of harmonics became known as "Aristoxenians," whether or not they were so properly speaking.

Quotations from later technical writers on harmonics help to flesh out the distinction made by the foregoing philosophers. A musician named Didymus[18] (1st century CE) wrote a comparison between the two schools of thought entitled *On the Difference Between the Aristoxenians and Pythagoreans*, where he states that the Pythagoreans, unlike those with a purely performative interest in music (whether vocal or instrumental), preferred using reason, but also used sense-perception as a starting point.[19]

For this characterization, Didymus evidently relied upon another theorist by the name of Ptolemaïs of Cyrene (date unknown, but necessarily no later than 1st century CE).[20] She wrote that the "Pythagoreans," were rationalists, but found space for sensory data. In particular, "Pythagoras and his followers" began with the data taken from their senses, which acted as an

[18] Porphyry, who is the sole source for this work, does not give much information about his identity. It seems most likely that this Didymus is Didymus of Hallicarnasus (*RE* s.v. Didymos 11) who *Suda* s.v. Δίδυμος, ὁ τοῦ Ἡρακλείδου says was a consummate musician (μουσικός…λίαν).

[19] καθόλου τοίνυν τῶν ἐπὶ μουσικὴν ἐλθόντων οἱ μὲν αἰσθήσει μόνον προσέσχον τέλεον παρέντες τὸν λόγον […] ἦσαν δ' οἵ τε ὀργανικοὶ ἰδίως τοιοῦτοι καὶ οἱ φωνασκικοὶ καὶ ἁπλῶς ὅσοι ἔτι καὶ νῦν συνήθως τῇ ἀλόγῳ τριβῇ λέγονται χρῆσθαι. οἱ δὲ τὴν ἐναντίαν τούτοις ὁρμήσαντες τὸν μὲν λόγον προετίμων κριτήν, τῇ δ' αἰσθήσει οὐκέτι οὕτω προσεῖχον, ἀλλ' ὅσον ἐς ἀφορμὴν μόνον, […] οὗτοι δ' εἰσὶν οἱ Πυθαγόρειοι; "In general, then, among those who have gone over music, some paid attention to sense perception alone, completely disregarding reason […] these were, in particular, the instrumentalists and the voice-trainers and, quite simply, those who still even now are said to habitually use a non-rational knack. The others, starting off the opposite way from them, prefered reason as the judge, and no longer paid such attention to sense perception, except insofar as [they would] only to a starting point […] these are the Pythagoreans" (Porph. *in Ptol. Harm.* 26, 6–18).

[20] Barker 1989, 239, n. 133.

initial guide or "spark."[21] After enough data had been taken in, they were able to let pure reason take over to do the necessary work of understanding, and if understanding conflicted with what they had sensed, the former overturned the latter.

So, just as with the study of nature among early philosophers, the early study of sound was marked by a preference for reason, but, even among the rationalist Pythagoreans later, more technically oriented authors noted a willingness to take sensory data into account. *How* they did so, and whether their practice coincided with their theoretical commitments, are questions best answered by treating early figures in turn.

4.2. Pythagoras and Harmonic Theory

Given the heavy Pythagorean footprint in the ancient historiography of harmonics, it is unsurprising that Pythagoras himself is said to have been interested in harmonics and the study of music. Much of the evidence for this, however, verges on the fantastic. For instance, later sources make the obviously fanciful claims that Pythagoras was able to shift his followers' psychology by playing music and that he alone of men could hear the ineffable "music of the [sc. celestial] spheres."[22] Such tales of Pythagoras' miraculous feats were typical of the Roman period, but one account merits especially close investigation: that Pythagoras discovered the numerical ratios behind the most common harmonic intervals and confirmed them by experiment. To do so, however, we must begin with the interpretational problems with the Pythagorean tradition itself and what it means to say that a musical interval corresponds to a numerical ratio.

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[21] Πυθαγόρας καὶ οἱ διαδεξάμενοι βούλονται τὴν μὲν αἴσθησιν ὡς ὁδηγὸν τοῦ λόγου ἐν ἀρχῇ παραλαμβάνειν πρὸς τὸ οἱονεὶ ζώπυρα τινα παραδιδόναι αὐτῷ, τὸν δὲ λόγον ἐκ τούτων ὁρμηθέντα καθ' ἑαυτὸν πραγματεύεσθαι ἀποστάντα τῆς αἰσθήσεως; "Pythagoras and his followers wished to take sense perception as an initial guide for reason, for giving it a spark, as it were, and proceeding from this point, reason works on its own, separated from sense perception" (Porph. *in Ptol. Harm.* 23, 25–28).
[22] E.g., Iamb. *VP* 64, 66.

4.2.1. Our Evidence on Pythagoras and the Pythagorean Tradition

While all of early Greek natural philosophy is fragmentary, evidence about Pythagorean interest in harmonics and acoustics has come down to us, for the most part, through different channels from other topics. Unlike topics such as human biology or astronomy, the doxographical vulgate stemming from the Lyceum seems to have had little interest in early theories of sound and musical intervals.[23] This is perhaps because the topic is one which does not easily lend itself to the process of epitomization into easily presentable summaries: often the debates presuppose a fairly sophisticated grasp of mathematics and were expressed in a complex technical vocabulary.[24]

Democritus is an early and important source for Pythagorean matters.[25] But, the later authors give us the widest (even if not always the most accurate) look into the *practice* of early harmonic research are the mathematically-oriented thinkers of the Roman era like Ptolemy, Nicomachus of Gerasa, and Theon of Smyrna, some of whom were inspired by the Neopythagorean revival of interest in Pythagoras.[26] Authors from the Academy and the Lyceum, especially Aristoxenus, also play a role—just as in the case of our knowledge of the theoretical debate described above—but they must frequently be approached through another layer of sources (often the Roman-era authors mentioned above).

But, as with everything touching upon Pythagoras and his school, there are many later additions of dubious authenticity. Scholars often mention the tendency, noted first by Zeller, that the further one gets from Pythagoras, the more detailed (and, implicitly, the more untrustworthy)

[23] Neither of the two authors (ps.-Plutarch and Stobaeus) from whom Diels reconstructed the text of Aëtius (who relied on Theophrastus) contains chapters on sound or music. Rather there are chapters that deal with voice and hearing (Diels 1879, 406–410), but within those chapters there is only one cursory mention of Pythagoras and none at all of other Pythagoreans.
[24] Cf. Creese 2010, 214–225.
[25] Cf. DK68 B26.
[26] The term 'Neopythagoreanism,' just like 'Neoplatonism,' is a modern invention to mark a resurgent interest in Pythagoras in philosophical circles, cf. Dillon 1977, 341–383 for the major figures.

the information becomes.[27] But the modern attempt to sift through this later evidence, which includes material about early Pythagorean acoustic theory and experimentation, was inaugurated by Burkert.[28]

Burkert's analysis rests on several points. But on the "Pythagorean Question"—what, if anything, can we say about early Pythagoreanism and Pythagoras himself—his conclusion is deflationary. For Burkert, the idea that Pythagoras was a philosopher and scientist is a mistake and many of the doctrines imputed to him and his immediate followers actually were invented in the post-Platonic Academy.[29] Burkert conceived of the historical Pythagoras more as a charismatic wise man who counseled a certain way of life and taught the doctrine of metempsychosis. This view, at least, is what we find in the pre-Academic sources (as well as Plato's only unambiguous reference to Pythagoras).[30]

The conclusions have been variously upheld[31] and challenged[32] in later studies, but all use Burkert's work as a starting point. So, as we begin to analyze the evidence concerning a Pythagorean tradition of harmonic experimentation (as well as scattered references to non-

[27] Zeller 1877, 256: "So weiss uns also die Überlieferung über den Pythagoreismus und seinen Stifter um so mehr zu sagen, je weiter sie der Zeit nach von diesen Erscheinungen abliegt, wogegen in demselben Mass einsilbiger wird, in dem wir uns dem Gegenstand selbst zeitlich annähern" (cited by e.g., Burkert 1972, 2 and Zhmud 2012, 3).
[28] One can sense the importance of Burkert's contribution by the *de rigueur* mention of him in the introductions of later studies of Pythagoreanism (cf. Huffman 1993, xiii; Kahn 2001 viii–x; Zhmud 2012, 3).
[29] Burkert 1972, 482.
[30] *Rep.* 600a. Cf. Isoc. *Bus.* 28; (possibly) Empedocles DK31 B129; Ion fr. 30 West; Hdt. 2.81, 4.95–96. The only pre-Platonic evidence of Pythagoras being a philosopher or scientist is Heraclitus DK22 B129, where Heraclitus says that Pythagoras "practiced inquiry" and had wide learning (πολυμαθίη). The genuineness of the fragment and its evidentiary value for the Pythagorean question have been debated (cf. Burkert 1972, 208–210; Kahn 2001, 17; Huffman 2008).
[31] E.g., Huffman in his studies of Philolaus (Huffman 1993) and Archytas (Huffman 2005). One could also place Kingsley 1995 in this category as Kingsley seeks to reinterpret much of Presocratic philosophy, and Empedocles and Pythagoreanism in particular as a mystical tradition.
[32] E.g., Kahn 2001, 1–39; Zhmud 2012 *passim*. Kahn is on the whole more cautiously optimistic, whereas Zhmud is more daring in attributing scientific interests to Pythagoras himself, self-consciously setting his work against that of Burkert.

Pythagoreans), we must keep in mind the general tendency to impute Academic notions to Pythagoreans and discoveries to Pythagoras.[33]

4.2.2. Pythagorean Harmonic Theory vs. Modern Harmonics

The question of source reliability is only part of the reason why ancient harmonic theory is such a difficult topic to assay; another, equally important, reason is that despite a historical relationship, ancient harmonics has a vastly different viewpoint from modern physics. From both an ancient and modern viewpoint, the hallmark of the Pythagorean use of reason in harmonic theory is the relation of the common musical intervals to numerical ratios. The octave could be expressed as 2:1, the perfect fifth as 3:2, and the perfect fourth as 4:3. This insight in turn fed into later reports of Pythagorean number-theory and especially of the mystical symbol known as the *tetraktys*: a triangle made of four rows of points which contained all the numbers necessary to create these musical intervals and added up to the "perfect" number ten.[34] The origin of this insight seems to be genuinely Pythagorean (in the broad sense of part of tradition founded by Pythagoras, not necessarily Pythagoras' own idea), since Pythagorean thinkers of the sixth- and fifth-centuries were aware of it.[35] But to appreciate the advance, we must first explore the relationship between music and number.

What, then, does it mean to express the octave, fifth, and fourth as the numerical ratios 2:1, 3:2, and 4:3? From a modern scientific standpoint, we are speaking about the ratio between

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[33] Cf. Burkert 1972, 10.

[34] Burkert 1972 72–73 and 186–188. The first row is a single dot, the second row two dots, etc. The numbers 1, 2, 3 and 4 are the only numbers needed to create the ratios behind the octave (2:1), fifth (3:2), and fourth (4:3). The symbol itself may well date back to this early period (cf. Kárpáti 1993, 6), but it is only in later sources that it takes on great importance (cf. the pseudo-Pythagorean *Golden Verses* 46–8).

[35] On Hippasus, see section 3.3 below. Philolaus DK44 B6 (cf. Huffman 1993, 147–165). Cf. Iamb. *in Nic.* pp. 118.23–119, 2 εὕρημα δ' αὐτήν φασιν εἶναι Βαβυλωνίων καὶ διὰ Πυθαγόρου πρώτου εἰς Ἕλληνας ἐλθεῖν. εὑρίσκονται γοῦν πολλοὶ τῶν Πυθαγορείων αὐτῇ κεχρημένοι, ὥσπερ Ἀρισταῖος ὁ Κροτωνιάτης καὶ Τίμαιος ὁ Λοκρὸς καὶ Φιλόλαος καὶ Ἀρχύτας οἱ Ταραντῖνοι καὶ ἄλλοι πλείους; "They say that [ratio in harmonies] was a discovery of the Babylonians and came first to Greece through Pythagoras. At any rate, many of the Pythagoreans are found to have used it, like Aristaeus of Croton, Timaeus of Locri, Philolaus and Archytas, the Tarentines, and many others."

the frequencies of the two sounds making up the interval, where frequency is the number of waves per unit of time of any given sound wave. For example, a tone with a frequency of 200 Hz is one octave away from one at 400 Hz. What we hear—pitch—is not a physical, mind-independent quality like frequency, but rather is the auditory experience we have of frequency.[36]

All this, of course, is far from the ancient understanding. Rather, the early Pythagoreans seemed to have thought that tones *were* numbers in some way. No early Pythagorean sources survive explaining this view, but doubtlessly the fact that sounds corresponded so precisely with numbers helped give rise to the doxographical view that Pythagoras made number his principle of existence.[37] The contention that "all is number" is probably the best known summary of Pythagorean philosophy, and one that has its roots in Aristotle's account.[38]

Given this rarefied view of the identity of things and numbers, did Pythagoras or the Pythagoreans simply discover the ratios through *a priori* speculation? This is unlikely. The most likely impetus to this discovery was the fact that lengths of string in the correct ratios create the intervals. For example, a two-unit long ideal string (i.e., with the tension and thickness kept the same) will create a tone one octave lower than the one unit string. And so on for the rest of the Pythagorean intervals.

This has led some scholars have argued that the insight was necessary "craft knowledge" to construct stringed instruments, and thus not much of a theoretical advance.[39] Yet the construction of Greek musical instruments does not naturally lend itself to this insight since they often had strings of equal length, but varying tension—and the correct tension could easily have

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[36] The study of pitch is a classic topic of psychoacoustics – the study of how humans perceive sound, cf. Howard and Angus 2009, 131–133.
[37] The connection is made clear by Aëtius: Πυθαγόρας Μνησάρχου Σάμιος πρῶτος φιλοσοφίαν τούτῳ τῷ ῥήματι προσαγορεύσας, ἀρχὰς τοὺς ἀριθμοὺς καὶ τὰς συμμετρίας τὰς ἐν τούτοις, ἅς τινας ἁρμονίας καλεῖ; "Pythagoras of Samos, son of Mnesarchus, who was the first to call philosophy by that name, [thinks] that numbers and the relationships in them, which he calls certain harmonies, are principles" (Aët. 1.3.8).
[38] Arist. *Met.* 987b11–12; 987b23ff.
[39] Van der Waerden 1943, 172.

been achieved with measurement "by ear."[40] Furthermore, even if instrument makers had some idea about these intervals from the physical construction of instruments, it does not follow that they applied their knowledge across different instruments, or understood that the ratios worked for *any* numbers rather than for a set ratio of lengths. Thus, it seems that this is not just a case of practical knowledge making its way into philosophical debates, since the pre-Pythagorean understanding of pitch was also pre-theoretical. The crux of their contribution was that they were the first to explain the relationships between pitches in a general, quantifiable way.

4.2.3. The Harmonic Experiments of Pythagoras

With the preliminaries of source criticism, as well as the differing emphases of modern and ancient harmonics, out of the way, we may move on to the account of Pythagoras' harmonic experiments. Although the contribution to harmonic theory seems to be genuinely Pythagorean in the sense of arising in a fifth-century Pythagorean context, it is a fraught question whether it so more narrowly: that is, whether Pythagoras himself was the source of this insight. The question is an important one for the history of Greek science and experimentation since ancient sources claim that Pythagoras undertook a multitude of empirical tests to confirm his hypothesis. Yet the sources are late, and must be considered carefully, especially since our earliest source that connects Pythagoras himself to harmonic theory is the Academic Xenocrates, suggesting, per Burkert's thesis, that Academic notions could have made their way into the account.[41] Of course, Xenocrates belonged to the very earliest generation of the Academy, and was well-positioned to know about Pythagoras through connections to Pythagoreans like Archytas. However, one must always keep in mind that philosophers are not always the most unbiased

[40] Guthrie 1962, 224 and Burkert 1972 374–5. Cf. Aristotle's division of harmonics at *APo.* 79a1 into "mathematical" and "by ear" harmonics (p. 109, n. 10).
[41] Fr. 87 Isnardi-Parente (= Porph. *in Ptol. Harm.* p. 30, 1ff. Düring). Porphyry quotes a Heraclides (almost certainly Heraclides Ponticus who D.L. 5.88 says wrote a book Περὶ τῶν Πυθαγορείων), who in turn quotes Xenocrates.

historians of philosophy, as they tend to see their predecessors through the lens of their own system.

The tradition is quite diffuse in later sources, and some leave out the most fantastic bits, but the earliest account of the discovery is contained in the 1st–2nd century CE mathematician Nicomachus.[42] Nicomachus' account is a mix of the unbelievable and the serious, typical of his era's portrayal of Pythagoras and shows the Samian as a culture hero or *prôtos heuretês*, often a divinity, who makes a miraculous discovery and shares his (or more rarely her) boon with humankind.[43]

Nicomachus' account goes as follows: while walking past a blacksmith, Pythagoras happened to hear the concords (the octave, the fifth and the fourth) sounding from the blacksmith's hammer blows upon the anvil.[44] Fascinated by the coincidence, he then weighed the different hammers, and ruled out other possible variables such as the force of the strikes, the shape of the hammers, or any change undergone by the iron by undescribed tests.[45] Presumably because he thought tension of strings the most obvious variable in changing tone for musical instruments, he then suspended pieces of metal of the same weight as the hammers from cords,

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[42] Nicom. *Harm.* 6. The same story is alluded to or told by (in rough chronological order): Theon Smyrn. 56, 9–57, 10; Gaud. *Harm.* 11; Aristid. Quint. 94–5; Censor. 10; Iamb. *VP* 26, *in Nic. Harm.* pp. 121–2; Chalcid. *in Tim.* 45; Macrob. *Somn. Scip.* 9–13; Boëth. *Mus.* 1.10; Isid. *Et.* 3.16.1.

[43] On the figure of the *prôtos heuretês* see the still-classic study of Kleingünther 1933. Cole 1967, 48ff. highlights the divinity of many of these discoverers; on Pythagoras as a (semi-)divinity, cf. Arist. fr. 192; [Apollon.] *Ep.* 50; Porph. *VP* 20.

[44] παρά τι χαλκοτυπεῖον περιπατῶν ἔκ τινος δαιμονίου συντυχίας ἐπήκουσε ῥαιστήρων σίδηρον ἐπ' ἄκμονι ῥαιόντων καὶ τοὺς ἤχους παραμὶξ πρὸς ἀλλήλους συμφωνοτάτους ἀποδιδόντων […] ἐπεγίνωσκε δ' ἐν αὐτοῖς τὴν δὲ διὰ πασῶν καὶ τὴν διὰ πέντε καὶ τὴν διὰ τεσσάρων συνῳδίαν; "walking by a smithy, due to the intervention of some divinity, he heard the hammers beating iron upon the anvil and the sounds were mixed with one another in a most concordant way […] he recognized among them the octave, the fifth, and the fourth" (Nicom. 6, 11–17).

[45] ποικίλαις πείραις παρὰ τὸν ἐν τοῖς ῥαιστῆρσιν ὄγκον εὑρὼν τὴν διαφορὰν τοῦ ἤχου, ἀλλ' οὐ παρὰ τὴν τῶν ῥαιόντων βίαν οὐδὲ παρὰ τὰ σχήματα τῶν σφυρῶν οὐδὲ παρὰ τὴν τοῦ ἐλαυνομένου σιδήρου μετάθεσιν; "by manifold tests discovered that the weights of the hammers were responsible for the difference in noise, not the force of the strikers, nor the hammers' shapes, nor the changing shape of the iron as it was beaten." (Nicom. *Harm.* 6, 22–6).

again controlling for variables such as cord length and thickness.[46] So the story goes, when he plucked one string weighed down by twelve "of some weight," and the other weighed down by six, he heard the octave.[47]

Nicomachus also records that, after establishing undertaking this foundational test, Pythagoras then set out to confirm his discovery and performed other experiments, using different instruments and isolating different variables, in what is perhaps the first ever mention of attempted falsification.[48] He used *kollaboi*, or screws used for tuning stringed instruments, to adjust the tension in the strings to the correct ratios. Also, he used non-stringed musical instruments to test the hypothesis: either by boring holes in *auloi* at the appropriate intervals, by using percussion instruments of the appropriate diameters.[49]

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[46] σηκώματα ἀκριβῶς ἐκλαβὼν καὶ ῥοπὰς ἰσαιτάτας τῶν ῥαιστήρων πρὸς ἑαυτὸν ἀπηλλάγη. καὶ ἀπό τινος ἑνὸς πασσάλου διὰ γώνων ἐμπεπηγότος τοῖς τοίχοις, ἵνα μὴ κἀκ τούτου διαφορά τις ὑποφαίνηται ἢ ὅλως ὑπονοῆται πασσάλων ἰδιαζόντων παραλλαγή, ἀπαρτήσας τέσσαρας <χορδὰς> ὁμοῦλους καὶ ἰσοκώλους, ἰσοπαχεῖς τε καὶ ἰσοστρόφους ἑκάστην ἐφ' ἑκάστης ἐξήρτησεν, ὁλκὴν προσδήσας ἐκ τοῦ κάτωθεν μέρους. "Then, having accurately taking the weights, he removed for himself pieces of metal that weighed exactly the same as the hammers. From a single rod attached to the corners of the walls diagonally, in order that there be no apparent difference, or any distortion even be suspected had he used individual rods, he hung four <strings>—made from an equal number of strands of the same material, equally thick and equally twisted, and after he had hung them, he attached a weight from the bottom part [of each string]" (Nicom. 6, 26–34).

[47] τὴν μὲν γὰρ ὑπὸ τοῦ μεγίστου ἐξαρτήματος τεινομένην πρὸς τὴν ὑπὸ τοῦ μικροτάτου διὰ πασῶν φθεγγομένην κατελάμβανεν. ἦν δὲ ἡ μὲν δώδεκά τινων ὁλκῶν, ἡ δὲ ἕξ. ἐν διπλασίῳ δὴ λόγῳ ἀπέφαινε τὴν διὰ πασῶν, ὅπερ καὶ αὐτὰ τὰ βάρη ὑπέφαινε. τὴν δ' αὖ μεγίστην πρὸς τὴν παρὰ τὴν μικροτάτην (οὖσαν ὀκτὼ ὁλκῶν) διὰ πέντε συμφωνοῦσαν, ἔνθεν ταύτην ἀπέφαινεν ἐν ἡμιολίῳ λόγῳ, ἐνῷπερ καὶ αἱ ὁλκαὶ ὑπῆρχον πρὸς ἀλλήλας· πρὸς δὲ τὴν μεθ' ἑαυτὴν μὲν τῷ βάρει, τῶν δὲ λοιπῶν μείζονα, ἐννέα σταθμῶν ὑπάρχουσαν, τὴν διὰ τεσσάρων, ἀναλόγως τοῖς βρίθεσι. καὶ ταύτην δὴ ἐπίτριτον ἄντικρυς κατελαμβάνετο; "[By plucking] the [string] stretched by the greatest weight alongside that with the smallest weight, he heard the octave; and the one string had twelve units of weight, the other six. Therefore he defined the octave in a duple (2:1) ratio, which the weights themselves also showed. Again, the greatest [weight] to the smallest (which had eight units [of weight]) made a concordance of a fifth, and from this showed that [the fifth exists] in a hemiolic (3:2) ratio, in the very same ratio that the weights had to one another. In relation to next in weight, weighing greater than the rest at nine units, it [made] a fourth in proportion to the weights. And this he straightaway recognized as epitritic (4:3)" (Nicom. 6, 36–49).

[48] Meriani 1995, 86.

[49] ἐπιβάθρᾳ τε ταύτῃ χρώμενος καὶ οἷον ἀνεξαπατήτῳ γνώμονι εἰς ποικίλα ὄργανα τὴν πεῖραν λοιπὸν ἐξέτεινε, λεκίδων τε κροῦσιν καὶ αὐλοὺς καὶ σύριγγας καὶ μονόχορδα καὶ τρίγωνα καὶ τὰ παραπλήσια, καὶ σύμφωνον εὕρισκεν ἐν ἅπασι καὶ ἀπαράλλακτον τὴν δι' ἀριθμοῦ κατάληψιν; "And using this foundation, and, as it were, an infallible guide, he extended his test to sundry instruments, beating vessels, flutes, panpipes, the monochord, the trigon, and such others, and he discovered the same conception of concordance according to number in all of them" (Nicom. 6, 69–74). Cf. Theon Smyrn. p. 56–7 Hiller where some of the same confirmatory tests are also attributed to Pythagoras (discussed below in section 5).

Fig. 4.1: A Rennaisance illustration of Pythagoras' experiments.[50]

Placing aside the improbably serendipitous encounter at the blacksmith—attributed by some authors to divine intervention[51]—Nicomachus' account of Pythagoras' experiment is quite impressive from a modern vantage point. He has used the weights to precisely quantify tension, an obviously relevant variable. The account even makes clear that the *precise* amount of weight does not matter (by using the phrase τινων ὁλκῶν); rather, it is the ratio between weights which is the relevant variable. He has also controlled for potential confounding variables and even attempted to falsify his results by performing confirmatory experiments.

Yet, a closer look raises suspicions about the passage. For example, the weight of the hammers will have an effect on the sound they make when hitting the anvil, but not according to

[50] A Rennaisance illustration of Pythagoras' experiments, found in Gaffurius' *Theorica Musicae* (Gaffurius 1492). Starting from top-left and moving clockwise, there is biblical culture hero Jubal, "the father of all such as handle the harp and organ" (*Gen.* 4:21); Pythagoras playing bells and glasses filled up in certain ratios (see section 4.4 below); Pythagoras' experiment as described by Nicomachus; and finally Pythagoras and Philolaus (!) playing *auloi*.
[51] Nicom. *Harm.* 6 and Iamb. *VP* 116 say that the discovery was due ἔκ τινος δαιμονίου συντυχίας; "by the intervention [LSJ s.v. συντυχία, 2c] of some divinity."

the required ratios (e.g., striking two hammers, one double the weight of the other, will not create an octave).[52] The same problem plagues Pythagoras' supposed confirmatory tests: applying the ratios directly to the diameter of drums or the location of holes in a wind instrument will not result in the correct intervals either. Furthermore, the setup of the experiment is flawed (or at the very least unclear) since it would be impossible for the strings to vibrate correctly unless the weights were somehow fixed.

Perhaps the most important problem, however, is that the ratio between the hanging weights, and thus the tensions in the string, is not correct. The relevant ratio is between the square roots of the weights: in order to get an octave, for example, one would have to suspend four units (that is, two squared) of weight to every one unit. All these physical problems with the setup of the experiment and its results suggest that the account is mainly a literary creation.

However, even though Pythagoras' experiments as described by Nicomachus are not scientifically valid, there is here perhaps an echo of an early instrument used to model musical intervals called the *kanôn*.[53] The instrument itself was a single string stretched over a marked board; the musician could then move a bridge and divide the vibrating portion of the string at whatever interval was desired.[54]

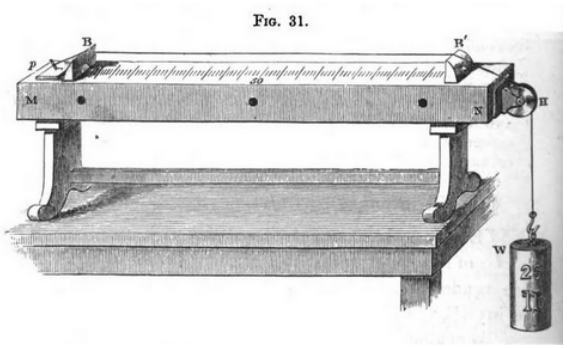

Fig. 4.2: A modern representation of the *kanôn*.[55]

[52] Barker 1989, 257, n. 47.
[53] Barker 2007, 25–9.
[54] West 1992, 240.
[55] A modern representation of the *kanôn*, taken from Tyndall 1875, 84. The portion labeled B is the fixed bridge, B' the moveable bridge which can divide the string to a desired ratio based on the markings on the board M. Note that

Obviously, such an instrument is more suited to research or demonstration than performance: having only one string would make playing all but the simplest melodies extremely cumbersome. This is borne out by the sources as well: no author mentions a monochord *kanôn* used purely for performance[56] and all of the other stringed instruments surveyed by West in his treatment of Greek music have at least three strings.[57]

The important point, however, is that the frequency of a string *is* inversely proportional to its length. Thus, by plucking a string of a given length and then plucking a string twice that length, a researcher would create an octave using the Pythagorean proportions of 2:1, and so on for the other intervals. This suggests that the intervals were demonstrated experimentally using a purpose-built apparatus at a date earlier than the more indiscriminate tradition found in Nicomachus, where the results were incorrectly transferred to other relevant variables (such as tension). Indeed, some sources state that Pythagoreans (rather than the teacher himself) engaged in dividing the *kanôn* to the exclusion of any other experiment.[58]

Of course, the possibility rests on the date of the first use of the *kanôn*, which is disputed. It must predate the Euclidean (or pseudo-Euclidean) treatise by the name of *Division of the Canon*. Furthermore, we know that a story originating with the Hellenistic historian Duris of Samos connects a theorist called Simos with the use of the *kanôn*, but Simos' date is unknown.[59]

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the wheel (H) and the weight (W) used to adjust the tension of the string, as opposed to its length, is a later feature added to monochords and is not described in the ancient material. However, it does correspond with the ancient harmonic tests ascribed to Pythagoras which also used fixed weights to create a precise and measurable tension.

[56] In fact, as noted by West 1992, 80, n. 146, Ptol. *Harm.* 2.12 discusses why the *kanôn* is *not* fit to be a performance instrument in a chapter entitled *On the inconvenience of the monochord kanôn* (Περὶ τῆς δυσχρηστίας τοῦ μονοχόρδου κανόνος).

[57] West 1992, 62–64.

[58] E.g., Porph. *in Ptol. Harm.* p.120 Düring: ἄλλοι δὲ τούτων [sc. Pythagoreans] ἔτι ἄμεινον φρονεῖν ἔλεγον, ὅτι ἐκ τῆς τοῦ κανόνος κατατομῆς εὑρέθησαν οἱ λόγοι [sc. of the concords]; "Others among [the Pythagoreans] said that it was better to think that the ratios were discovered from the division of the *kanôn*." Of course, later sources revert to form and say that Pythagoras himself invented the instrument (e.g., D.L. 8.12).

[59] *FGrHist* 76 fr. 23 = Porph. *VP* 3. West 1992, 240 suggests that the story that Simos stole the idea of using the *kanôn* from Pythagoras implies that there was a pre-existing tradition connecting Simos to the instrument's invention.

Duris' dates are known and so he affords us a rough *terminus ante quem* of the late fourth century BCE. More exact dating of the first experimental use of the *kanôn*, then, must rely on indirect evidence, and many dates have been essayed.[60] Yet it should be noted that the rudiments of the *kanôn* are quite simple, and that any stringed instrument could have been used in the manner of a *kanôn*, even in the absence of a precisely measured and marked fretboard, since any string stretched over a board can demonstrate the main harmonic intervals, if one presses down in the correct spots.[61] Thus, it seems very probable that the principle behind the use of the *kanôn* was understood by instrument makers and playres before the invention of the precisely marked monochord *kanôn* by harmonic researchers.[62]

Thus, the conclusion about "Pythagoras'" experiments is deflationary for several reasons. They work neither as history nor as science. Rather they have all the marks of literary invention attached to the name of Pythagoras. But they have a kernel of truth to them in that they descend from actual harmonic experimentation using a stringed instrument, which could very well have led to the genuinely Pythagorean connection between harmonic and numerical intervals. However, there is one very important caveat: the variable identified as most relevant in Pythagoras' tests—tension—is not the correct one. Rather the harmonic ratios work as ratios of length, which then, incorrectly, must have been transferred to tension. This transference does not inspire confidence that the tests concerning tension were actually performed. But even if Pythagoras' role in early harmonic investigation is minimized, that of his supposed followers comes to the fore.

[60] Most settle for a Post-Aristotelian date (e.g., Van der Waerden 1943, 177; Creese 2010, 84–104 and 129)
[61] I owe this point to John Franklin *per litt*.
[62] There is some possible evidence of other "experimental" (i.e., used for clarifying musical theory, not performance) stringed instruments (see section 3.3 below). Cf. West 1992, 78–9 and Barker 2007, 80–1.

4.3. Hippasus, Glaucus, and the Discs

Although the tradition concerning Pythagoras' harmonic experiments gathered many dubious accretions from the outset, one testimonium about an immediate follower stands out. Socrates at *Phd.* 108d tells his interlocutor Simmias that to describe the soul's journey through the underworld is a task for the "craft of Glaucus," and that to explain it even exceeds the craft. In order to explain the proverbial craft, a scholium on this passage draws on material from Aristoxenus' *Lecture on Music* and a work entitled *On Theory* by a certain Nicocles:

> ση<μείωσαι> πα<ροιμίαν> ἐπὶ τῶν μὴ ῥᾳδίως κατεργαζομένων ἤτοι ἐπὶ τῶν πάνυ ἐπιμελῶς καὶ ἐντέχνως εἰργασμένων. Ἵππασος γάρ τις κατεσκεύασε χαλκοῦς τέτταρας δίσκους οὕτως ὥστε τὰς μὲν διαμέτρους αὐτῶν ἴσας ὑπάρχειν, τὸ δὲ τοῦ πρώτου δίσκου πάχος ἐπίτριτον μὲν εἶναι τοῦ δευτέρου, ἡμιόλιον δὲ τοῦ τρίτου, διπλάσιον δὲ τοῦ τετάρτου, κρουομένους δὲ τούτους ἐπιτελεῖν συμφωνίαν τινά. καὶ λέγεται Γλαῦκον ἰδόντα τοὺς ἐπὶ τῶν δίσκων φθόγγους πρῶτον ἐγχειρῆσαι δι' αὐτῶν χειρουργεῖν, καὶ ἀπὸ ταύτης τῆς πραγματείας ἔτι καὶ νῦν λέγεσθαι τὴν καλουμένην Γλαύκου τέχνην. μέμνηται δὲ τούτων Ἀριστόξενος ἐν τῷ Περὶ τῆς μουσικῆς ἀκροάσεως καὶ Νικοκλῆς ἐν τῷ Περὶ θεωρίας.[63]
>
> Take note of a proverb for things that are not easily accomplished or done with very great care and skill. For Hippasus constructed four bronze discs in such a way that their diameters were equal, but the thickness of the first had an epitrite [i.e, 4:3] relation to the second, a hemiolic [3:2] relation to the third, and a double [2:1] relation to the fourth. By striking them, he created certain concords. And Glaucus, having perceived the sounds in the discs, is said to have been the first to attempt to play [music] with them, and from this matter even now the "craft of Glaucus" is spoken of. Aristoxenus mentions these things in his *Lecture on Music,* as does Nicocles in *On Theory*.

The testimonium is also found verbatim in Zenobius' second-century CE collection of proverbs, although without the sources at the end[64] and in Eusebius, who contains a version of the material abbreviated in Zenobius.[65] These authors also relate the story in order to explain the proverb quoted by Plato, and so probably rely on the same sources as the scholiast.

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[63] Sch. Pl. *Phd*. 108d (ed. Cufalo).
[64] Zenob. 2.91 (= *CPG* I, 55).
[65] Eus. *Contr. Marc.* 1.3.5.

Before exploring the content of the testimonium, we must first consider how likely it is to be genuine. Aristoxenus is the oldest source that we can trace, since the most plausible identification of Nicocles is a fourth-century CE grammarian and teacher of the Emperor Julian.[66] Due to his date, he too presumably relied on Aristoxenus' work either directly or indirectly. Aristoxenus is usually highly regarded as a source for the history of musical theory,[67] but some are more skeptical on his worth in this matter, since no genuine work of Hippasus seems to have survived down to Aristoxenus' time.[68] A couple of considerations, however, play into Aristoxenus' favor. First, he had access to a Pythagorean community of his day, which could have preserved the memory of Hippasus' investigation, even if it were not more widely known.[69] Second, the scholiast tells us that Glaucus of Rhegium played a major role in promulgating Hippasus' demonstration, enough so that it gave rise to a proverb. So, it is probable that Glaucus was an intermediary source for Aristoxenus, and reliance on a written work of Hippasus would not be necessary. Finally, in a more general sense, Aristoxenus' story lacks the telltale sign of later accounts: the presence of Pythagoras. If Aristoxenus' information were invented at some point, attributing it to lesser-known figure like Hippasus is puzzling; the logic of such spurious attributions usually assigns breakthroughs to well-known figures.

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[66] *FGrHist* 587. The older edition of the Platonic scholia (Greene 1938) prints <Νι>κοκλῆς, but the name is actually sound, textually speaking (cf. Cufalo 2007, 38).
[67] Cf. Burkert 1972, 206, n. 71; Barker 1989, 31, n. 6.
[68] E.g., Creese 2010, 94. D.L. 8.84 states that Hippasus wrote no book, although this is contradicted by D.L. 8.7. Given the profusion of pseudo-Pythagorica in later centuries, the former passage in Diogenes Laertius is probably the correct one.
[69] Cf. D.L. 8.46 (=Wehrli fr. 19): τελευταῖοι γὰρ ἐγένοντο τῶν Πυθαγορείων, οὓς καὶ Ἀριστόξενος εἶδε, Ξενόφιλός τε ὁ Χαλκιδεὺς ἀπὸ Θρᾴκης καὶ Φάντων ὁ Φλιάσιος καὶ Ἐχεκράτης καὶ Διοκλῆς καὶ Πολύμναστος, Φλιάσιοι καὶ αὐτοί. ἦσαν δ' ἀκροαταὶ Φιλολάου καὶ Εὐρύτου τῶν Ταραντίνων; "For the last of the Pythagoreans lived [then], whom Aristoxenus saw: Xenophilus of Chalcedon from Thrace and Phanton of Phliasa and Echecrates and Diocles and Polymnastus (they were Phliasians too). They were the students of Philolaus and Eurytus, the Tarentines." Aristoxenus' father and teacher Spintharus may also have known Pythagoreans living in Tarentum (Iamb. *VP* 197).

However mysterious he may be, we do know that Hippasus was a figure of importance for early Pythagoreanism. Aristotle mentions in the *Metaphysics* that he, like Heraclitus, identified fire as the principle (ἀρχή) of all things, but does not note anywhere else a connection to Pythagoreanism.[70] This, however, is not strong evidence that he was *not* a Pythagorean, since Aristotle's task in this passage of the *Metaphysics* is not to trace the development of philosophical schools *per se*, but to divide his predecessors based on their identification of the ἀρχή. Thus Hippasus is placed with the natural philosophers presumably because he said the principle of everything was fire.[71] But it does not follow that Hippasus was not Pythagorean in the sense of being historically connected to Pythagoras or that he had nothing to do with mathematics; it simply means that Aristotle believed that he did not develop a cosmology based on a mathematical first principle.

In any case, the later tradition tips the scales, as it is unanimous in placing Hippasus among the earliest generation of Pythagoreans.[72] Most importantly, later sources portray him as the head of a sect of Pythagoreans, called *mathematici*, who emphasized a mathematical understanding of the universe rather than Pythagoras' ritually pure way of life. For this reason, the "ritual" Pythagoreans (called *acusmatici*) denied that that the *mathematici* were even Pythagoreans, but rather followers of Hippasus.[73] The reliability of this later distinction between ritualists and mathematicians is contested, and at stake is the Pythagorean question itself. If the distinction is genuine, that would imply that Pythagoras was more a religious wise man along Burkert's lines.[74] If the distinction was a later invention, there is one fewer piece of evidence for

[70] *Met.* 984a7. There is perhaps a connection between Hippasus' fire and the "central fire" in the cosmology of Philolaus, but the evidence is tenuous (Zhmud 2012, 94–95).
[71] Arist. *Met.* 989b30–990a31.
[72] E.g., D.L. 8.84; *Suda s.v.* Ἵππασος; Iamb. *VP* 88, 267; Porph. *VP* 36.
[73] Clem. *Strom.* 5.9.59; Iamb. *Comm. Math.* 76, *VP* 81; Porph. *VP* 36–7.
[74] Burkert 1972, 192–208.

a strong separation between science and religion in early Pythagoreanism, and, perhaps, for Pythagoras himself.[75] But if we put this question about Pythagoras to one side, it is intriguing that Hippasus is seen as the archetypal Pythagorean mathematician.

A further, if more fanciful, connection to mathematics is also hinted at with the story that he publicized a mathematical doctrine (either the construction of a dodecahedron from triangles or, more probably, the irrationality of certain numbers), and died at sea as punishment for divulging secret doctrines of the Pythagoreans.[76] Even adjusting for later embellishments, it seems clear that this story too offers a picture where Hippasus was both a Pythagorean and a thinker interested in offering mathematical explanations.

Thus Hippasus has a good claim to be an early figure of importance in early Pythagoreanism, but how early is also a matter of some dispute. He certainly belongs in the fifth century along with all the other philosophers mentioned alongside him in the *Metaphysics.* Some scholars have placed him in the middle of the fifth century on the basis of the supposed impossibility of dating the discovery of irrational numbers any earlier.[77] Others have placed him in the beginning of the fifth century, or even in the late sixth century.[78] The most compelling ancient evidence points to the first half of the fifth-century: he supposedly took part in a conspiracy of Pythagoreans at Croton dateable to around 530 BCE, as noted by Iamblichus.[79] and two later fifth century mathematicians (Hippocrates of Chios and Theodorus of Cyrene[80]) are

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[75] Zhmud 2012, 169–183.
[76] Dodecahedron: Clem. *Strom*. 5.9.57 and Iamb. *VP* 246; irrational numbers: Plut. *Numa* 22 (which, it must be noted, gives the story but does not name Hippasus explicitly). Cf. von Fritz 1945, who cautiously supports the tradition and Stamatis 1977, 190 who, less plausibly, credits it to Pythagoras by adopting an alternate reading of Proclus.
[77] E.g., Burkert 1972, 456.
[78] E.g., Zhmud 2012, 124–125.
[79] Iamb. *Comm. Math.* 77–78, *VP* 254–7. On the conspiracy directed against governments in Italy controlled by Pythagoreans and Hippasus' involvement cf. Minar 1942, 50–94; Horky 2013, 106–124
[80] Theodorus of Cyrene is especially interesting since we know independently (Pl. *Tht.* 147b–148d) that he proved the irrationality for all $\sqrt{x}$ (where x is a non-square number), from $\sqrt{3}$ to $\sqrt{17}$. Of course that leaves the more basic

known to have worked after him. Given that the only argument for the later dating depends on a hypothetical, it is probably safer to rely on the ancient evidence and opt for an earlier date.

Therefore, all signs suggest that this test is genuine evidence of quite early Pythagorean harmonic experimentation undertaken by Hippasus. It certainly also seems close to the modern ideal of an experiment. The scholiast describes a process where Hippasus wished to test a hypothesis (whether there was a mathematical relationship between various musical notes) and isolated a variable (the thickness of the discs) while keeping other parts of the system the same (the material, the shape, the diameter).

Whether the experiment would actually work as described, and thus have a stronger claim to genuineness, depends on the exact nature of the "discs." The use of bronze is obvious enough—the discs would have to vibrate in order to make a sound and metal percussion instruments were well known in Greek antiquity, as well as in older Near Eastern civilizations.[81] Especially interesting is West's observation that metal tube and disc chimes dating from the eighth-century have been found in Southern Italy (i.e., the area of Hippasus' hometown Metapontum).[82] Thus, it seems that Hippasus' demonstration, although intended to prove a theoretical point, might have grown from practical antecedents.

But the most important feature of the discs is the exact measurement of the thicknesses, for that is the variable which Hippasus wished to modify. Would discs of these thicknesses have proven the point that Hippasus sought? The mathematical relationships governing the vibration of flat, two dimensional circular plates are quite complicated, much less those governing true three-dimensional objects, but graduating the thickness of discs in this way would result in the

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$\sqrt{2}$ which is also irrational. The most likely reason that Theodorus did not seek to prove it was that it had already been proven, and given the stories of Hippasus divulging irrational numbers, Hippasus probably was the one to have done it and therefore Theodorus' predecessor (Heath 1921, 204–205).

[81] Blades 1970, 164–176; West 1992, 124–128.

[82] West 1992, 234.

correct tones, although in an opposite relationship to strings (i.e., a thicker disc will sound an octave higher, but a longer string an octave lower).[83] Hippasus could not have possibly understood the entire mathematical relationship governing the system that he created; rather, he was successful in isolating and testing one relevant variable and, presumably, in keeping other relevant variables, like whether the disc is clamped down on the side or suspended from the center, the same, albeit without identifying them.

Hippasus' early date also brings up a question of priority with the other genuine experiment varying the length of a string using a *kanôn*. Should Hippasus be credited with both the discovery of the ratios corresponding to musical intervals and the first experiment to demonstrate it? Of course, certainty is impossible in this matter but consideration of the process used to create the experimental instruments tends toward the priority of a stringed instrument. The construction of this sort of instrument is a much simpler proposition than creating a set of bronze instruments intentionally made for proving a point. However, even if Hippasus did take inspiration from simpler instruments, he certainly was the first we know of to have understood that these ratios were valid not only for stringed instruments, but also others like tuned percussion instruments. This insight points to a more generalized, and therefore more scientific, understanding of the relationship between number and sound.

There is some evidence that the idea of constructing a musical instrument expressly for research—first securely attributable to Hippasus—caught on with later musicians and musical researchers. We have already mentioned the monochord *kanôn* above as a possible inspiration to later stories of Pythagoras' discovery of the harmonic intervals, although the dating of the *kanôn's* invention is debatable. West has also suggested that two stringed instruments named

[83] Creese 2010, 94. For a look at how complicated the physics behind this gets, as opposed to the relatively simple relation between the length of an ideal string and the frequency of its vibration, cf. Fletcher and Rossing 1998, 60–63.

after fifth-century musical theorists (the *epigoneion* and *simikon*) had a greater number of strings than usual performance-oriented instruments and were used to discover the smallest possible intervals empirically, much like the empiricists mentioned by Plato in the *Republic* looking to establish by ear the smallest possible difference in tone.[84] But, the most important of these figures—and the one who certainly knew of Hippasus' test—was "Glaucus" mentioned by the scholiast on Plato who preserves the account of Hippasus' test.

The Glaucus in question is certainly Glaucus of Rhegium.[85] We know nothing about his life, but he dates to the late fifth or even early fourth century.[86] He was an important early source on the historiography of music and ps.-Plutarch's *On Music* quotes several passages from Glaucus' work entitled *On Ancient Poets and Musicians*.[87] Nor were Glaucus' interests merely focused on the musical: he also showed an interest in Pythagoreanism as a system of thought, since he stated that Democritus studied under an anonymous Pythagorean.[88]

Since Glaucus is suspected to have travelled around Italy in order to perform research for his work,[89] he may have encountered the discs by visiting Metapontum. The scholiast informs us that Glaucus "perceived (ἰδόντα) the notes in the discs and first attempted to play (χειρουργεῖν) them by means of the [discs]." The language used suggests that Glaucus had a direct acquaintance with Hippasus' demonstration and did not come by his information either from reading (highly unlikely since Hippasus wrote nothing) or hearsay. The phrase ἰδόντα τοὺς ἐπὶ

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[84] West 1992, 78–9. Cf. Barker 2007, 80–81 and above p. 108, n. 5.
[85] His fragments were collected by Müller 1841, but cf. Huxley 1968 for a discussion with a more complete reckoning of the evidence.
[86] D.L. 9.38 states that Glaucus was a contemporary of Democritus and Philolaus (cf. note 86 below).
[87] Ps.-Plut. *De Musica* 4. The author does not specify Glaucus' hometown, but calls him "Glaucus from Italy," which in context must refer to Rhegium. The title Ὑπὲρ τῶν ἀρχαίων ποιητῶν, quoted in ps.-Plut. *De Mus.* 7 is probably the same work. So too is his *On Poets* reported at ps.-Plut. 833cd, whose name is probably a generic simplification.
[88] Τῶν Πυθαγορικῶν τινὸς ἀκοῦσαί φησιν αὐτὸν Γλαῦκος ὁ Ῥηγῖνος, κατὰ τοὺς αὐτοὺς χρόνους αὐτῷ γεγονώς; "Glaucus of Rhegium, who lived in the same time as him [sc. Democritus], says that he was the student of one of the Pythagoreans." (D.L. 9.38).
[89] Huxley 1968, 49; Franklin 2010, 31.

τῶν δίσκων φθόγγους is an odd one, but if the usage of ὁράω is not metaphorical, perhaps alludes to Glaucus "seeing" Hippasus' experiment in action.[90]

But his interest was not scientific at first glance. We are told that he was the first to χειρουργεῖν the discs. The verb χειρουργεῖν in context means "to play music" as distinct from singing on the one hand,[91] and the academic study of music on the other.[92] Given the word choice and the nature of the bronze discs, Glaucus most likely used them as a tuned percussion instrument (like the modern tuned cymbals called crotales). Yet it is hard to understand how the explanation of the proverb is supposed to function if he had only four tones available to him. Furthermore, it is also difficult to see how this would count as remarkable to a contemporary audience when, as previously noted, tuned chimes predated even Hippasus.

One suggestion is that Glaucus expanded the original apparatus to a full scale and amazed audiences with his virtuoso playing.[93] That is certainly possible, but there is another possibility which both explains the later interest and places Glaucus in the intellectual context of the late-fifth century. He could have combined musical performance with an explanation of the instrument on display—showing his expertise in both music and the workings of nature at the same time. Such a combination of performance and theory is attested elsewhere among sophists of the day. Sophists most often had recourse to a display speech, or *epideixis*, which was open to

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[90] That is not to say that Glaucus must have seen Hippasus himself give the demonstration, since their dates would make this possibility remote. More likely, he saw the demonstration which was credited to Hippasus

[91] πότερον δὲ δεῖ μανθάνειν αὐτοὺς ᾄδοντάς τε καὶ χειρουργοῦντας ἢ μή (Arist. *Pol.* 1340b20, cf. *Pol.* 1342a3, fr. 52 Rose). The pseudo-Aristotelian *Definitiones* c. 9 explicitly differentiates the types of music: ἡ μουσικὴ εἰς τρία διαιρεῖται· ἔστι γὰρ ἡ μὲν διὰ τοῦ στόματος μόνον, οἷον ἡ ᾠδή· δεύτερον δὲ διὰ τοῦ στόματος καὶ τῶν χειρῶν οἷον ἡ κιθαρῳδία· τρίτον ἀπὸ τῶν χειρῶν μόνον, οἷον ἡ κιθαριστική; "music is divided into three parts: first, [music] through the mouth only, e.g., song; second, through the mouth and the hands; for example, singing to the accompaniment of a cithara; third, from the hands only, e.g., playing the cithara."

[92] παραδώσω τῷ ἑταίρῳ Σωτηρίχῳ, ἐσπουδακότι οὐ μόνον περὶ μουσικὴν ἀλλὰ καὶ περὶ τὴν ἄλλην ἐγκύκλιον παιδείαν; ἡμεῖς γὰρ μᾶλλον χειρουργικῷ μέρει τῆς μουσικῆς ἐγγεγυμνάσμεθα; "Shall I hand this over to our companion Soterichus, who is zealous not only in music but also in the rest of a general education? For we have been trained more in the instrumental part of music." (ps.-Plut. *De Mus.* 13).

[93] Barker 2007, 84–5.

the public, sometimes for a fee. Of course, these speeches were mainly displays of rhetorical fireworks, not musical talent. Yet the presentation of the sophists was not unrelated to that of poets, and, because of the musical nature of Greek poetry, of musicians. During the delivery of epideictic speeches, sophists were known to don special purple clothing like that of rhapsodes.[94] Avowed sophists like Hippias or Critias could hold forth on musical topics.[95] Conversely, figures whom we see mainly as musical theorists, like Damon of Athens, were classified as sophists.[96] Indeed, the term σοφιστής, as well as the more general ὁ σοφός, could refer to poets before being attached to this sort of itinerant teacher and gaining a negative connotation after Plato.[97]

Finally, and most strikingly, a remarkable papyrus fragment even gives us a contemporary (or near-contemporary) picture of an *epideixis* mixing music and critical comment by a sophist, not a professional musician. The papyrus itself (*P.Hibeh* 13) is a piece of mummy cartonnage, and is paleographically dated to the early 3rd century BCE.[98] The text, however, is older[99]:

πολλ]άκις ἐπηλθέ μοι θ̣αυμάσαι, ὦ ἄνδρες [Ἕλληνες
εἰ ἀ]λλοτρίας τιν[ες] τὰς ἐπιδείξεις τῶν ὀ[ικειων τε-
χν]ῶν ποιούμεν[οι] λανθάνουσιν ὑμᾶς· λ[έγοντες γὰρ
ὅ]τ̣ι ἁρμονικοί εἰσι καὶ προχειρισάμενοι ὠ[ΐδας τινας
ταύτας συγκρίνουσιν τῶν μέν ὡς ἔτυχεν
κατηγοροῦντες, τὰς δὲ εἰκῆι ἐγκω[μιάζ]οντες.
καὶ λέγουσι μέν ὡς οὐ δεῖ αὐτοὺς οὔ[τε ψ]ά̣λ̣τας
οὔτε ὠΐδας θεωρεῖν· περὶ μὲγ γὰρ τ̣[αῦτ]α ἑτέροις
φασιν παραχωρ[ε]ῖν, αὐτῶν δ̣ὲ ἴδιον [εἶ]ναι τὸ θε-

[94] Ael. *VH* 12.32; Pl. *Hipp. Min.* 368c, cf. Kerferd 1981, 29.
[95] Hippias: Pl. *Prot.* 318e; Philostr. *VS* 1.2.1. Critias: Pollux 4.64. Cf. Barker 2007, 68–78.
[96] ὁ δὲ Δάμων ἔοικεν ἄκρος ὢν σοφιστὴς καταδύεσθαι μὲν εἰς τὸ τῆς μουσικῆς ὄνομα πρὸς τοὺς πολλοὺς ἐπικρυπτόμενος τὴν δεινότητα; "Damon seemed, being the consummate sophist, to don the name of music for the many, hiding his cleverness." (Plut. *Pericles* 4). Cf. Guthrie 1971, 35 n.1.
[97] Cf. Pind. *Isth.* 5.28; Aesch. fr. 314.
[98] Grenfell and Hunt 1906, 45–6; Brancacci 1988.
[99] The exact date is unknown but the current consensus seems to posit a date in the early fourth century based on language and subject matter. Attribution is similarly contentious. Grenfell and Hunt 1906 (the first publication) and Ruelle 1907 attribute it to Hippias of Elis; Brancacci 1988 attributes it more plausibly to Alcidamas, a generation or so later.

ωρητικὸν μέρος[100]

> Often it has occurred to me, men of Greece, to wonder whether some of those making demonstrations unrelated to their own crafts escape your attention; for those who say that they are harmonicists and choose certain songs, compare them by denigrating [some] chance songs and praising others at random. They claim that they need not study the singers or harpists themselves. They say that that they concede these things to others, but that their part [of music] is theoretical…

The papyrus is an *epideixis* in its own right, but one directed *against* the sophists who claim a spurious "theoretical" expertise in "harmonics"; instead of deferring to musicians whose achievement in their craft gives them good judgment, they speak about musical subjects without the necessary experience. Further down, however, the author perhaps even suggests a performative aspect to these sophistic display speeches when he claims that these *harmonikoi*:

> εἰς τ]ο̣ῦτο δὲ ἔρχονται τόλμης ὥστε [ὅλον τὸν βίο]ν̣ κ̣α̣[τα
> τρίβ]ε̣ι̣ν ἐν ταῖς χορδαῖς, ψάλλοντες μ̣ὲ̣ν [πολὺ χ]ε̣ῖ[ρον τῶ]ν
> ψαλ]τῶ̣ν· ἄιδοντες δὲ τῶν ὠιδῶν, συνκρίνοντες δὲ
> τοῦ τ]υ̣χόντος ῥήτορο̣ς πάντα πάντω[ν χεῖ]ρον ποιοῦντες·
> καὶ π]ερὶ μὲν τῶν ἁρμ[ο]νικῶν καλούμ[ενω]ν ἐν οἷς δή
> φ[ασι]ν διακεισθάι πως, οὐθ' ἥντινα φω̣ν̣[ὴν] ἔχοντες λέγ̣ε̣ιν
> ἐν[θο]υσιῶντες δὲ, καὶ παρὰ τὸν ῥυθμ[ὸν δὲ] π̣α̣ίοντες
> τὸ ὑποκείμενον σανίδιον αὐτοῖ̣ς [ἅμα τοῖς] ἀ̣π̣[ὸ] τοῦ
> ψ[αλ]τηρίου ψόφοις

> And they come to such a point of presumption that they spend their whole life among the strings, harping far worse than harpers, singing [far worse] than singers, and making comparisons [far worse] than any old rhetor, doing everything worse than everyone. And concerning so-called 'harmonics' in which they say they are disposed [towards] in some way, not even being able to speak a single sound, but full of inspiration and striking the platform underneath them with the rhythm at the same time as the sounds coming from the harp...

Here the author of the papyrus tells us that even though the harmonicists spend time[101] among strings (perhaps experimenting with a stringed instrument like the *kanôn*, since they claim that their part of music is "theoretical"), they try to partake in the same crafts as musicians, singers,

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[100] *P.Hibeh* 13.

[101] Of course, the phrase ὅλον τὸν βίον κατατρίβειν is mostly conjecture; however, from the more secure surrounding context it is a plausible one.

and orators.[102] He even quite strikingly paints the image of the harmonicist/sophist striking his stage to the time of the harp.[103] It is not merely that he judges the harpist without knowing anything about the harp, it is that he judges the harpist while himself playing the harp badly. So, perhaps, we have here an image of the sophist both playing an instrument and lecturing, a combination which would give context for what, exactly, Glaucus did with Hippasus' experiment that seemed so impressive to give rise to the proverb.

Overall, the testimony about Hippasus' experimental discs and Glaucus' use of them, meager though it is, points to an important early use of harmonic experimentation. Hippasus may very well have had precedents to follow in the construction of instruments intended for performance or even in the stringed instrument called the *kanôn* used to demonstrate the same point as his discs. However, Hippasus is the first individual that we know of to construct an instrument in a deliberate way to demonstrate a generally applicable truth about musical sound. But all this would have been much more obscure if not for the role of Glaucus of Rhegium. Glaucus, under whose name the experiment and the instrument became famous, most likely had first-hand experience of the demonstration (especially given that both hailed from Magna Graecia). A combination of performance and learning was a typical mixture in his day, and even though no source explicitly mentions how Glaucus used Hippasus' bronze discs, we may surmise that he combined practical and theoretical interests in a form well-known to his potential audience, thus ensuring the preservation a record of this early harmonic experiment.

[102] For more on the context of musician-sophists in this papyrus in particular, cf. Barker 2007, 68–78 and Creese 2010, 142–146.
[103] The σανίς can be a wooden structure and not necessarily a plank as early as Homer: it seems to mean 'dais' at *Od.* 21.51–2.

4.4. Lasus of Hermione

The final possible case of harmonic experimentation is that of the poet Lasus of Hermione.[104] According to his entry in the *Suda*, he was sometimes counted among the seven sages and was the first to write a treatise on the topic of music.[105] He also showed an innovative spirit in his own poetry, composing a poem without a single use of the letter sigma.[106]

We can be relatively confident about Lasus' date. The *Suda* gives his birth date as the 58th Olympiad, or 546 BCE. We know that he introduced dithyrambic contests to Athens in 508 BCE.[107] He must have spent some time in Athens before this point, for Herodotus informs us that he was in the entourage of the tyrant Hipparchus who was assassinated in 514 BCE.[108] So, we are fortunate to have for Lasus' activities a firm date of the late sixth and perhaps early fifth centuries—certainly earlier than Hippasus.

Lasus' experiment roughly follows the same model as that of Hippasus and those credited to Pythagoras. He is said to have demonstrated that the basic concords (the octave, fifth, and fourth) are expressible by numerical ratios using the construction of a special apparatus. Of course that would make him a predecessor of Hippasus and an older contemporary of Pythagoras. Some have argued that this would imply that Lasus was influenced by Pythagoras, but there is no evidence of this.[109] Nor is the possibility attractive, given the inventive nature of the Pythagoras-tradition. Thus, if we can trust the testimony about Lasus' harmonic

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[104] The relevant tesimonia are collected in Brussich 2000.
[105] Λάσος, Χαρβίνου, Ἑρμιονεύς, πόλεως τῆς Ἀχαΐας, γεγονὼς κατὰ τὴν νη΄ Ὀλυμπιάδα, ὅτε Δαρεῖος ὁ Ὑστάσπου. τινὲς δὲ τοῦτον συναριθμοῦσι τοῖς ζ΄ σοφοῖς, ἀντὶ Περιάνδρου. πρῶτος δὲ οὗτος περὶ μουσικῆς λόγον ἔγραψε; "Lasus of Hermione, son of Charbinus, from the city of Achaea, who lived in the 58th Olympiad when Darius, son of Hystaspes [lived]. Some count him among the seven sages, instead of Periander. He was the first to write a treatise on music [*On Music*?]" (*Suda* s.v.Λάσος). The Suda (or a source) slips up here by placing Hermione in Achaea rather than in the Argolid; Suda s.v. Ἀνθ' Ἑρμίωνος correctly, but less precisely, calls it a "city in the Peloponnese."
[106] On which cf. Porter 2007.
[107] *FGrHist* 239A 46.
[108] Hdt. 7.6.
[109] Barker 1989, 31, n. 8.

experimentation, we would have evidence of a pre-Pythagorean (or at least, non-Pythagorean) tradition of the experiments concerning music and sound.

The evidence, however, is slenderer than is typically assumed. The procedure is laid out only in Theon of Smyrna, a second century CE author of a mathematical textbook. Theon, perhaps quoting the Peripatetic author Adrastus,[110] gives an account of Pythagoras' discovery of the concords and his various tests used to confirm it:

> τοὺς δὲ συμφωνοῦντας φθόγγους ἐν λόγοις τοῖς πρὸς ἀλλήλους πρῶτος ἀνευρηκέναι δοκεῖ Πυθαγόρας, τοὺς μὲν διὰ τεσσάρων ἐν ἐπιτρίτῳ, τοὺς δὲ διὰ πέντε ἐν ἡμιολίῳ, τοὺς δὲ διὰ πασῶν ἐν διπλασίῳ…ἐξετάσας τοὺς λόγους διά τε τοῦ μήκους καὶ πάχους τῶν χορδῶν, ἔτι δὲ τῆς τάσεως γινομένης κατὰ τὴν στροφὴν τῶν κολλάβων ἢ γνωριμώτερον κατὰ τὴν ἐξάρτησιν τῶν βαρῶν…ἢ δι' ὄγκων καὶ σταθμῶν οἷον δίσκων ἢ ἀγγείων. ὅ τι γὰρ ἂν ληφθῇ τούτων κατά τινα τῶν εἰρημένων λόγων, τῶν ἄλλων <ἴσων> ὄντων, τὴν κατὰ τὸν λόγον ἀπεργάσεται συμφωνίαν.[111]
>
> Pythagoras seems to have been the first to have discovered that sounds are concordant in ratios to on another, the fourfth in an epitrite relation, the fifth in a hemiolic relation, and the octave in a duple relationship…[the ratios between further intervals are given]…testing the ratios through lengths and thicknesses of strings, and further by creating tension by the turning of *kollaboi* or, more accurately through the hanging of weights…or through masses and bulks like discs or vessels. Whatever among these was taken through one of the aforementioned ratios, all else being equal, it produced the concord [corresponding] to the ratio.

Theon's description belongs squarely in the Pythagoras tradition described above, and even takes Hippasus' experiment using discs and attributes it to Pythagoras. Other than further confirmation of how easily information attached itself to the name of Pythagoras, it does not offer any new insight into the early history of harmonic research. After this description, however, Theon notes

[110] Theon informs us that he is quoting directly from Adrastus earlier starting at line 6 of page 49 in Hiller's edition. However, it is unclear for how long the direct quotation continues. Theon introduces the experiment under consideration at p. 59 with a generic ὥς φασι, which may imply that he is following more than one source, or simply that the information is well-known. In any case, there is not enough information to make a secure attribution to Adrastus.

[111] Theon Smyrn. 56, 9–57, 10. Theon's text is lacunose from this point forward, and to avoid confusion I use a simple ellipsis … to mark my skipping over extraneous text, and a bracketed ellipsis <…> to mark an actual lacuna.

that other early thinkers also attempted to understand concords using similar tests. The text is uncertain, and so it is worth an extended look:

> ταύτας δὲ τὰς συμφωνίας οἱ μὲν ἀπὸ βαρῶν ἠξίουν λαμβάνειν, οἱ δὲ ἀπὸ μεγεθῶν, οἱ δὲ ἀπὸ κινήσεων [καὶ ἀριθμῶν], οἱ δὲ ἀπὸ ἀγγείων [καὶ μεγεθῶν]. Λᾶσος δὲ ὁ Ἑρμιονεύς, ὥς φασι, καὶ οἱ περὶ τὸν Μεταποντῖνον Ἵππασον Πυθαγορικὸν ἄνδρα συνέπεσθαι τῶν κινήσεων τὰ τάχη καὶ τὰς βραδυτῆτας, δι' ὧν αἱ συμφωνίαι <...> ἐν ἀριθμοῖς ἡγούμενος, λόγους τοιούτους ἐλάμβανεν ἐπ' ἀγγείων. ἴσων γὰρ ὄντων καὶ ὁμοίων πάντων τῶν ἀγγείων τὸ μὲν κενὸν ἐάσας, τὸ δὲ ἥμισυ ὑγροῦ <πληρώσας> ἐψόφει ἑκατέρῳ, καὶ αὐτῷ ἡ διὰ πασῶν ἀπεδίδοτο συμφωνία· θάτερον δὲ πάλιν τῶν ἀγγείων κενὸν ἐῶν εἰς θάτερον τῶν τεσσάρων μερῶν τὸ ἓν ἐνέχεε, καὶ κρούσαντι αὐτῷ ἡ διὰ τεσσάρων συμφωνία ἀπεδίδοτο, ἡ δὲ διὰ πέντε, <ὅτε> ἓν μέρος τῶν τριῶν συνεπλήρου, οὔσης τῆς κενώσεως πρὸς τὴν ἑτέραν ἐν μὲν τῇ διὰ πασῶν ὡς β´ πρὸς ἕν, ἐν δὲ τῷ διὰ πέντε ὡς γ´ πρὸς β´, ἐν δὲ τῷ διὰ τεσσάρων ὡς δ´ πρὸς γ´.[112]
>
> Some people thought it right to understand these harmonies from weights, others from sizes, others from motions [and numbers], others from vessels [and sizes]. Lasus of Hermione, so they say, and the followers of the Pythagorean man Hippasus of Metapontum attended to quicknesses and slownesses through which the harmonies <…> thinking in numbers, he comprehended such ratios in vessels. For with all the vessels being equal and similar, he left one empty, and <filling> another half full with liquid, he made a sound with each, and the octave was returned to him. And further, leaving one of the vessels empty, he filled another one part to four, and the fourth was returned to him when he struck them. The fifth [was returned to him] when [one vessel] was filled one part to three; there being [a ratio of] empty space to the other [space] in the octave, 2:1; in the fifth 3:2, and in the fourth 4:3.

Immediately we should note the lacuna after the phrase δι’ ὧν αἱ συμφωνίαι marked both by Hiller in his *editio princeps* and in the new edition of Petrucci.[113] The presence of the lacuna is necessary for both grammatical and interpretive reasons. Grammatically, the infinitive συνέπεσθαι seems to rely on a missing finite verb (ὥς φασι being taken parenthetically) and is unlikely to take the accusative τὰ τάχη καὶ τὰς βραδυτῆτας as an object when we would expect a dative. The retention of the singular after the supposed lacuna is also suspect, since

[112] Theo. Smyrn. p. 59 Hiller.
[113] Hiller 1878, 59; Petrucci, 2012, 129. Petrucci, however, bases his text off Hiller’s and has not examined the MSS of Theon afresh (63). The same goes for the edition of Delattre Biencourt 2010, which along with Petrucci’s edition helped raise the status of Theon as an important representative of then-current Platonism.

beforehand we have the compound subject Λᾶσος δὲ ὁ Ἑρμιονεύς…καὶ οἱ περὶ τὸν Μεταποντῖνον Ἵππασον.

A popular solution to this problem is to assume, alongside Burkert, that the extent of the lacuna is not too large and that the singular refers only to Lasus.[114] Yet, this assumption is not without its own interpretative difficulties. First, οἱ περί τινα is a relatively common periphrasis and in later, scholarly Greek prose often stands for the person himself, with any emphasis on the followers being purely secondary.[115] The emphasis on the prepositional object, rather than any unnamed followers of Hippasus, seems to be the case here as well. Although one could counter that it is odd for the plural οἱ περὶ...Ἵππασον to change to an understood singular subject after the lacuna, the usage is not unprecedented.[116] A more intractable difficulty emerges when Theon explicitly says that Lasus and Hippasus (or his followers) dealt with the "speeds and slownesses" of movements, which the vessel test does not concern. Barker also notes that there is no evidence of connecting pitch to velocity until Archytas, a fact which calls into question the attribution to Lasus in the sixth century.[117] Finally, Theon explicitly differentiates between those who seek to understand by looking to movements (οἱ δὲ ἀπὸ κινήσεων) and those who do so by looking at vessels (οἱ δὲ ἀπὸ ἀγγείων), and states emphatically that Lasus and Hippasus belong to the former. On their own, none of these difficulties are fatal, but cumulatively they strongly point to a textual problem.

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[114] Burkert 1972, 377–378, and esp. n. 36. Others who agree are, e.g., West 1992, 234, Privitera 1965, 71, and Petrucci 2012, 365–366. Cf. Lasserre 1954, 35 and Zhmud 2012, 311 who are more skeptical of the attribution to Lasus.

[115] Kühner-Gerth 1898 §403d; Schwyzer 1939, 416–417. Dickey 2007 135 notes that there is a "tendency toward periphrasis" of all kinds in scholarly Greek prose, but does not mention the construction οἱ περί τινα.

[116] E.g., Arist. *De Gen. Corr.* 314a24–28: Ἐναντίως δὲ φαίνονται λέγοντες οἱ περὶ Ἀναξαγόραν <u>τοῖς περὶ Ἐμπεδοκλέα</u>· <u>ὁ μὲν</u> γάρ φησι πῦρ καὶ ὕδωρ καὶ ἀέρα καὶ γῆν στοιχεῖα τέσσαρα…; "The followers of Anaxagoras seem to speak in a way opposed to those of Empedocles. For the one says that fire and water and air and earth are the four elements…"

[117] Barker 1989, 31, n. 9; Privitera 1965, 71.

Since the lacuna is of indeterminate length, it is certainly possible that another name was introduced, and the obvious candidate is Pythagoras himself. We have seen that just before introducing Hippasus and Lasus, Theon states that Pythagoras used "masses and bulks like discs and vessels" to confirm his more famous experiment of suspending weights from strings. This possibility is further strengthened if we look at Theon's account immediately after the description of the vessel experiment:

> οἷς ὁμοίως καὶ κατὰ τὰς διαλήψεις τῶν χορδῶν θεωρεῖται, ὡς προείρηται, ἀλλ' οὐκ ἐπὶ μιᾶς χορδῆς, ὡς ἐπὶ τοῦ κανόνος, ἀλλ' ἐπὶ δυεῖν· δύο γὰρ ποιήσας ὁμοτόνους ὅτε μὲν τὴν μίαν αὐτῶν διαλάβοι μέσην πιέσας, τὸ ἥμισυ πρὸς τὴν ἑτέραν συμφωνίαν τὴν διὰ πασῶν ἐποίει…[describing the other intervals follows]…ὃ δὴ καὶ ἐπὶ τῆς σύριγγος ἐποίει κατὰ τὸν αὐτὸν λόγον. οἱ δ' ἀπὸ τῶν βαρῶν τὰς συμφωνίας ἐλάμβανον, ἀπὸ δυεῖν χορδῶν ἐξαρτῶντες βάρη κατὰ τοὺς εἰρημένους λόγους, οἱ δ' ἀπὸ τῶν μηκῶν καὶ τῶν χορδῶν <…> ἐπίεσαν, τὰς συμφωνίας ἐν ταῖς χορδαῖς ἀποφαινόμενοι.
>
> In a way similar to this, he also considered the divisions of strings, as said before, but not on one string, like on the *kanôn*, but on two strings. For making two strings equally tense, he divided one by pressing down on its middle, and the half made an octave in relation to the other [string]…This also he did on the panpipe according to the same ratio.[118] Some understood the harmonies from weights, hanging weights from two strings according to the ratios mentioned, and some from strings and their lengths <…> they pressed down, displaying the harmonies in the strings.

There is no change of subject between the vessel experiment and this familiar experiment using strings. Furthermore, Theon says, that he is repeating himself (ὡς προείρηται) by describing an experimenter using strings. If we return to his description of Pythagoras' experiments quoted above, we see that Theon says that Pythagoras tested the lengths of strings.[119] And if we look further afield, we also see that Pythagoras was said to have confirmed his discovery about the

[118] The *syrinx* is any pipe without a reed, and in this case, most likely a pan-pipe. The ratios between the lengths of pipe necessary to make an octave, however, do not match those needed for the division of a string, and so this is another erroneous test.

[119] ἐξετάσας τοὺς λόγους διά τε τοῦ μήκους καὶ πάχους τῶν χορδῶν; "testing the ratios through the length and thickness of strings" (Theon Smyrn. 57, 1–2).

concords by using a *syrinx*.[120] Theon goes on to say that some unidentified people used weights, which probably refers to Pythagoras' famous experiment with the hammers and implies a contrast with the preceding material. But these anonymous people are also said, yet again, to understand the concords from lengths (ἀπὸ τῶν μηκῶν), which must be lengths of string, and so the contrast with preceding material cannot be total.

Scholars have hesitated to assign this test to Pythagoras as well (perhaps because of the unfortunate effect of taking away a rare piece of evidence for the very mysterious, yet intriguing Lasus). For instance, Burkert passes over the question of the lacuna's length entirely.[121] Petrucci, in his commentary on these passages, finds Pythagoras an unlikely candidate because introducing Pythagoras' experiments again would be an uneconomical and repetitive choice on the part of Theon.[122] Yet Theon repeats himself elsewhere in the treatise; for example, he mentions the division of the *kanôn* twice in his work.[123]

The repetition and problematic interpretation of the text perhaps represents an imperfect combination of different source material, but it seems more likely that the text is quite unsettled here.[124] In fact, the possibility of serious dislocation is made more likely by the textual tradition of Theon. Theon's work divides into two parts and the MSS for each part rely on just a single manuscript.[125] For the section on music, all later MSS rely on a twelfth century manuscript, denoted A by Hiller. Thus a mistake in A could, and one most likely did, disrupt our text of

[120] E.g., Nicom. *Ench.* 6.1.71–2; Iamb. *VP* 26.119; Censorin. *De Die Natali* p. 17; Isid. *Etym.* 3.16.1. Cf. Ptol. *Harm* 1.8 which does not mention Pythagoras' name but connects the test with *syrinxes* with the hanging of weights from strings, and Porph. *in Ptol. Harm.* 119, who attributes experiments with *syrinxes*, more plausibly, to "Pythagoreans."
[121] Burkert 1972, 377.
[122] Petrucci 2012, 365–6.
[123] At Theon Smyrn. 57, 11–58, 12 and again, with more detail, at Theon Smyrn. 87, 4–93, 16.
[124] Cf. Barker 1989, 219, n. 40.
[125] Hiller 1878, v–vi; Petrucci 2012, 17–19. There is an independent witness for some parts of the first half of Theon's work, but, unfortunately, not the one under consideration here (Petrucci 2012, 17).

Theon concerning these harmonic experiments.[126] We are left with little recourse, however, since we have no other witnesses against which to check the readings derived from A.

With the state of the text here in mind and the widespread parallels in other texts, it seems most plausible to attribute the vessel experiment not to Lasus (or even to Hippasus), but to Pythagoras. Lasus' role in harmonic experimentation, however, cannot be totally discounted; Theon introduces him in a section explicitly about experiments after all. Perhaps, then, we should assume that Lasus' actual experiment is lost in the lacuna.[127] If it were, one would expect Lasus' testing procedure to concern "the speeds and slownesses of movement," i.e., a test that would connect the variation of speed with pitch.

Of course, there is no way to confirm this suspicion, but one could easily imagine something along the lines of the whirled noise-makers called *rhomboi*, mentioned by Archytas to make this exact point: "it is clear that a swift motion makes a high-pitched sound, and a slow motion a low-pitched one. The same thing comes about with bull-roarers moved around in the mysteries. If they are moved calmly, the produce a low sound, but if strongly, a high-pitched one."[128] The *rhombos* itself was a piece of wood or metal attached to a cord and spun around to make a humming sound; it is an instrument found in many cultures, and had certain cult associations in Greece.[129] While not, perhaps, a true experiment, since there would be no way to quantify accurately the speed, it is certainly a valid demonstration of the general point that speed and tone are related. And given that Hippasus is also said to have paid attention to speed, perhaps we may see a progression from Lasus to Hippasus to a fellow Pythagorean Archytas with this

[126] Another lacuna appears at Theon Smyrn. 60, 12 as well.
[127] As does Lassere 1954, 35, cf. Burkert 1972 193, n. 36.
[128] ὥστε δῆλον ὅτι ἁ ταχεῖα κίνασις ὀξὺν ποιεῖ, ἁ δὲ βραδεῖα βαρὺν τὸν ἄχον. ἀλλὰ μὰν καὶ τοῖς ῥόμβοις τοῖς ἐν ταῖς τελεταῖς κινουμένοις τὸ αὐτὸ συμβαίνει· ἡσυχᾶι μὲν κινούμενοι βαρὺν ἀφιέντι ἄχον, ἰσχυρῶς δέ, ὀξύν (DK47 B1, 56–60).
[129] Gow 1934 provides a good overview of the instrument; cf. West 1992, 122 and Huffman 2005, 159–60.

type of demonstration.[130] Archytas does, in fact, state that he is following some unnamed predecessors who were involved in the sciences, including music.[131]

As with the other experiments ascribed to Pythagoras, the vessel experiment described by Theon is highly unlikely to have originated with Pythagoras. Furthermore, it may not even have been originally carried out in a Pythagorean context. The pseudo-Aristotelian *Problemata* describes the same experiment, but does not mention Pythagoras or any Pythagorean for that matter.[132] Furthermore, we run into the same problem as Pythagoras' other "experiments": the physics of the test described does not work.[133] The description does get right that the amount of air left in a vessel can change the tone, but not if the vessel itself is struck (as in this case). Rather differing amount of air left in the vessel may result in different tones if air moves across the top of the vessel, as with blowing on bottles with various amounts of water inside. If indeed an experiment like this was undertaken successfully in the ancient world, its nature must have been changed via transmission from studying the resonance of the air inside the vessel to striking the vessel itself.[134] And again the proportions are incorrect for this system, and most likely were imported to this sort of demonstration from an experiment that actually works as described (i.e., the discs of Hippasus or the use of a stringed instrument like the *kanôn*).[135]

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[130] As Richard Janko has pointed out to me *per litt.* this fits well with Lasus' demonstrated interest in sound within poetic composition, as his asigmatic poetry attests.

[131] καλῶς μοι δοκοῦντι τοὶ περὶ τὰ μαθήματα διαγνώμεν καὶ οὐδὲν ἄτοπον ὀρθῶς αὐτούς, περὶ ἑκάστου φρονέν. περὶ γὰρ τᾶς τῶν ὅλων φύσιος καλῶς διαγνόντες ἔμελλον καὶ περὶ τῶν κατὰ μέρος, οἷα ἐντι, καλῶς ὀψεῖσθαι ... παρέδωκαν ἁμῖν σαφῆ διάγνωσιν...οὐχ ἥκιστα περὶ μωσικᾶς; "Those concerned with the sciences seem to me to make distinctions well, and it is not at all surprising that they have correct understanding about individual things as they are. For, having made good distinctions concerning the nature of wholes they were likely also to see well how things are in their parts…they have handed down a clear set of distinctions…not least concerning music" (DK47 B1, 11–19, trans. Huffman 2005, 108–109).

[132] Ar. *Prob.* 922b35–39.

[133] Burkert 1972, 378; Barker 1989, 31–32, n. 11.

[134] Perhaps this is by analogy with Hippasus' experiment hitting metal discs or Pythagoras "hearing" the concords in the hammers hitting the anvil.

[135] On the relevant equation for the frequency of air vibrating within a closed container like a bottle (a "Helmholtz resonator"), cf. Fletcher and Rossing 1998, 13–14.

4.5. The Early Pythagoreans and Harmonic Tests

Even in the mists of early Pythagoreanism, we can see the use of empirical investigation in the service of their mathematical world-view. Of course, some background must be assumed from the construction of and performance on musical instruments. Yet, these craft insights were never generalized and quantified as they were in the Pythagorean tradition. Furthermore, they were never *confirmed* using other instruments—a practice which is highly suggestive not only of an experiment, but the modern experimental method.

Yet we must be hesitant when attributing these insights to specific figures. Pythagoras, of course, attracted many stories in later periods, and the account of his "discovery" of the harmonic ratios—while quite interesting—show both signs of later tenets as well as an incomplete grasp of the reported results. A different problem occurs for Lasus, who was connected to harmonic experimentation by exactly one source with a very problematic text. The one figure for whom we seem to have reliable information, however, is Hippasus—a mysterious figure certainly, but one undoubtedly of the highest importance for the development of early Pythagoreanism. His experiment with discs, coupled with probable experimentation using strings by anonymous contemporaries on the principle of the *kanôn*, not only showed a strikingly prescient idea of scientific practice, but also laid the groundwork for a millennium of harmonic study to come.[136]

[136] Cf. section 6.2.2.

CHAPTER FIVE: HISTORY AND *HISTORIA* IN HERODOTUS

5.1. Introduction

When it comes to the practice of *historia* among early Greek thinkers, Herodotus offers a rare opportunity. Unlike many Presocratic philosophers and harmonic theorists, we are not dealing with scraps of evidence—either *ipssissima verba* or summaries—taken from their original context and reported in another, often hundreds of years later by authorities with quite different intellectual commitments. Unlike the writers that make up the Hippocratic Corpus, with Herodotus we have a self-contained work from the pen of a single, identifiable author, with no problems of attribution and comparatively little problem with dating.

Yet, even with all these benefits, Herodotus and his text bring interpretative problems of their own. To that end, I will begin by sketching the main currents of thought about Herodotus and his work and situate where this treatment will fall in this landscape. Then, I will investigate his methodological commitments, which have many resonances with those found in the other branches of *historia* investigated thus far. Finally, I will consider descriptions of experiments found in the *Histories* and argue that they correspond closely to those found elsewhere in Greek science of the time. On one hand, this will serve to confirm the thesis—put forward most recently and forcefully by Thomas—that Herodotus is not primarily an archaic thinker, but one who is deeply engaged with the scientific thought of his time. On the other, however, it will also show that Herodotus differs from other, more technical, authors in the way in which he presents the scientific material within a larger narrative. He does not straightforwardly describe

experiments, but inserts them within history itself, especially as shown in the case of the Egyptian king Psammetichus in Book II. Thus, his conception of experimentation fits nicely into the other "scientific" aspects of Herodotus' work.

5.2. Herodotus and his *Histories*

Herodotus and his work have always been difficult to characterize. Part of the reason for this is perhaps that we know so little about the man himself. A writer's biography, of course, does not give us a key to the entire meaning of a work, but it can offer clues. In Herodotus' case, however, we have very little to work with. The biographical tradition is comprised of several sources of varying quality.[1] First, we have the information that Herodotus tells us about himself, usually indirectly, in the *Histories*. Although he is often very forthcoming with what he thinks, he is much less so about his identity, and so this source, although the most reputable, is scanty. From the work's *incipit*, we know that he comes from Halicarnassus and that he travelled around the Mediterranean world. Past that, he remains silent about his life.[2]

We also have some biographical information contained in the *Suda* that offers a bit more information. Herodotus was driven out of Halicarnassus by the tyrant Lygdamis[3], who also put his cousin, the epic poet Panyasis, to death.[4] He ended up in Samos and eventually returned to Halicarnassus to drive out the tyrant.[5] But, again, he was driven out by the citizens, presumably

[1] On which, see, e.g., Jacoby 1913, 205–280; Brown 1988; Asheri et al. 2007, 1–7. None of the scholarship is particularly optimistic about the amount of reliable information contained in the biographical tradition.
[2] An ancient tradition places Herodotus' birthplace at Thurii (Arist. *Rhet.* 1409a 27–29; Duris *FGrHist* 532 F1; Jul. *Epist.* 152). The biographical tradition, however, says that Herodotus died at Thurii after his travels, and so most likely this represents a conflation of his place of birth and of death (as maintained by Str. 14.2.16 and Plut. *De Exilio* 604f3–5).
[3] *Suda* s.v. Ἡρόδοτος.
[4] *Suda* s.v. Πανύασις.
[5] Cf. Hdt. 3.60, where he mentions seeing an engineering feat of the Samians.

due to more political intrigue, and went to Thurii (stopping possibly in Pella[6]), where he helped with the Athenian colonization and, finally, died.[7]

The *Suda*'s account of Herodotus' life, however, leaves out two episodes crucial for our understanding of the *Histories*. The first is his travels around the Mediterranean world. In the *Histories*, Herodotus explicitly claims to have visited many places in Egypt, the Greek mainland, Greek islands, and Syria, to name only a few.[8]

However, a grand tour both within and outside the Greek world for the purposes of learning was a well-known phenomenon of the time and similar accounts of foreign travel—especially to Egypt—are given for many philosophers.[9] Herodotus' predecessor Hecataeus travelled abroad a generation before him and also interacted with Egyptian priests for his own research.[10] Thus, it is curious that these travels are not mentioned in the biographical tradition since, as we shall see, Herodotus puts great methodological weight on direct observation.

The second episode of note is Herodotus' time in Periclean Athens. Although the *Suda* does not mention any time spent in Athens, other ancient sources do. Alongside suspicious stories such as the young Thucydides crying at Herodotus reading his *Histories*,[11] other notices are more interesting. An elegiac couplet from Sophocles shows that he was familiar with a Herodotus, quite possibly the historian.[12] More securely, the third-century historian Diyllus is

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[6] This may be a case of mistaken chronology, for the *Suda* also tells us: διέτριψε δὲ Ἑλλάνικος σὺν Ἡροδότῳ παρὰ Ἀμύντᾳ τῷ Μακεδόνων βασιλεῖ κατὰ τοὺς χρόνους Εὐριπίδου καὶ Σοφοκλέους; "Hellanicus spent time with Herodotus in the court of Amyntas, king of the Macedonians, in the time of Euripides and Sophocles" (*Suda* s.v. Ἑλλάνικος).
[7] On his connection with and probable visit to Athens, see below, p. 144.
[8] E.g., Hdt. 2.12; 1.52; 2.44; 4.195.
[9] E.g., Thales (D.L. 1.27); Solon (Plut. *Solon* 2); Xenophanes (Plut. *De Super.* 171e); Pythagoras (Isoc. *Bus.* 28); Democritus (D.L. 9.35). On the extent of his travels, cf. Jacoby 1913, 247–267; Lloyd 1975, 61–76; Brown 1988. Others have a very skeptical take on Herodotus' travels, especially Armayor in Armayor 1985 (which implausibly doubts that he even explored Egypt!).
[10] On the famous interaction between Hecataeus and the Egyptian priests, cf. Moyer 2011, 44ff.
[11] Marcellin. *Vit. Thuc.* 54; Phot. *Bibl.* 19b; *Suda* s.v. Θουκυδίδης.
[12] West *IEG*, fr. 5.

quoted saying that Herodotus read his work aloud at Athens and was awarded a sum of ten talents by the *boulê*.[13] While this visit has often been seen as the beginning of a pro-Athenian and pro-democratic tendency in his work,[14] from the standpoint of his intellectual affinities it is interesting for another reason: it places Herodotus in the intellectual center of the day and engaging in public recitation of his works, just like other sophists and philosophers. This would lend credence to the thesis that Herodotus was not merely a backward and archaic thinker, but one who was conversant with then-current debates at the then intellectual center of Greece.[15]

These two points have loomed large in the modern phase of Herodotean scholarship, which began in the nineteenth and early twentieth centuries. As widely noted, the starting-point for many current debates is Jacoby's extended *Realencyclopädie* entry on Herodotus.[16] Within his magisterial treatment, he noted a thematic inconsistency between the ethnographic and geographic passages on the one hand, and the more properly "historical" material on the other. Jacoby saw this "inconsistency" in terms of phases of Herodotus' career and thus formulated the problem as a chronological one: whether Herodotus started as a literary historian or as an ethnographic and geographic explorer.[17] He believed that Herodotus started as the former and only gradually turned into the latter, starting the Western historiographical and ethnographic (or, as we might now say, anthropological) traditions in the process.[18]

The "analytical" approach to Herodotus' *Histories* was in time countered by a unitarian reaction, where scholars argued that Herodotus was in fact an accomplished literary artist who

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[13] Plut. *De Herod.* 862b. Jerome's Latin translation of Eusebius' *Chronicle* (Hieron. *Chron.* 83.4) places this in the fourth year of the 83rd Olympiad (445 BC).
[14] On Herodotus' Athenian visit and its impact on him, see Fornara 1971, 35–58; Ostwald 1991.
[15] But cf. Thomas 2000, 9–16, which stresses that Athens was not the only location of intellectual life in fifth-century Greece and warns against over-stressing Herodotus' Athenian connection.
[16] Jacoby 1913.
[17] "das eigentliche Problem, das H.s Werk uns stellt...ob H. seine literarische Laufbahn gleich als Historiker oder noch als geographisch-ethnographischer Forschungsreisender begonnen hat" (ibid., 333).
[18] Jacoby 1913, 352–360.

was able to create a satisfying whole from disparate parts. However, the question is less urgent for historical purposes, including intellectual history, because it is, at root, an aesthetic one. Thus many scholars have put aside questions of Herodotus' success in creating a perfectly connected whole, and instead have analyzed the text that we have from different angles.[19]

But as we look at the work as a whole, even if it is not a perfect unity, another interpretive problem immediately arises: what is the nature of Herodotus' *Histories*? Such a seemingly simple question has given rise to a great number of sometimes contradictory responses due to its kaleidoscopic nature. Some as early as Edward Gibbon have seen Herodotus as simple and unserious, at times almost a storyteller for children.[20] Others have seen him as essentially archaic in his thought, preserving past glory as the prose version of the epic poets[21] or upholding traditional Greek religious values during a time when they were in radical flux.[22] Other popular avenues include approaching the *Histories* through the lens of oral tradition.[23] Of course there are many differences among these approaches, but among them we may identify a very general tendency to see Herodotus in light of his past models.

Yet by focusing only on Herodotus' past, we may miss the ways in which he was part of the intellectual foment of the time. Although not always stressed, this side of Herodotus has never entirely been neglected either. Nestle, for instance, sought to identify Herodotus' usage of specific sophists and philosophers—sometimes even at the level of specific passages.[24] Other

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[19] Cf. Fornara 1971, 16 "[t]o ask, therefore, 'What is Herodotus at this stage' is to find a classification and lose the author," a sentiment seconded by Lateiner 1989, 5. Fornara's point that our answer to the question does not affect the outcome of many other lines of inquiry (Fornara 1971, 1–24) seems to me entirely sensible.
[20] "…Herodotus…, who sometimes writes for children, and sometimes for philosophers" (Gibbon 1776/1953, 811 n52, quoted by Harrison 2000, 7).
[21] E.g., Nagy 1987.
[22] E.g., Harrison 2000.
[23] E.g., Fehling 1989, 209–211; Murray 2001.
[24] Nestle 1908, 6–14 deals with the Presocratic philosophers and medical writers in a general sense; 14–28 deals with the sophists. In a now-unfashionable *Quellenforschung*, Nestle believes that the echoes of the Sophists' exact

scholars have stressed that Herodotus' *historia* is closer to contemporary science than has often been realized. Lateiner showed the shared importance of personal observation to both Herodotus and the Hippocratic Corpus.[25] Similarly, in addition to being the "father of history" and the "father of lies," Müller has christened Herodotus the "father of empiricism," again setting him in a broad fifth-century intellectual context and noting his empirical way of studying the world.[26]

However, the most important recent treatment of Herodotus' interaction with current philosophy and medicine is Rosalind Thomas' *Herodotus in Context: Ethnography, Science and the Art of Persuasion*.[27] Thomas' work places Herodotus alongside other self-described practitioners of *historia*: natural philosophers, medical writers, and sophists. Unlike Nestle, however, Thomas does not engage in source criticism or insist on tying specific passages of Herodotus to their counterpart in the meager fragments of the natural philosophers or the pseudonymous works of the Hippocratic corpus.[28] The effect is to place Herodotus more generally, but also more successfully in the 5th century intellectual milieu, while avoiding the hypothesis—much harder to prove—that Herodotus read (or heard) this or that thinker personally.[29]

Of course, this vision of Herodotus is germane to the topic at hand: the methodological commitments and practice of the early Greek study of nature. Thus, I take Thomas' work as a starting point: Herodotus' methodology and his descriptions of experiments confirm Thomas' thesis about Herodotus as a contemporary thinker. On the other hand, however, Thomas' account

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language can be found in specific passages (Nestle 1908, 23–27). Nestle 1942, 503–514 develops this account of Herodotus as conversant with Ionian philosophy, but not interested in their "metaphysical questions" (505).

[25] Lateiner 1986. Cf. Lateiner 1989, 221 which compares Herodotus' empirical method favorably to natural philosophers and Althoff 1993 which also connects Herodotus to the writers of the Hippocratic Corpus.

[26] Müller 1981. Cf. 317–18: "Wesentliche Grundsätze empirischer Philosophie sind bei ihm keimhaft angelegt, so dass er mit einer gewissen Berechtigung als 'Vater der Empirismus' bezeichnet werden darf."

[27] Thomas 2000.

[28] Ibid., 16–18.

[29] The one exception is Hecataeus, whose work Herodotus often shows familiarity with (e.g., Hdt. 2.15; 2.143; 4.20 with Asheri et al. 2007, *ad loc*. and section 5.4.2 below).

does not treat the subject of experimentation at length, even though we find empirical tests just like in other genres. Thus, Herodotus' *Histories* also offers very good evidence for the thesis—complimentary to that of Thomas—which we have been developing: that early Greek science contained a fairly complex idea of experimentation, even if it does not always conform to the modern one. The evidence that the *Histories* affords is all the more valuable for having been transmitted to us in a complete work, rather than the imperfectly preserved or attributed source material studied in previous chapters.

5.3. ὄψις, ἀκοή, γνώμη, and ἱστορία: Herodotus' empirical methodology

In the midst of his Egyptian *logos* in Book 2, Herodotus pauses to address his readers directly:

> Μέχρι μὲν τούτου ὄψις τε ἐμὴ καὶ γνώμη καὶ ἱστορίη ταῦτα λέγουσά ἐστι, τὸ δὲ ἀπὸ τοῦδε Αἰγυπτίους ἔρχομαι λόγους ἐρέων κατὰ τὰ ἤκουον· προσέσται δέ τι αὐτοῖσι καὶ τῆς ἐμῆς ὄψιος.[30]
>
> Up to this point, these things I have spoken about are my viewing, judgment, and investigation, but after this, I am going to speak the accounts of the Egyptians according to what I heard. But something from my own viewing will be added to them as well.

Later he marks the end of the Egyptian' own account of their history quite clearly by stating, in strikingly similar language:

> Ταῦτα μέν νῦν αὐτοὶ Αἰγύπτιοι λέγουσι, ὅσα δὲ οἵ τε ἄλλοι ἄνθρωποι καὶ Αἰγύπτιοι λέγουσι ὁμολογέοντες τοῖσι ἄλλοισι κατὰ ταύτην τὴν χώρην γενέσθαι, ταῦτ' ἤδη φράσω· προσέσται δέ τι αὐτοῖσι καὶ τῆς ἐμῆς ὄψιος.[31]
>
> These are the things the current Egyptians say happened in this land, but those things which other men and the Egyptians, in agreement with the others, say [happened], I will now relate. And something of my own viewing will be added to them as well.

These statements are emblematic of Herodotus' research methodology.[32] For Herodotus, the most persuasive evidence is seen directly, either by Herodotus himself or by a trustworthy third

[30] Hdt. 2.99.
[31] Hdt. 2.147.
[32] Schepens 1980, 54–56. On Herodotus' ranking of autopsy and hearsay, I have drawn upon Hartog 1988, 260–273.

party. This is the best case; otherwise, Herodotus makes do with hearsay (ἀκοή).[33] Although he never explicitly makes the comparison, he makes clear that direct observation is preferable to hearsay in other ways. For example, Herodotus will report second-hand accounts without necessarily vouching for them.[34] In another instance, he echoes Heraclitus when he states that "people trust their ears less than their eyes," a saying with obvious methodological implications.[35]

Herodotus often takes pains to stress that he has personally seen his evidence, which can take many forms. Some of this visible evidence consists of traces of the past left in the present. For instance, when speaking about the (in this case, historically accurate) derivation of the Greek alphabet from the Phoenician one, he buttresses his account by saying that he has personally seen "Cadmean letters" engraved on a tripod and that they look similar to Ionic ones.[36]

Herodotus also tells us when he has personally seen some natural phenomenon or feature of the landscape. For example, when discussing the natural history of Egypt, he posits that Egypt was originally underwater and describes a number of signs that support this conclusion. These

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[33] E.g., Hdt. 4.16: οὐδενὸς γὰρ δὴ αὐτόπτεω εἰδέναι φαμένου δύναμαι πυθέσθαι […] ἀλλ' ὅσον μὲν ἡμεῖς ἀτρεκέως ἐπὶ μακρότατον οἷοί τε ἐγενόμεθα ἀκοῇ ἐξικέσθαι, πᾶν εἰρήσεται; "For I am not able to inquire of any direct witness who says that they know [sc. what is north of Scythia]…but as much as we have been able to arrive at accurately and to the furthest extent from hearsay, everything will be said." The translation of 'hearsay' for ἀκοή is usual (e.g., Asheri et al. 2007, 230), but should be understood as not necessarily untrustworthy as the English often connotes.

[34] E.g., Hdt. 4.95–96: τετάρτῳ δὲ ἔτεϊ ἐφάνη τοῖσι Θρήιξι, καὶ οὕτω πιθανά σφι ἐγένετο τὰ ἔλεγε ὁ Σάλμοξις. Ταῦτά φασί μιν ποιῆσαι. Ἐγὼ δὲ περὶ μὲν τούτου καὶ τοῦ καταγαίου οἰκήματος οὔτε ἀπιστέω οὔτε ὦν πιστεύω τι λίην...; "In the fourth year [Salmoxis] appeared to the Thracians [sc. from the underground chamber] and thus what Salmoxis said [sc. about life after death] became believable to them. They say that he did this, but for my part, concerning this man and his underground chamber, I neither disbelieve nor do I strongly believe any part of it…"

[35] ὦτα γὰρ τυγχάνει ἀνθρώποισι ἐόντα ἀπιστότερα ὀφθαλμῶν (Hdt. 1.8). Asheri et al. 2007, 82 take this as a statement of methodological principle, but it should be noted that the phrase occurs within a story and is proverbial. Cf. p. 44, n. 18 for Heraclitus.

[36] E.g., Hdt. 5.59: Εἶδον δὲ καὶ αὐτὸς Καδμήια γράμματα ἐν τῷ ἱρῷ τοῦ Ἀπόλλωνος τοῦ Ἰσμηνίου ἐν Θήβῃσι τῇσι Βοιωτῶν ἐπὶ τρίποσι τρισὶ ἐγκεκολαμμένα…; "I myself have seen Cadmean letters in the temple of Ismenian Apollo in Boeotian Thebes, engraved on three tripods…" This is also an argument by analogy in a very general sense. Cf. Corcella 1984, 60–62 for analogy used to uncover past time.

include sea-salt on the surface of the pyramids, parts of Egypt jutting out into the sea, and, in a striking parallel to Xenophanes, seashells high in the mountains.[37]

He is also especially careful to reassure his reader that he has seen something when the object in question is out of the ordinary or unbelievable. In 2.65–76, Herodotus speaks about a number of animals that are sacred to Egyptians, including fantastic ones like the phoenix or "winged serpents." In order to learn more about the latter, he travels to a site where they are said to congregate. There he describes seeing the bones of the serpents strewn over the ground in numbers so great that he could not adequately convey them in his writing.[38] Herodotus is aware that parts of his account are hard to believe; for instance, he notes that the story of ibises fighting these serpents when they fly into Egypt from Arabia is just a *logos*.[39] Thus, he also seeks to reinforce parts of the account by his own autopsy of the serpents' remains.

But we should also note that in none of these examples is Herodotus a merely naïve empiricist, thinking that knowledge comes simply from direct observation. Rather, using his *gnômê* or judgment, he integrates observations into arguments which can apply to things that he has not seen directly, an obvious methodological parallel to Democritus' ὄψις τῶν ἀδήλων τὰ φαινόμενα.[40] Herodotus was not around to see the Phoenicians bring writing to Greece, nor to see Egypt underwater, but his observations coupled with his power of reasoning bring him to

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[37] E.g., Hdt. 2.12: Τὰ περὶ Αἴγυπτον ὦν καὶ τοῖσι λέγουσι αὐτὰ πείθομαι καὶ αὐτὸς οὕτω κάρτα δοκέω εἶναι, ἰδών τε τὴν Αἴγυπτον προκειμένην τῆς ἐχομένης γῆς κογχύλιά τε φαινόμενα ἐπὶ τοῖσι ὄρεσι καὶ ἅλμην ἐπανθέουσαν, ὥστε καὶ τὰς πυραμίδας δηλέεσθαι…; "I believe and am personally quite sure about what I have been told about Egypt since I saw Egypt jut out from the surrounding land, and seashells appearing in the mountains, and salt forming so as to damage [the surface of] the pyramids…" For Xenophanes, see p. 68, n. 57.

[38] Hdt. 2.75: Ἀπικόμενος δὲ εἶδον ὀστέα ὀφίων καὶ ἀκάνθας πλήθεϊ μὲν ἀδύνατα ἀπηγήσασθαι; "Arriving, I saw bones and spines of snakes, impossible to describe with regards to their number."

[39] Ibid.: Λόγος δέ ἐστι ἅμα τῷ ἔαρι πτερωτοὺς ὄφις ἐκ τῆς Ἀραβίης πέτεσθαι…; "There is a story that at the arrival of spring, the flying serpents fly from Arabia…"

[40] For Corcella 1984, 59 γνώμη is essentially analogical reasoning. While γνώμη can certainly include analogical reasoning (see below), this is probably defining it a bit too loosely (as Lloyd 1976, 164 notes, all arguments in some sense can be said to have an analogical component). By the term I mean something a bit more exact (see the Introduction, section 1.2.6).

those conclusions. Sometimes, as in the case with the "Cadmean letters," his conclusions are accurate. And even though his investigation into the alphabet was inspired by the myth of Cadmus (that is, the historical memory of Phoenician origin), he did not simply accept the authority of tradition, but confirmed the historical hypothesis using observations of the present.

Other times, however, his arguments can lead him astray. Even so, arguments that lead to mistaken conclusions can also contain a wealth of information about one's working method. One such informative "mistake" is Herodotus' discussion of the Nile in 2.17–34. Within a single discussion of the river's ultimate source (2.28–34), we see him use all of his preferred sources: sight, hearsay, and, finally, argument.

Herodotus begins in 2.28, by informing his readers that there were no reliable reports from Egyptian, Libyan, or Greek sources about the source of the Nile, except a single, doubtful story given to Herodotus by the clerk or scribe (γραμματιστής) of the holy treasure at Temple of "Athena" in Saïs.[41] However, later in his account (2.32), he does introduce another report. Perhaps he was reluctant to bring it up originally since it comes to him third-hand, originally from a group of Nasamonians (a tribe from Libya) via Etearchus, king of the Ammonians (from the Shrine of Ammon in modern day Siwa[42]), via "men of Cyrene."[43] The story goes that the group of Nasamonians travelled deep into the desert, were kidnapped, and were taken even

[41] Τοῦ δὲ Νείλου τὰς πηγὰς οὔτε Αἰγυπτίων οὔτε Λιβύων οὔτε Ἑλλήνων τῶν ἐμοὶ ἀπικομένων ἐς λόγους οὐδεὶς ὑπέσχετο εἰδέναι εἰ μὴ ἐν Αἰγύπτῳ ἐν Σάϊ πόλι ὁ γραμματιστὴς τῶν ἱρῶν χρημάτων τῆς Ἀθηναίης. Οὗτος δ' ἔμοιγε παίζειν ἐδόκεε…; "Nobody among the Egyptians, Libyans, or Greeks who conversed with me professed to know about the sources of the Nile, except the scribe of the holy treasures of Athena in Egyptian Saïs. But this man seemed to me to be joking… (Hdt. 2.28). On this scribe and his account, see below.

[42] Asheri et al. 2007, 261.

[43] Ἀλλὰ τάδε μὲν ἤκουσα ἀνδρῶν Κυρηναίων φαμένων ἐλθεῖν τε ἐπὶ τὸ Ἄμμωνος χρηστήριον καὶ ἀπικέσθαι ἐς λόγους Ἐτεάρχῳ τῷ Ἀμμωνίων βασιλέϊ, καί κως ἐκ λόγων ἄλλων ἀπικέσθαι ἐς λέσχην περὶ τοῦ Νείλου, ὡς οὐδεὶς αὐτοῦ οἶδε τὰς πηγάς. Καὶ τὸν Ἐτέαρχον φάναι ἐλθεῖν κοτε παρ' αὐτὸν Νασαμῶνας ἄνδρας…; "But I heard the following things from men of Cyrene who said that they went to the oracle of Ammon, and entered into conversation with Etearchus, king of the Ammonians, and then, after other topics, entered into conversation about the Nile, how nobody knew its source. And Etearchus said that once some Nasamonian men came to him…" (Hdt. 2.32).

further south to a city next to a river running west to east.[44] This, Etearchus suggests, was the Nile.

But Herodotus is aware that, aside from all the fantastic details of the kidnapping, this story is not conclusive evidence since it is reported at several removes. Therefore, he also attempts to buttress the account with an analogical argument:

> Τὸν δὲ δὴ ποταμὸν τοῦτον τὸν παραρρέοντα καὶ Ἐτέαρχος συνεβάλλετο εἶναι Νεῖλον, καὶ δὴ καὶ ὁ λόγος οὕτω αἱρέει. Ῥέει γὰρ ἐκ Λιβύης ὁ Νεῖλος καὶ μέσην τάμνων Λιβύην· καὶ ὡς ἐγὼ συμβάλλομαι τοῖσι ἐμφανέσι τὰ μὴ γινωσκόμενα τεκμαιρόμενος, τῷ Ἴστρῳ ἐκ τῶν ἴσων μέτρων ὁρμᾶται. Ἴστρος τε γὰρ ποταμὸς ἀρξάμενος ἐκ Κελτῶν καὶ Πυρήνης πόλιος ῥέει μέσην σχίζων τὴν Εὐρώπην […] Ὁ μὲν δὴ Ἴστρος, ῥέει γὰρ δι' οἰκεομένης, πρὸς πολλῶν γινώσκεται, περὶ δὲ τῶν τοῦ Νείλου πηγέων οὐδεὶς ἔχει λέγειν· ἀοίκητός τε γὰρ καὶ ἔρημός ἐστι ἡ Λιβύη δι' ἧς ῥέει. Περὶ δὲ τοῦ ῥεύματος αὐτοῦ, ἐπ' ὅσον μακρότατον ἱστορέοντα ἦν ἐξικέσθαι, εἴρηται. […] Οὕτω τὸν Νεῖλον δοκέω διὰ πάσης τῆς Λιβύης διεξιόντα ἐξισοῦσθαι τῷ Ἴστρῳ.[45]
>
> Etearchus suggested that this river flowing by was the Nile, and reason chooses this as well. For the Nile issues from Libya and cuts Libya in half. And, as I conclude by conjecturing on what is not known through what is visible, [the Nile] flows equally to the Ister in measure. For the river Ister issues forth from the Celts and the city of Pyrene and cuts Europe in half […a description of the Ister's course…]. The Ister (for it flows through the inhabited world) is known by many, but about the sources of the Nile, nobody is able to say. For Libya, through which it flows, is uninhabited and deserted. Concerning its course, to the greatest extent that one is able to learn about it by inquiring, will be said. […a description of the Nile's known course…]. Thus, I think that the Nile, running through the entirety of Libya, is equal to the Ister.

Herodotus' argument is a classic case of analogy.[46] Because Herodotus cannot access any information about the lower course of the Nile, either by viewing it himself or by speaking to one who has viewed it, he must make do with drawing a conclusion by what is known. Indeed, the contrast he draws between the unknown (τὰ μὴ γινωσκόμενα) and the visible (τοῖσι ἐμφανέσι)

[44] It is debatable whether this was truly the Nile (Lloyd 1976, 138). In any case, the reported flowing from west to east reminded Greeks of the Ister (Asheri et al. 2007, 261).
[45] Hdt. 2.33–34.
[46] Cf. section 1.2.6 and Lloyd 1966, 210ff.; Corcella 1984, 41–54. On Herodotus' use of analogy, cf. Lloyd 1975, 164–5; Corcella 1984 and Thomas 2000, 200–212.

is a very interesting one, since he implies that they are opposites and, thus, that seeing is, or is closely connected to, knowing.[47]

Of course, this particular inference is incorrect since the areas that correspond to Herodotus' Libya and Europe are not actually mirror images of one another. In this, Herodotus was led astray by the cumulative authority of almost all previous geographers, and indeed of fifth-century Greek thought at large. Hecataeus and geographers even before him offered a schematic view of the world in which the various parts are reflections of each other, especially due to their different climates.[48] And Herodotus, although not completely beholden to his predecessors' ways of thinking, did import some of it.[49] For instance, we can see the tendency towards polarization when he states that oxen in the cold north of Scythia, for example, do not grow horns[50] whereas horns on oxen in the hot southern country of Libya grow so large that the hit the ground.[51] The reasoning also whereapplied to physical geography and, in this particular case, he holds that the Nile's nature is opposed to that of other rivers.[52]

But besides the incorrect conclusion, the passage makes clear two important points about Herodotus' working method. First, the passage neatly summarizes the types of evidence that Herodotus used and his ranking of them. Second, he shows a high degree of methodological awareness and he is quite open with the reader about the confidence he has in his conclusions. Lastly, it shows that Herodotus used the best evidence available to him, and only when direct

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[47] Cf. Anaxagoras (and Democritus') motto ὄψις ἀδήλων τὰ φαινόμενα, discussed in chapter 2, section 2 above.
[48] Thomson 1948, 106–110; Lloyd 1966, 341–345; Lloyd 1976, 139–40. Cf. Hartog 1988, 13–33 on the Scythians "others" and their relation to the "normal" Greeks especially. This environmental determinism is not peculiar to Herodotus and can be found in, e.g., [Hp.] *Aër* 3–6; [Hp.] *Vict.* 37–38; Arist. *HA* 606b3ff.; *Prob.* 910a38–b10; Posidon. *ap.* Str. 3.7, etc. It often can take a normative cast, where extremes in climate create morally inferior people, but the "moderate" climate of Greece creates desirable character traits.
[49] As Thomas 2000 shows (chapter 3 in general and 78–79 in particular).
[50] Hdt. 4.29.
[51] Hdt. 4.183.
[52] Cf. Hdt. 2.19 and p. 158 below.

evidence failed did he apply theoretical models. In the last point, especially, he is closer to many fields of modern science than he has often been given credit for.

5.4. Experimentation and Psammetichus, the scientist-king

Although it is clear that Herodotus valued and used observation in his *Histories* within a hierarchy of evidence, his relationship with experiment—a specific type of observation—is less clear. This is not surprising; as opposed to pure observations, nowhere in the *Histories* does Herodotus mention undertaking experiments or tests of any kind himself. Yet, there are several instances in Herodotus' narrative where he describes experiments undertaken by others, and especially by kings.

At first glance royal power and empirical investigation is an odd pairing. But it becomes less so when we consider this pairing in relation to Herodotus' treatment of kings as a whole. Many scholars have noticed that Herodotus is especially interested in the character of kings, tyrants, and their "wise advisors." In particular, Christ has shown that "inquisitive kings" in Herodotus act as a mirror to the inquiring historian himself and that these foreign kings take part in observation of all sorts, from pure observation to measurement and experimentation.[53]

At the outset we should distinguish between experiments that seek to make a point about nature and those which are general tests without a "scientific" purpose—that is, aiming to study nature. As Christ shows, Herodotus offers plenty of instances of the latter.[54] Xerxes, upon having the same dream twice, tests whether it is truly god-sent by ordering Artabanus to sleep in his bed, to see whether the dream appears to him too.[55] Cambyses sought to prove that he was in full possession of his wits by playing a twisted game of William Tell: he proposes that if he can hit his servant's child in the heart with an arrow, he would prove himself in control of his senses

[53] Christ 1994.
[54] Ibid., 182–200.
[55] Hdt. 7.12–18. Cf. Christ 1994, 193–197.

(Herodotus' word is σωφρονέειν—an almost comically inappropriate term). In a doubly outrageous move, he even has his servants open up (ἀνασχίζειν) the boy's corpse to see whether the arrow hit its target—besides being pointlessly cruel, also a polluting action in the mind of Herodotus' Greek audience.[56]

Yet we should draw the distinction—absent in Christ's treatment, but mentioned in the introduction—between a testing procedure and a scientific experiment. Herodotus' kingly tests are not unambiguous evidence of innovation, but of motifs familiar from Greek epic and in world mythology generally. They describe kings attempting to prove or confirm the reality of a situation or character within the narrative.

For tests more specifically geared toward nature, we may consider, for instance, the famous "experiment" of Darius where he brings together Greeks and Indians from each side of his empire to question them on their diametrically opposed funerary practices. This at first glance seems like a simple test, meant, on the one hand, to prove Darius' wisdom and (perhaps more to the point) his power in having dominion over such a large expanse that it contains such disparate attitudes. Yet the passage is also infused with the relativism of contemporary Greek thought, and more specifically the contemporary dichotomy between *nomos* and *physis*. By asking the emissaries of each territory in turn their funeral customs, he is able to prove that cultural attitudes are not inherent, but that, in the words of Pindar, "*nomos* is king."[57] Admittedly, it is contested among modern scientists whether the social sciences can be experimentally investigated in the same way as physical sciences.[58] But, as always, we must be wary of imposing on Herodotus modern attitudes about the "proper" domain of science—for him as well as for Greeks of his

[56] Cf. pp. 82–83 on contemporary medicine and this taboo. Herodotus (or his priestly source) makes a point of portraying Cambyses as flouting this taboo elsewhere as well (e.g., Hdt. 3.37).
[57] Hdt. 3.83.
[58] Indeed, recent meta-studies have shown that social scientific experiments are less likely to be successfully replicated (e.g., Camerer et al. 2018).

time, the study of nature indeed included what we would call anthropology. Thus, in this passage Darius gives a structurally simple example of a scientific experiment: a test used to prove a point about (in this case, human) nature.

But it is another foreign king who stands out as most strikingly involved with the Greek science of Herodotus' time: the Egyptian Psammetichus. Just like other kings in Herodotus, Psammetichus is both a historical personage and a literary character. While Herodotus gets some details about the former correct, the reported scientific interests belong to the latter, and Herodotus represents the king as a practicing *histôr* with contemporary Greek intellectual concerns.

Historically, Psammetichus was the king Psamtek I (664–610 BCE).[59] He inherited an Egypt fractured by various royal claimants and placed at the edge of Assyrian power. The Assyrians, however, were on the decline, and Psamtek took the opportunity to reassert Egyptian independence and unity (aided by Greek and Carian mercenaries).[60] Alongside political centralization, Psamtek also strengthened Egypt's economic situation by promoting foreign trade, including trade with Greeks through the port of Naucratis. Throughout his reign, Psamtek also utilized foreign, including Greek, mercenaries as a counterbalance to internal enemies discontented with the new *status quo*. Certainly, then, we may confidently state that the period of Psamtek's reign was a point of much cultural interaction between Egyptian and foreign—including Greek—elements.

Herodotus' Psammetichus corresponds somewhat with the historical record. He, for instance, reunifies Egypt.[61] He is also portrayed as a sympathetic and effective king. Unlike

[59] On his reign, cf. Lloyd 2000, 364–372. For Greek and Egyptian relations up to the time of Alexander (incl. the reign of Psamtek I), see Vittmann 2003, 194–23.
[60] Lloyd 2000, 365.
[61] Hdt. 2.151–154.

Darius, who hubristically attacked the nomadic Scythians in their own homeland, Psammetichus turned them away from invading Egypt by entreaties and a hefty payment.[62] He is also a pious figure: when his soldiers desert their posts, he catches them and does not punish them, but entreats them not to abandon "their paternal gods…children and wives."[63]

This piety presumably did not go unrewarded in Herodotus' mind since an oracle foretold his unification of Egypt with the help of "bronze men from the sea" (i.e., Greek mercenaries in plate-bronze armor).[64] This relationship between the king and the Greeks was especially important from Herodotus' point of view, since he believes that Psammetichus was responsible for the first Greek–Egyptian interpreters, an indispensable aide for any Greek researching Egypt.[65] On Herodotus' telling, the king sent Egyptian children to the Greek settlements in Egypt to learn the language, from whom contemporary interpreters were descended.[66] While the historicity of this story may be doubted,[67] the aetiological myth certainly does indicate a strong connection in Herodotus' mind between Psammetichus and Greek culture.

5.4.1. Measuring the Depth of the Nile

One such topic which connected Psammetichus to Greek thought was the Nile. Of course the Nile was the subject of intense interest for both Greek and Egyptians. For the Egyptians it was a life-giving presence controlled by divine forces and not an anomaly to be explained.[68] On the other hand, the Nile was the subject of wonder to the Greeks precisely because it presented a

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[62] Hdt. 1.105.
[63] Hdt. 2.30. Psammetichus' high-minded appeal contrasts with the one soldier's vulgar response: that wives and children follow from "this," pointing to his αἰδοῖον.
[64] Hdt. 2.152.
[65] On Hdt.'s use of interpreters and his understanding of foreign language in general see Hartog 1988, 231–248; Harrison 1998.
[66] Hdt. 2.154. Asheri et al. 2007 *ad loc.* notes that this story is probably false, as plenty of time had elapsed for Egyptians to become conversant with the Greek language.
[67] As Asheri et al. 2007, 355 notes there would have been plenty of time for bilingualism to develop outside a narrow caste set up by royal fiat.
[68] Bonneau 1964, 135–136. On the Nile and its connection to the divine (or rather the divinity responsible for the Nile's flooding), see Bonneau 1964, 219–240.

conflict to Greek science. It was (and is) the most conspicuous natural feature in Egypt and thus well within the subject matter of an inquiry into nature focused on Egypt. But it is also what Herodotus would call a *thôma*—a wonder—which seemed to the ancients to fall outside the natural order by, e.g., its size, its regularity of flooding, and by flooding in the summer rather than the winter. The Nile had, as Herodotus notes, a δύναμιν…τὰ ἔμπαλιν πεφυκέναι τῶν ἄλλων ποταμῶν; as his word choice (πεφυκέναι) makes clear: it is not merely an extreme in nature, but in some way naturally opposed to all other rivers.[69]

Thus, from its very beginnings with Thales, Presocratic natural philosophy attempted to explain away the Nile's paradoxical nature, and especially that of its regular flooding in the summer. Thales explained the inundation by claiming that the Etesian winds check the outflow of the Nile into the sea, which then caused predictable flooding.[70] Anaxagoras thought that melting snows on Ethiopian mountains ran into the Nile.[71] Democritus combined these theories and created his own evaporations from the melting snow are blown by the Etesian winds, causing rainstorms.[72] And these are just some of the more illustrious names among the Presocratic thinkers interested in the Nile in addition to other, lesser-known figures.[73]

Just like these Presocratic natural philosophers, Psammetichus is also portrayed as investigating the Nile. In his extended treatment of the Nile's nature, its sources, and its flooding (2.10–31), Herodotus mentions a story told to him by the "scribe of the holy treasures" at the temple of Athena at Saïs, an important source for him about the Nile:

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[69] Hdt. 2.19. On Herodotus' understanding of Greek thought about the Nile, see Froidefond 1971, 118–123, Thomas 2000, 163–164 and 182–185; Graham 2003b.
[70] DK11 A16.
[71] DK59 A91.
[72] DK68 A99.
[73] These other figures include Diogenes of Apollonia (DK64 A18); Oenopides of Chios (DK41 A11); Thrasyalces of Thasos (DK35 A1). The last of these is a mysterious figure who, supposedly, was the source for Aristotle's theory of the Nile's flooding (Str. 7.1.5).

> Ὡς δὲ ἄβυσσοί εἰσι αἱ πηγαί, ἐς διάπειραν ἔφη τούτου Ψαμμήτιχον Αἰγύπτου βασιλέα ἀπικέσθαι· πολλέων γὰρ αὐτὸν χιλιάδων ὀργυιέων πλεξάμενον κάλον κατεῖναι ταύτῃ καὶ οὐκ ἐξικέσθαι ἐς βυσσόν. Οὗτος μὲν δὴ ὁ γραμματιστής, εἰ ἄρα ταῦτα γενόμενα ἔλεγε, ἀπέφαινε, ὡς ἐμὲ κατανοέειν, δίνας τινὰς ταύτῃ ἐούσας ἰσχυρὰς καὶ παλιρροίην, οἷα [δὲ] ἐμβάλλοντος τοῦ ὕδατος τοῖσι ὄρεσι, <ὥστε> μὴ δύνασθαι κατιεμένην καταπειρητηρίην ἐς βυσσὸν ἰέναι.[74]
>
> [The scribe] said that Psammetichus, the king of Egypt, tested by trial whether the sources [of the Nile] are bottomless. For he let down into it a woven rope many thousands of fathoms and did not arrive at the bottom. This scribe, if indeed he was speaking of things that [actually] happened, as I understood, showed that there are certain strong eddies there and a reverse flow, which, when water fell upon the banks, make it unable for a sounding-line let down to reach the bottom.

Several features of this account point to a "Greek" way of seeing the great river. The idea of measuring and quantifying suggests that it is something foreign which must be understood and assimilated to human understanding—a hallmark of what Hartog calls the "rhetoric of otherness."[75] The "otherness" of the Nile is again underscored by Psammetichus' result that the Nile does not *have* a bottom. Furthermore, in the action of measuring the Nile, the Egyptian king also mirrors Herodotus himself who, seemingly from personal experience, claims that that one can measure eleven fathoms of mud at the bottom of the Nile by letting down a sounding line.[76] Of course, Psammetichus very well *could* have searched for a source of the Nile, but we must always be aware that Herodotus is always apt to ascribe particularly Greek motivations and thought patterns to non-Greeks, and especially to Psammetichus, in his work.

Despite the connection to contemporary Greek interests, though, we should not dismiss the Egyptian sources of Herodotus' account. Directly before Psammetichus' experiment, Herodotus mentions that the scribe told him that the sources of the Nile lie beneath two mountains with the Egyptian names Krophi and Mophi, which corresponds with Egyptian

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[74] Hdt. 2.28.
[75] Hartog 1988, 230–237.
[76] Hdt. 2.5. Cf. Lloyd 1976, 40, which notes that either Herodotus' measurement is imprecise or by a "day's voyage" from the coast he means a *particular* day's voyage, rather than a day during normal conditions.

sources.[77] This too, posits a bottomless source to the Nile, but one which is not proven experimentally, but taken on the authority of a priestly tradition. Herodotus himself initially discounts this story (he says the scribe ἔμοιγε παίζειν ἐδόκεε), but never dismisses it entirely. Perhaps he saw Psammetichus' experiment confirming what had already been known by Egyptian tradition; in any case, the use of parallel Greek and Egyptian evidence calls into the question the validity of the dichotomy in Herodotus' mind.

From a more empirical point of view, however, the Egyptians were accomplished river- and seafarers from quite early on in their history, and a necessary part of sailing would be the use of a sounding-line or pole by sailors to check the depth of the water around them. But more precise measurements of the Nile's flood were also recorded by Nilometers—a pit (fed by an underground passage) or a column, with graduated markings that would measure the rise of Nile during the inundation.[78] This data would then be recorded so that the authorities could compare it with historical data.[79] The point was to predict the harvest: if the Nile did not rise high enough, the fields would not be sufficiently watered; if it rose too high, the fields would be flooded. Many Nilometers were located in temples, as it was the prerogative of the priestly caste and the

[77] Ἔλεγε δὲ ὧδε, εἶναι δύο ὄρεα ἐς ὀξὺ τὰς κορυφὰς ἀπηγμένα, μεταξὺ Συήνης τε πόλιος κείμενα τῆς Θηβαΐδος καὶ Ἐλεφαντίνης, οὐνόματα δὲ εἶναι τοῖσι ὄρεσι τῷ μὲν Κρῶφι, τῷ δὲ Μῶφι· τὰς ὧν δὴ πηγὰς τοῦ Νείλου ἐούσας ἀβύσσους ἐκ τοῦ μέσου τῶν ὀρέων τούτων ῥέειν, καὶ τὸ μὲν ἥμισυ τοῦ ὕδατος ἐπ' Αἰγύπτου ῥέειν καὶ πρὸς βορέην ἄνεμον, τὸ δ' ἕτερον ἥμισυ ἐπ' Αἰθιοπίης τε καὶ νότου; "He said that there are there two mountains with peaks tapering off to a point, lying between the city of Syene in the Thebaid and Elephantine. The names of the mountains are Krophi and Mophi. The bottomless sources of the Nile flow from the middle of these moutnains, and half of the water flows to the north to Egypt, and half south to Ethiopia (Hdt. 2.28). The Famine Stele (from the Ptolemaic period, but drawing upon earlier Egyptian material) mentions the mountain Krophi (Barguet 1953, 22).

[78] Borchardt 1906 is the classic study of all the literary and some archaeological evidence; Friedman 2008 is more up-to-date, but also more cursory. The oldest Nilometer record is the so-called "Palermo stone," dated to the fifth dynasty (25th–24th century BCE), but they were used well into Roman times (Str. 17.1.48; Hld. 9.22; P.Oxy. I 43v). There also seems to have been local officials responsible for recording measurements (P.Col. VII 175v speaks of Neilos the *Neilometros*).

[79] D.S. 1.36.12 attests to the priests keeping detailed records of the flood (ἐκ πολλῶν χρόνων τῆς παρατηρήσεως ταύτης παρὰ τοῖς Αἰγυπτίοις ἀκριβῶς ἀναγεγραμμένης).

pharaoh himself to keep these records, especially since it was the pharaoh who was thought ultimately responsible for appeasing the god responsible for the flooding.[80]

Even if we set aside the narrower (and unanswerable) question about the historicity of this account, Herodotus is not entirely misrepresenting the actions of an Egyptian king with this passage. Both were involved with various measurements of the Nile. The important difference is Herodotus' reported intention. The Egyptian evidence for measuring the Nile is for a practical purpose—to ensure that a part of it is navigable or to predict the upcoming harvest, without a clear theoretical motivation. Herodotus (and Psammetichus in Herodotus' account) does not express any practical motivation to their measurements—it is simply to understand the Nile as an anomalous part of nature, but a part of nature nonetheless.

Does Herodotus' account, then, describe an experiment? In terms of its object—a river subject to periodic, but puzzling phenomena—we may answer in the affirmative. However, it is only in the most general sense that there is a controlled intervention into the thing being measured. However, perhaps this apparent simplicity is not a flaw from a scientific point of view, but due to the fact that it is a direct measurement of something, rather than in the service of analogical reasoning. In this feature, at least, it is more straightforwardly empirical than complex tests in other authors.

5.4.2. Psammetichus' Linguistic Experiment

Psammetichus relatively simple and direct test of the depth of the Nile's sources can be contrasted with the famous linguistic experiment contained at the beginning of Book II:

> Ψαμμήτιχος δὲ ὡς οὐκ ἐδύνατο πυνθανόμενος πόρον οὐδένα τούτου ἀνευρεῖν οἳ γενοίατο πρῶτοι ἀνθρώπων, ἐπιτεχνᾶται τοιόνδε. Παιδία δύο νεογνὰ ἀνθρώπων τῶν ἐπιτυχόντων διδοῖ ποιμένι τρέφειν ἐς τὰ ποίμνια τροφήν τινα τοιήνδε, ἐντειλάμενος μηδένα ἀντίον αὐτῶν μηδεμίαν φωνὴν ἱέναι, ἐν στέγῃ δὲ ἐρήμῃ ἐπ'

[80] Friedman 2008, 3387.

> ἑωυτῶν κεῖσθαι αὐτὰ καὶ τὴν ὥρην ἐπαγινέειν σφι αἶγας, πλήσαντα δὲ τοῦ γάλακτος τἆλλα διαπρήσσεσθαι. Ταῦτα δὲ ἐποίεέ τε καὶ ἐνετέλλετο [ὁ] Ψαμμήτιχος θέλων ἀκοῦσαι τῶν παιδίων, ἀπαλλαχθέντων τῶν ἀσήμων κνυζημάτων, ἥντινα φωνὴν ῥήξουσι πρώτην. Τά περ ὦν καὶ ἐγένετο. Ὡς γὰρ διέτης χρόνος ἐγεγόνεε ταῦτα τῷ ποιμένι πρήσσοντι, ἀνοίγοντι τὴν θύρην καὶ ἐσιόντι τὰ παιδία ἀμφότερα προσπίπτοντα «βεκός» ἐφώνεον ὀρέγοντα τὰς χεῖρας. Τὰ μὲν δὴ πρῶτα ἀκούσας ἥσυχος ἦν ὁ ποιμήν· ὡς δὲ πολλάκις φοιτῶντι καὶ ἐπιμελομένῳ πολλὸν ἦν τοῦτο τὸ ἔπος, οὕτω δὴ σημήνας τῷ δεσπότῃ ἤγαγε τὰ παιδία κελεύσαντος ἐς ὄψιν τὴν ἐκείνου. Ἀκούσας δὲ καὶ αὐτὸς ὁ Ψαμμήτιχος ἐπυνθάνετο οἵτινες ἀνθρώπων «βεκός» τι καλέουσι, πυνθανόμενος δὲ εὕρισκε Φρύγας καλέοντας τὸν ἄρτον. Οὕτω συνεχώρησαν Αἰγύπτιοι καὶ τοιούτῳ σταθμωσάμενοι πρήγματι τοὺς Φρύγας πρεσβυτέρους εἶναι ἑωυτῶν. Ὧδε μὲν γενέσθαι τῶν ἱρέων τοῦ Ἡφαίστου [τοῦ] ἐν Μέμφι ἤκουον· Ἕλληνες δὲ λέγουσι ἄλλα τε μάταια πολλὰ καὶ ὡς γυναικῶν τὰς γλώσσας ὁ Ψαμμήτιχος ἐκταμὼν τὴν δίαιταν οὕτως ἐποιήσατο τῶν παιδίων παρὰ ταύτῃσι τῇσι γυναιξί.[81]
>
> Psammetichus, since he was unable in any way discover by inquiring who were the first humans, he contrived the following. He gave two newborn children of random people to a shepherd to raise in accordance with the following plan: he commanded that nobody should utter a sound in front of them, and to put them in an empty room by themselves, and brought goats in to them, to give them their fill of milk and do [everything] else. Psammetichus did and commanded these things since he wished to hear what word the children would say first, once they had stopped making non-significant cries. This is what happened. When a time of two years had gone by, when the shepherd doing these things opened the door and entered, both children fell down and uttered "*bekos*," reaching out their hands. When he heard these things, the shepherd was first silent. But as he again and again returned and took care of them, there were many an instance of this word, so signifying this to his master he brought the children into his sight at his command. Psammetichus himself hearing them inquired who among men called something "*bekos*," and inquiring learned that the Phrygians call bread [this]. So the Egyptians conceded and concluded from this matter that the Phrygians were older than them. This I heard from the priests of Hephaestus in Memphis, but the Greeks say many other frivolous things, including that Psammetichus cut out the tongues of women and made it so the children lived among the women.

The complexity of the experiment has appeared strikingly modern to modern scholars in the controlled way that Psammetichus sets up his inquiry. As A. Lloyd has noted, many of the details that Herodotus has added are all significant in terms of experimental design: two infants are needed in order to stimulate communication, their parents are randomly selected (ἀνθρώπων τῶν ἐπιτυχόντων) in order to have generalized results, and, most importantly, they are kept

[81] Hdt. 2.2.

away from any linguistic stimuli that might bias their "natural" development.[82] In addition to the factors identified by Lloyd, one can identify other features such as the shepherd confirming the significance of the results by making sure that their cry was not a singular instance. Otherwise, the Egyptian shepherd would have had no way to differentiate true language use from non-significant noise that happened to be the same as some word.

Despite its sophistication, however, the experiment is also remarkable since it actually does not "work." Any infant sequestered like this and kept away from human language (or any interaction, for the most part), would not learn to speak spontaneously. Indeed, later accounts of "feral children"—children who have grown up without meaningful human contact—suggest that after a certain period without language, the child would no longer be able to learn to speak (although the "critical period" seems to be longer than the three years that the newborns were sequestered by Psammetichus).[83] In other words, the capability of language is inherent, but the use of language—much less a specific language—is not inevitable.[84] Nor does it make sense that the infants know any word, for bread or otherwise, given the conditions of their upbringing. On the other hand, the details of the account, as opposed to the reasoning, are not simply pure invention either: inscriptional evidence from Asia Minor proves that *bekos* is indeed a Phrygian word.[85]

Even though there does appear to be a kernel of truth to Herodotus' account, it also raises many not immediately obvious issues. What is the theoretical background to this experiment?

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[82] Lloyd 1976, 5–6.
[83] Malson 1972, 37–61.
[84] See Gera 2003, 73–74 for the modern linguistic understanding of issues brought up by this experiment.
[85] Haas 1966, 84–85; 139. The derivation is debated: Beekes 2009 s.v. and Haas 1966, 84 suggest that it comes from *b^{h}eHg- 'to bake,' (which makes it cognate with Gk. φώγω, 'to roast' and Eng. 'bake'); Gera 2003, 88 n54 suggests, less persuasively, that it is related to Gk. πέσσω 'to cook' (from PIE *pek^{w}-). Further complicating our understanding of the word's early history, Hippon. fr. 125 West speaks of the Κυπρίων βεκός and some scholars (e.g., Beekes 2009 s.v.) refer to this fragment as evidence that the word was at least thought to be Cyprian. The original context of the line in Hipponax, however, is quite uncertain.

What is it trying to prove? How? Who are Herodotus' sources? And perhaps most interestingly, yet most difficult of all to answer, is it likely that this experiment was actually performed?

Let us begin with Herodotus' sources. According to his usual practice, Herodotus names his source for this episode explicitly: the priests of Hephaestus (the Greek name for the Egyptian craftsman god Ptah) at Memphis. Priests, of course, were a major source for Herodotus, and the Memphite priests especially so. He draws upon them often throughout his *History*, including many parts in his extended section on the history of Egypt (2.99–142).[86] His reliance on priests for his Egyptian *logos* is understandable, since priests were the keepers of historical memory in Egypt, as was generally known by Greeks around Herodotus' time.[87] He was comfortable enough in evaluating his sources to make critical judgments about priests attached to different temples; the priests of Heliopolis, for instance, were the most learned (λογιώτατοι) of the Egyptians.[88]

But, on the other hand, Herodotus alludes to another version of the experiment, current among 'the Greeks,' where Psammetichus is not a mostly-benign investigator, but a cruel tyrant who carries out his test with absolutely no regard for the well-being of his subjects. In this story, he mutilates the children's' mothers by cutting out their tongues, using his own unlimited power to further his investigation at the expense of his subjects. This view is contrary to Herodotus' positive portrayal of Psammetichus as a "friend of the Greeks"[89]—not just in terms of political interaction, but, more importantly in this case, cultural closeness. Indeed, this variant

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[86] Also see, e.g., Hdt. 2.28, 54, 3.37 (probably, given the hostility toward Cambyses and his treatment of the Memphite priests). On the Memphite priests as the source for 2.99–142, cf. Lloyd 1975, 90. On Egyptian priests as a source for Herodotus (and other Greek authors) more generally, cf. Lloyd 1975, 89–100; Moyer 2011, 51–82.
[87] E.g., the Egyptian priest's famous chiding of Solon: καί τινα εἰπεῖν τῶν ἱερέων εὖ μάλα παλαιόν ὦ Σόλων, Σόλων, Ἕλληνες ἀεὶ παῖδές ἐστε, γέρων δὲ Ἕλλην οὐκ ἔστιν…'νέοι ἐστέ,' εἰπεῖν, 'τὰς ψυχὰς πάντες;" "And one of the priests, a very aged man, said, 'Solon, Solon, you Greeks are always children, there is no such thing as an old Greek…you are all young,' he said, 'in soul.'" (Pl. *Tim.* 22b).
[88] Hdt. 2.3. On the term λόγιος as a fairly general term of learned authority in Herodotus, see Luraghi 2009.
[89] In the words of Borst 1957, 39 ("Griechenfreund").

Psammetichus is more emblematic of other "oriental despots" found elsewhere in Herodotus and eastern foreigners in Greek literature more broadly, who do not have the Greek virtue of restraint.[90] Of course, Herodotus' attitude is not one of total Greek chauvinism either; there are plenty of examples of cruel behavior on the part of Greek tyrants as well.[91]

So who are the "Greeks" that Herodotus is mentioning here? Many scholars suggest that he is speaking about his predecessor (and rival) Hecataeus.[92] There is, however, a tendency to assume that Herodotus is responding to Hecataeus even when we have no external confirmation that Hecataeus discussed a topic, simply because he was Herodotus' most important predecessor and Herodotus was heavily indebted to him.[93] As no external source connects this story to the early geographer, we have reason to question a Hecataean reference here.

Moreover, mentions of the experiment found outside Herodotus do not point to any source other than Herodotus himself. Aristophanes in the *Clouds* coined the term βεκκεσέληνε to mean 'dotard' or 'old fool,'[94] and the word seems to refer to the tale of Psammetichus in a relatively involved joke. The word is modelled after προσέληνος (literally, '[existing] before the moon'), which the Arcadians called themselves on account of their supposed antiquity.[95]

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[90] On Herodotus and "eastern despots," cf. Gammie 1986, 175–185; Hartog 1988, 322–339; Dewald 2013, 43–48. Dewald 2013, in particular, sees the Eastern despot as Herodotus' model for the abuse of power, and especially of the despot's control over his subject's bodies (cf. Hartog 1988, 332–334). On the trope of the cruel, luxurious, slavish, etc. barbarian more generally in Greek literature and thought of the time, see Hall 1989; Hall 2002, 172–189.

[91] E.g., Periander at Hdt. 5.91–93. But cf. Dewald 2013 who argues that Herodotus portrays Greek tyrants as less straightforwardly cruel and unrestrained than Eastern ones.

[92] E.g., Lloyd 1976, 8–12; Gera 2003, 71–72 ("perhaps"); Asheri et al. 2007, 243. How and Wells 1912, 156 also suggests that this is a "hit" on Hecataeus, but is non-committal about the suggestion.

[93] Cf. Thomas 2000, 1, n. 1: "[Hecataeus] is probably attributed with far more than he can reasonably bear, and the Hecataean fragments are especially austere." Indeed, many are simple geographical glosses contained in Stephanus of Byzantium (out of an impressive sounding 373 fragments in *FGrHist* 1, more than 300 are these geographical glosses).

[94] Ar. *Nub.* 398.

[95] As first reported by the early historian Hippys of Rhegium (*FGrHist* 554 F7).

Aristophanes, thus, swaps in the Phrygian word βεκός (minus the nominal ending –ος)[96] as a prefix to highlight Strepsiades' extreme old age—referring to Psammetichus' test and the fact that the Phrygians are the oldest people in the world. But none of this points to a source outside Herodotus; indeed, Herodotus is the most probable source (rather than Hecataeus or some nameless historian), since he most likely gave public recitations in Athens, thus giving the Athenian public a frame of reference for Aristophanes' joke.

In addition, another version has the children uttering *bekos* because they learned to imitate the bleating of the goat used to nurse them.[97] But, this too must stem not from the "Greek version" in Herodotus' account, since the unnamed Greeks do not make a goat the children's caregiver, but their own mothers (minus their tongues). Other details like there being only one child, or that βεκός is a Lydian or Paphlagonian word, are most likely conscious innovations on Herodotus' account made by later sources contained quoted by the *Suda* or scholia, if not outright mistakes.[98] Thus, even though Herodotus knew of an alternative Greek tradition, we are unable to state with much confidence whence he drew it.

Since we have no ultimate source in hand for Herodotus, we are justified in asking whether the report of Psammetichus' linguistic experiment was ultimately Egyptian in provenance and, relatedly, was it likely to have been performed. These questions admit only of degrees of probability, but the ancient evidence does point toward tentative conclusions.

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[96] Some later sources say that the foreign word was actually βέκ, which was Hellenized to βέκος (Sch. Ar. *Nub.* 398c, 398d, 398e; Sch. Aristid. *Rhet.* 3, 7). The variant βαίκ is also found, but as Richard Janko has pointed out to me is the result of Byzantine homophony.

[97] The Greek words for goats' (or sheep's) bleating are βληχή or μήκη (cf. the μηκάδες αἶγες of Homer). Both are very roughly approximate the consonantal sounds found in βέκος (i.e., labial + velar). Some later grammarians differentiate between the two, saying that sheep βληχᾶσθαι, but goats μηκᾶσθαι (e.g., Poll. *Onom.* 5.88), but this is just an artificial schematization, probably based on the Homeric epithet. In other sources they are ambiguous or interchangeable (e.g., Ar. *Pax* 398; Opp. *C.* 2.365; Hsch. s.v.).

[98] E.g., *Suda* s.v. βεκεσέληνε; Sch. Ar. *Nub.* 398c, 398f; Apostol. 4.89 (*CPG* II, 328).

Because of the impossibility of a definitive answer, the question of origin has divided scholars. Most find that the experiment is only understandable in the light of Greek thought current in Herodotus' time.[99] Others are cautious in dismissing Herodotus' and, perhaps more importantly, the Egyptian priests' testimony that the test was carried out by an Egyptian king.[100] By doing so, we would be retreating into the "father of lies" interpretation of Herodotus, and, while Herodotus is certainly not above the occasional misstatement or falsehood, his "mistakes" are more complicated than mere malice.

Both sides on the debate over the source of Psammetichus' experiment, however, are broadly in agreement as to *how* it should be approached. The question is not one of strict historicity—for we possess no hitherto unnoticed piece of evidence that would vindicate or disprove Herodotus' exact account—but of the intellectual assumptions undergirding the experiment.

In favor of an Egyptian provenance, Borst pointed to the supposed "entirely non-Greek formulation of the question" behind the entire experiment: which people were first and oldest.[101] The Egyptians had a clear idea of their status as the "first" people, as attested both by Herodotus in the passage above, but also in native sources.[102] Finally, he points to the fact that the Greeks of Herodotus' time would have had no motivation for such an experiment—for them the remote antiquity of Egyptian civilization was a given.

Furthermore, there was a rich Egyptian tradition of science from which Herodotus or his sources could have drawn. Our evidence is patchy, but we have pharaonic papyri attesting to a

[99] E.g., How and Wells 1912, 156; Salmon 1956; Lloyd 1976, 9–11; Vannicelli 1997, 203–4; Asheri et al. 2007, 242.
[100] E.g., Borst 1957, 39–40; Sułek 1989, 646–7; Munson 2005, 20.
[101] Borst 1957, 39 ("ganz ungriechische Fragestellung").
[102] For the latter, see, for example, Pritchard 1969, 8: a creation myth where the gods create the first humans in Thebes, the "first city."

high level of attainment in mathematics, astronomy, and medicine.[103] And although there is no evidence in these sources of the scientific investigation of language, medical doctrine offers an interesting parallel to Psammetichus' experiment.[104] Surviving medical treatises include gynecological and obstetric material and, as How and Wells' commentary notes, "[t]he Egyptians certainly attached great importance to the cries of children."[105] The reference here is a bit obscure, but the commentators seem to be referring to a passage from the Ebers papyrus—a collection of remedies and magical cures dating from the Eighteenth dynasty (1570–1320 BCE). The writer recommends listening to the cries of infants in order to predict their chances of surviving into childhood. In one particular case, the papyrus gives an "assessment of a child the day it is born. If it says *ꜥnjj*, it lives; if it says *mbj*, it dies" (the latter probably being a form of "no.")[106] Of course this is an erroneous test, but the parallelism to Psammetichus' experiment is interesting. While the object of the test is different, the similarity in waiting for an infant to make its first significant noise is in the Egyptian scientific background to Psammetichus' experiment.

On the other hand, several factors complicate Herodotus' assertion that the priests of Memphis are transmitting an Egyptian tale. First, scholars have noticed that *bekos* is very similar to the Middle Egyptian word *beḳ* ('oily,' 'white,' thence 'clear of character,' 'innocent').[107] Psammetichus—or rather the unnamed scholars that Psammetichus tasks with finding out which

[103] On Egyptian science in general see Reineke 1986; Depuydt 2017. Rossi 2010 stresses the non-literary evidence for Ancient Egyptian science and the imperfect fit of the term for Ancient Egyptian material. For the particular sciences mentioned here, good overviews can be found in DeYoung 2000 (astronomy), Imhausen 2006 (mathematics), and Nunn 2002 (medicine).
[104] Reineke 1986, 72–3 speaks of Egyptian *Sprachwissenschaft*, but the evidence he adduces concerns the study of *correct* language (i.e., grammar in the ancient sense) and scribal training, rather than the study of the nature of language itself.
[105] How and Wells 1912, 156.
[106] Ghalioungui 1987, 213.
[107] As noted by, e.g., How and Wells 1912, 156 and Salmon 1956, 323. For the word *beḳ* and its semantic range in Middle Egyptian see Faulkner 1976, 78.

language *bekos* belongs to[108]—could scarcely have been ignorant of that fact or have given up the opportunity to assert the primacy of the Egyptians. Furthermore, scholars have also noted that bread is the quintessential sustenance for mortals in the Greek mind,[109] although this argument is somewhat weakened by the fact that bread was an Egyptian staple as well.

But perhaps more importantly, the Greek intellectual commitments behind the story are readily apparent, and considerable in scope. Philosophers contemporary with Herodotus, including the sophists, were greatly interested in human language—partially in response to the growing rift between philosophical doctrine and everyday language.[110] Gorgias, for instance, famously made the paradoxical assertion that, even if something existed, and if we could know it, we could not communicate our knowledge via language.[111] Not all sophists were quite as pessimistic about our linguistic abilities, however. Sophists like Lycophron and, especially, Prodicus searched for scientifically exact definitions to words, a habit which had a great impact on later Greek philosophy.[112] In a wider sense, these definitions were part of a shared project of establishing "correct usage" (ὀρθοέπεια) or "correctness of names" (ὀρθότης ὀνομάτων), which was also a special concern of the sophist Protagoras, and which is dealt with extensively in Plato's *Cratylus.*[113]

We even find possible evidence of contemporary interest in childhood language acquisition in the treatise called the *Dissoi Logoi* or *Contrasting Arguments*. The treatise is an

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[108] ὁ Ψαμμήτιχος ἐπυνθάνετο οἵτινες ἀνθρώπων βεκός τι καλέουσι (Hdt. 2.2.4).
[109] E.g., Vannicelli 1997, 205–207.
[110] Some general accounts of the sophistic interest in language can be found in Guthrie 1971, 204–219; Classen 1976, 215–247; Kerferd 1981, 68–77; Barney 2006, 90–95; de Jonge and van Ophuijsen 2010, 485–498.
[111] DK82 B3, 83–87.
[112] Lycophron: DK83 A1 and A3 give Lycophron's attempted definitions of certain concepts. We know a bit more about Prodicus' procedure of teasing out slight semantic variations in seeming synonyms: DK84 A13–20. We also have a few surviving definitions, such as his definition of "phlegm" (DK84 B4 via Galen, unsurprisingly). On Prodicus' linguistic thought, also cf. Mayhew 2011 for texts and commentary.
[113] There is debate whether ὀρθοέπεια and ὀρθότης ὀνομάτων refer to the same concept (Guthrie 1971, 205; de Jonge and van Ophuijsen 2010, 489–490). See also below, pp. 171–173.

anonymous work contained in some MSS of Sextus Empiricus. It puts forward various (sometimes quite bad) arguments against the independent existence of the good, the fine, justice, and the truth by giving equal time to arguments on both sides (the δισσοὶ λόγοι of the title). In this, the author is well within the mainstream of sophistical thinking. Regrettably, dating is difficult and attribution is nearly impossible since the author is anonymous in the MSS and the material is too general to allow for anything other than speculation on authorship.[114] Still, based on a passage that the Peloponnesian war is the latest (τὰ νεώτατα) in a series of wars reaching back into mythological times, most scholars agree that the work dates from the late fifth or early fourth century BCE.[115] It is also perhaps significant that the author uses several ethnographical examples in order to prove the culturally relative nature of what is shameful, including some found in Herodotus as well.[116] While this is not conclusive evidence that the *Dissoi Logoi* used Herodotus as a source (or perhaps even *vice versa*), it does support, or at the very least does not call into question, the conventional dating.

In any case, the author's argument on childhood language acquisition seems to fit well within the same intellectual context as Herodotus' account of Psammetichus:

> αἰ δέ τωι μὴ πιστόν ἐστι τὰ ὀνύματα μανθάνειν ἁμέ, ἀλλ' ἐπισταμένως ἅμα γίνεσθαι, γνώτω ἐκ τῶνδε· αἴ τις εὐθὺς γενόμενον παιδίον ἐς Πέρσας ἀποπέμψαι καὶ τηνεῖ τράφοι, κωφὸν Ἑλλάδος φωνᾶς, περσίζοι κα· αἴ τις τηνόθεν τῆιδε κομίξαι, ἑλλανίζοι κα. οὕτω μανθάνομεν τὰ ὀνύματα, καὶ τὼς διδασκάλως οὐκ ἴσαμες.[117]
>
> If someone is not persuaded that we learn words, but [thinks that we] know them as soon as we are born, let him understand [the truth] from the following: if someone should send a child away to the Persians right after he has been born and raise him there, hearing

[114] Robinson 1979, 34–54 goes over the history of proposals which run from a work from the circle of Socrates in the late 5th century BCE to a forgery of the Byzantine era (not mentioned in Robinson 1979, cf. Conley 1985).
[115] *Dialex.* 1.8: ἔν τε τῶι πολέμωι (καὶ τὰ νεώτατα πρῶτον ἐρῶ) ἁ τῶν Λακεδαιμονίων νίκα, ἂν ἐνίκων Ἀθηναίως καὶ τὼς συμμάχως, Λακεδαιμονίοις μὲν ἀγαθόν, Ἀθηναίοις δὲ καὶ τοῖς συμμάχοις κακόν; "in war (and I speak first of the most recent) the victory of the Lacedaemonians which they won [against] the Athenians and their allies, was good for the Lacedaemonians, but bad for the Athenians and their allies." *Dialex.* 1.9–11 continues with the Persian war all the way back to the Titanomachy.
[116] *Dialex.* 2.9–19 (cf. Hdt. 3.31 and 4.64–65 for similar reports on the Persians and Scythians)
[117] *Dialex.* 6.12 (= DK90). I use the text of Robinson 1979.

> nothing of Greek speech, he would speak in Persian. If one should send him here from there, he would speak in Greek. Thus we learn words, and we do not know our teachers.[118]

This thought experiment provides a striking parallel to Psammetichus' experiment.[119] By removing a child from normal linguistic development, the author seeks to prove a point about the nature of language, namely, that no particular language is primary or "natural." The position staked out here is the exact opposite of the assumption behind Psammetichus' experiment—that in the absence of any linguistic stimuli, humans will default to an original language. And this original language is natural in the sense that it is the language that humans speak without any influence from cultural forces, or as the Greeks would put it, from *nomos*.

Thus, in a general sense, the author of the *Dissoi Logoi* and Herodotus' portrayal of Psammetichus are participants in the sophistic debate over whether language is natural (φύσει) or conventional (νόμῳ)—a specific and important instance of the wider debate between *physis* and *nomos*.[120] This linguistic debate is best known through Plato's presentation of it in the *Cratylus*, where the eponymous figure argues (384c–386e) on behalf of a natural correspondence between word and referent, while the character Hermogenes argues for the opposite position (384c–386e).[121] Importantly, however, Herodotus and the author of the *Dissoi Logoi* are not having precisely the same debate as in the *Cratylus*. Rather, both are subsidiary debates over language contained within the larger *physis–nomos* framework. Nor were these two debates the only instances of the framework being used in contemporary philosophy of language. Yet another

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[118] That is, we do not remember the exact sources from which we learn a language in childhood. Cf. [Pl.] *Alc.* 111a: οἷον καὶ τὸ ἑλληνίζειν παρὰ τούτων ἔγωγ' ἔμαθον, καὶ οὐκ ἂν ἔχοιμι εἰπεῖν ἐμαυτοῦ διδάσκαλον…; "for example, I learned speaking Greek from [many], and I would not be able to speak of my own teacher…" (referred to by Robinson 1979, *loc. cit.*).

[119] Most recently investigated by Gera 2000 (cf. Gera 2003, 82–83).

[120] Cf. Heinimann 1945, 156–162, who places the linguistic debate in the context of the wider *nomos–physis* antithesis of the fifth century BCE. Plato singles out Prodicus (*Crat.* 384b) and Protagoras (*Crat.* 391c) as concerned with it.

[121] The bibliography on correctness of names in the *Cratylus* is enormous, but cf. Ademollo 2011, 1–14 for an up-to-date overview of the dialogue.

related debate was whether the origin of names for things arose through a natural, but random process of variation over generations, or whether an inspired name-giver imposed a word for each thing at a single point in time.[122] Democritus, for instance, seems to have opted for the former, naturalistic account even though each word's relationship to its object was conventional.[123] The latter account can be found, for example, in the Derveni papyrus, where Orpheus plays the role of a name-giver, although not necessarily the original one.[124] Even so, it seems to be a naturalized version of the idea in some Mediterranean religious traditions that a god (or someone with a particularly close relationship to the divine) plays the role of the primordial name-giver.[125]

As it is certain that Herodotus was aware of the wider *physis–nomos* debate in other parts of the *Histories*, it is understandable that it would be on his mind here as well.[126] But given the extensive Greek theoretical background of Psammetichus' experiment, it is difficult to see how the story could be transmitted directly from Egyptian sources, as Herodotus informs his readers. It is possible that the "experiment" recorded here is the result of miscommunication on

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[122] Ancient sources frame the debate as whether names are established φύσει or θέσει, but scholars note that this debate, again, is not precisely the same debate as whether names refer to their objects φύσει or νόμῳ (Gera 2003, 169–170; van Ophuijsen 2010, 485–498). Still, names established by a name-giver are a *nomos* in the sense that, after the original names are established, they are passed down and kept alive by the linguistic community. Also, there could be culturally-specific name-givers (cf. *Crat.* 390a), which relates to the culturally relative aspect of *nomos*.

[123] DK68 B5. This account of the evolution of speech in D.S. 1.8.3–4 is not attributed to Democritus by name, but by scholarly consensus (first suggested by Reinhardt 1912 and supported at greater length by Cole 1967, 60–69). DK68 B26 describes Democritus' theory of the evolution of language in more detail, including his connection to other thinkers like Pythagoras. Cf. Baxter 1992, 157ff.

[124] *P.Derv.* Col. XXII, 1–3. Boyancé 1941 ascribes a similar doctrine to the early Pythagoreans, given Pythagoras' statement that ὁ τοῖς πράγμασι τὰ ὀνόματα θέμενος is the "second-wisest" thing (Iamb. *VP* 82); Baxter 1992, 109–110 is skeptical of this interpretation and its application to the type of "name-giver" found in Plato's *Cratylus*.

[125] E.g., Re in Egyptian mythology (Pritchard 1969, 4: "he who created the names, the lord of the Ennead."); Adam in Hebrew tradition (*Gen.* 2:19–20: "gave names to all cattle, and to fowl of the air, and to every beast of the field.") Greek sources prior to Plato (*Phdr.* 247c) do not speak of gods as the inventors of language, written or spoken (Gera 2003, 113–122).

[126] E.g., Hdt. 3.38 where Darius shows the relative nature of Greek and Indian funerary customs (cf. Asheri et al. 2007, loc. cit. "The relativistic spirit of Ionian science permeates this chapter, reinforced—as it seems—by a more recent experience of sophistic antilogy.") On Herodotus and the wider debate between *nomos* and *physis*, see Nestle 1908, 14–28; Heinimann 1945, *passim*; Thomas 2000, 102–134.

Herodotus part, as we have seen that there are some Egyptian sources that do speak of listening to the cries of children for prognostic reasons. However, this is merely speculation; Herodotus remains the only direct source for the account, despite traces of others found in later sources and Herodotus' own unclear references. What is indisputable, however, is that contemporary Greek thought structures the entire experiment: not only its linguistic underpinnings, but also the idea that a truth about can obtained by controlled observation.

5.5. Conclusion

In some ways Herodotus is emblematic of the Greek view of experimentation. Within the larger project of the *Histories*, he shows the careful use of observation, measurement, and, finally, experimentation of the natural world and of humanity as part of that world. We see this especially in Herodotus' account of Egypt, which is itself unsurprising. To the Greek mind, the singular and paradoxical nature of the Nile was a well-established topic for natural philosophy. And with the linguistic experiment of Psammetichus, it would make sense to place an investigation of the antiquity of various peoples in the context of a civilization older than the Greeks, and therefore establish Herodotus' authority as a historian through his connection to these sources.[127] Whether or not Herodotus was indebted to Egyptian sources for this linguistic experiment is impossible to confirm, as we no longer possess any such sources. However, the form of thought on display in this famous passage is undoubtedly Greek given the close links to experiments surveyed in the other genres constitutive of *historia*. The complex, but controlled nature of the experiment is an excellent illustration of the sophistication of Greek scientific thought.

However, we also should not consider Herodotus as just another instance of *historia* when his work is for us the foundational source of *historia* in the 5th century. Unlike the treatises

[127] Cf. Moyer 2011, 83.

of the Hippocratic corpus and, presumably, those of the Presocratics and others which we have lost, Herodotus does not simply portray experimentation directly to his audience in neutral manner. Rather, he weaves them into his wider historical narrative, especially in Book II. And although Herodotean kings are known for their inquiry, Psammetichus, with his sympathetic characterization and historical interaction with the Greeks, provided the perfect vehicle for discussing contemporary Greek thought concerning the natural world—both that particular to Egypt and as a whole.

CHAPTER SIX: CONCLUSION

In late 5th century Athens—near the end of the period of the natural philosophers, doctors, and others surveyed here—a contemporary author lampooned the science of the day:

> ΜΑΘΗΤΗΣ: ἀνήρετ᾽ ἄρτι Χαιρεφῶντα Σωκράτης
> ψύλλαν ὁπόσους ἅλλοιτο τοὺς αὑτῆς πόδας.
> δακοῦσα γὰρ τοῦ Χαιρεφῶντος τὴν ὀφρῦν
> ἐπὶ τὴν κεφαλὴν τὴν Σωκράτους ἀφήλατο.
>
> ΣΤΡΕΨΙΑΔΗΣ: πῶς δῆτα διεμέτρησε;
>
> ΜΑ: δεξιώτατα.
> κηρὸν διατήξας, εἶτα τὴν ψύλλαν λαβὼν
> ἐνέβαψεν εἰς τὸν κηρὸν αὑτῆς τὼ πόδε,
> κᾆτα ψυχείσῃ περιέφυσαν Περσικαί.
> ταύτας ὑπολύσας ἀνεμέτρει τὸ χωρίον.
>
> ΣΤ: ὦ Ζεῦ βασιλεῦ, τῆς λεπτότητος τῶν φρενῶν.
>
> STUDENT: Just now Socrates asked Chaerephon how many of its own feet a flea could leap. For after one had bitten Chaerephon on his brow, it jumped to Socrates' head.
>
> STREPSIADES: How then did he measure it?
>
> STUDENT: Very cleverly. Melting wax, then taking the flea, he dipped both its feet into the wax, and then Persian slippers were stuck to the cooling [wax]. Taking these off, he measured the distance [i.e., from brow to head].
>
> STREPSIADES: Lord Zeus! The subtlety of his wit!

The author, of course, was Aristophanes and his takedown of the natural science, motivated by growing tensions between traditional mores and intellectuals, was the *Clouds.* Standing in for both sophists and natural philosophers was Socrates—an obviously incorrect and unfair

characterization, as Plato already had claimed.[1] But for our purposes, it is the type of investigation undertaken by this Socrates—the natural philosopher *par excellence*—that is remarkable. As Dover notes in his commentary, Strepsiades' immediate question is not "did Chaerephon know" but "how then did he measure it," or to put it another way, how did he investigate it.[2] Not only does he measure it directly, but he does so with a direct intervention into the situation proceeding in sequential steps (cf. the εἶτα… κᾆτα). This description fulfills much of the definition of an experiment.

Of course, the experiment and its subject are absurd because the parody is absurd, and should not be taken as exactly characteristic of contemporary scientific methods. But the caricature must have had some resonance with the audience for the parody to make any sense. This all points to the conclusion that we have moving toward: that experimentation was part of the methodological repertoire of fifth and early fourth-century science. More particularly, our argument has followed two parallel tracks. First, those interested in natural science were more open to the use of the senses and sense-data than typically has been allowed. And secondly, that this openness was borne out in their practice: they investigated nature using a large number of complex observations, including experiments.

Despite the obvious resonance to the modern scientific method, however, we have shied away from the claim that Greek experimentation was exactly the same as that in modern science or, an even more anachronistic proposition, that the Greeks practiced the modern scientific method, whereby theories are disconfirmed by failed experiment. However, in these concluding remarks, I also wish to suggest that Greek science acted as a source for later experiments during the Scientific Revolution—a period which has often been claimed as the beginning of modern

[1] Pl. *Ap.* 19c2.
[2] Dover 1968, xl-xli.

science.[3] Most specifically, many later experiments were inspired by or taken directly from the early Greek sources investigated here, thus suggesting a direct historical link between the beginnings of scientific experimentation as currently understood and Greek antiquity.

6.1. Early Greek Empiricism: Theory and Practice

Modern readers often reduce early Greek science to early Greek natural philosophy, a tendency which, while understandable enough, can miss much of value in other sources. This study has attempted to bring in other sources to shed light on the question of empiricism in early Greek science. Furthermore, since natural philosophy—much less natural science—was practiced during this time, but not yet conceptualized as part of *philosophia* proper, methodologies could pass beyond later generic boundaries.

Even in antiquity it was often said that early natural philosophers mistrusted the senses and were devoted to *a priori* reasoning rather than empirical fact finding.[4] However a closer look shows that a picture which is more complicated than this doxographical commonplace. While some philosophers—the Eleatics in particular—did allow reasoning to take precedence, no philosophers entirely dismissed the world of the senses. Indeed, how could they when they were endeavoring to explain the natural world which is only perceptible through the senses in the first place? Rather, many thinkers like the Milesians, Anaxagoras, and Democritus used the senses as a starting point from which reason could proceed to a more nuanced view of nature. This

[3] Cf. Henry 2002, 1–9.

[4] For later ancient statements of this position (admittedly expressed in later terminology and motivated by their own views), see p. 40, n. 4 and also S.E. *M.* 7.89: πρῶτοι δ’ ἔδοξαν οἱ ἀπὸ Θάλεω φυσικοὶ τὴν περὶ κριτηρίου σκέψιν εἰσηγήσασθαι. καταγνόντες γὰρ τῆς αἰσθήσεως ἐν πολλοῖς ὡς ἀπίστου, τὸν λόγον κριτὴν τῆς ἐν τοῖς οὖσιν ἀληθείας ἐπέστησαν; “The natural philosophers [starting] from Thales first thought to introduce skepticism about the criterion [sc. of truth]. For by condemning sense-perception in many cases as untrustworthy, they established reason as the judge of truth in things that are.” Much of this makes it into the modern “doxography” too, although more careful scholars are not so dismissive.

procedure was encapsulated by the methodological slogan put forward by Anaxagoras and commended by Democritus: ὄψις ἀδήλων τὰ φαινόμνα.[5]

Thus, there existed for the Presocratics the theoretical possibility for empirical engagement like experimentation. The immediate question then becomes: did they have an idea of an experiment and did they put it into practice? Again, we are hampered by the paucity of evidence that remains. But, even so, we do find signs for a positive answer to both questions. For the first, thinkers like Anaxagoras (and even Zeno) "mentally performed" thought experiments, or rather used reasoning that mimics a performed experiment to sharpen their intuitions on certain matters. Of course, this by itself is not a sign of empiricism, since their thought experiments could be and indeed were used to call our senses into question. Rather, it gives evidence that the idea or "model" of an experiment to test nature had taken root.[6]

On the other hand, while the Presocratics created thought experiments like Zeno's paradoxes which speak to philosophical issues even today, they were also keen observers and took part in performable experiments. The most famous case here is Empedocles' test with a clepsydra. Often its use as the "known" portion of an analogy has led scholars to discount it as an experiment. But when we separate the point of the experiment from the way it is set up, we see that is presents a structure very much analogous to scientific practice today.[7] And we should expect this conclusion since the history of sciences shows that there have been

As we move on to the Hippocratic corpus, even in the single treatise examined in this study, the evidence is even more compelling. Doctors had to pay more attention to the world around them, if only for the obvious reason that the (immediate) stakes are much higher in medicine than in philosophizing. Accordingly, the single author of the originally connected

[5] pp. 48–49.
[6] Section 2.3.3.
[7] pp. 56–62.

treatises *On Generation–On the Nature of the Child–Diseases IV* used a well-defined thought process of observation (up to and including experimentation) for use in analogical reasoning. Just as with the Presocratics, analogy was the reason *why* the experiments were performed, but it should not blind us to the structural complexity of the experiments themselves. These treatises also show a methodological awareness of this process in the use of technical language. This is especially important since most evidence of this sort was lost for the Presocratics, as *ipsissima verba* were turned into fragments and testimonia.[8]

Understandably, then, the author of these treatises shows an empirical interest in a remarkably wide range of fields. For instance, he makes many observations of plants—sometimes describing how they grow in artificial conditions. This is understandable given his analogical cast of mind; plants undergo many of the same processes and are easily observed and tested. And as Mendel would show with his peas over two millennia later, drawing analogies between plants and animals is not necessarily a scientific failure.

We also find several more complex observations rising to the level of an experiment within these treatises. Sometimes, these require the construction of an apparatus or the repurposing of an already existing one (cf. Empedocles' *clepsydra*). But, perhaps, the most intriguing case is his test using chicken eggs. Unable to open up a cadaver for reasons of religious purity, he observed the development of the chicken's embryo over regular intervals in controlled conditions and applied his findings analogically to human development. Again we see that analogy does not preclude the idea of an experiment and is not always fallacious: embryos of different animals do show similar structures, especially early in the development process.[9]

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[8] pp. 82–83.

[9] This phenomenon was first codified by the naturalist Karl Ernst von Baer (1792–1876) in a series of four eponymous laws (Hall 1999, 70)

No less impressive is the evidence for research into harmonics, especially since we are not treated to entire contemporary treatises as we are with the Hippocratic corpus. The early practitioners of this study, like the natural philosophers, left room for the investigatory use of the senses in their epistemology. This is understandable, as there was no clear demarcation between philosophers and *harmonikoi* in this era; figures like Hippasus fall easily into both camps. Although our sources are not contemporary, they all suggest a rich methodological debate between harmonic 'empiricism' and 'rationalism.' Moreover, the better-informed technical authors claimed that Pythagoreans, the 'rationalists,' also used their senses as initial starting point—mirroring what we see with natural philosophers.[10]

The use of the senses by Pythagorean harmonicists is also borne out by the reports of their experimental inquiries. While the miracle story of Pythagoras' discovery of the harmonic ratios is most likely a later invention, it contains echoes of earlier genuine material. More particularly, the use of stringed instruments like the *kanôn*, were used to experimentally prove the relationship between basic harmonic intervals (octave, fifth, and fourth) and numerical ones (2:1, 3:2, 4:3, respectively). Other, lesser known personages more securely took part in such experimental inquiries, most importantly the Pythagorean Hippasus of Metapontum, who used purpose-built bronze discs to show the relationship in a generalized way.

But, perhaps most impressively, the ancient descriptions of these experiments' results correspond exactly to the physical phenomena. As Kuhn noted, harmonics is one of the few sciences that did not undergo a "paradigm shift," and later understanding, while more nuanced, was still built upon the foundation laid by ancient researchers.[11]

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[10] Section 4.1.
[11] Kuhn 1977, 40 and see below pp. 184–185 as well.

While the foregoing three types of ancient intellectuals are more or less universally recognized as "scientists," it is only more recently that scientific material in other sources has been seriously studied. In the case of historiography, and Herodotus in particular, the work of Thomas spurred this reevaluation. However, her work does not treat experimentation at length. But, as we have seen, experimentation actually provides an excellent case to confirm her thesis: Herodotus shows many similarities to the thinkers above.

On the one hand, Herodotus' methodology is thoroughly empirical, just as we would expect from a practitioner of early *historia*. He prioritizes what he has observed personally, often drawing inferences from that. But, on the other hand, Herodotus' text differs from other scientific material of the time in its form: the results of his inquiry are not simply offered to the audience *in propria persona*, but mediated through the greater story that he is endeavoring to tell.

This can be seen especially in the figure of Psammetichus. His famous *bekos* experiment, while impossible in terms of the results described, shows a sophisticated awareness of precisely controlled tests in Greek inquiry of the time. We should not chalk this up to mere scientific naïveté on the part of Herodotus or his sources. It actually points to a problem in all scientific investigation: observation and experimentation do not simply provide us with correct results. Even today, initial questions can be mistaken and results can be misconstrued, until further investigation can uncover the problem.

Thus, we can see throughout all the genres which made up the *historia peri phuseôs* a qualified optimism in the information which we can glean from the careful use of our senses. In practice, this optimism allowed early Greek thinkers to incorporate observational evidence into their accounts. Often, these observations were not simply incidental—although they certainly

incorporated many apt, but passive observations as evidence for their theories—but were tests meant to produce a regularity in nature for the investigator to observe and report. These experimental descriptions have often been noted and dismissed as analogies, as indeed many were used analogically. But when we separate the purpose of the experiment from the experiment itself we see that, rather than poorly mimicking the modern scientific method, early Greek scientists performed structurally complex experiments to study nature, motivated by their own theoretical concerns.

6.2. Future Directions

There is of course much more that could be said about the development of empiricism in early Greek science that we have had to pass over here. For instance, we highlighted only a single (albeit important) Hippocratic treatise, and more evidence could be gleaned from the corpus (although again with the concomitant problems of dating). But since this study offers a snapshot in time, although, as we have argued, an especially important one, one obvious direction is to extend the boundaries. This can be done both by looking backward at the pre-scientific, pre-philosophical background and by looking forward in time to different phases of the history of science. Below, I briefly sketch some ways in which this temporal extension could be pursued.

6.2.1. The Pre-Scientific and Pre-Greek Background

In terms of the conception and investigation of nature, there is comparatively less work done on the period before the era of *historia*. In general, this background has two parts. First, there are the much older scientific traditions of Egypt and the Near East. Scholarly orthodoxy holds that this did not exercise much influence on Greek science prior to the Hellenistic period. After Alexander's invasions, for instance, Greek scientists were able to avail themselves of

astronomical data gathered over centuries, which transformed the practice of astronomy.[12] Nor was the influence limited to mere data—entire sciences (including pseudosciences like astrology and alchemy) were imported into the world of Greek thought during this time. But much of this attention on the non-Greek background of Greek science focuses on direct borrowing. If we also look at general features, as well as expand our source material beyond just technical scientific authors, we are very likely to find meaningful parallels, just as noted in this study's chapter on Herodotus.[13]

Secondly, before the age of *historia* lies the intellectual background contained in the Greek epic tradition. Although there is not a clear and consistent idea of *physis* this early in the Greek tradition, the epic tradition does deal with many of the epistemological themes that we find in Greek science.

In the epic world of Homer, just as for the Presocratic natural philosophers, the world presents humans with many deceptive appearances which can be uncovered by, among other things, a well-designed test.[14] For instance, at the end of the *Odyssey*, Penelope sets up a test of arms which unveils Odysseus' true identity (at Athena's bidding). Of course in Homer, these tests mainly concern situations and characters rather than the natural world, but still the idea that knowledge can be gleaned from performing a test is obviously a relevant predecessor to the emergence of experimentation in early Greek thought.

6.2.2. Greek Experiments Rediscovered

But perhaps the most compelling material lies not before the age of *historia*, but long after it. Throughout this investigation, we have been careful to approach Greek experimentation

[12] The first *unambiguous* evidence of the Greek use of astronomical data from another cultural context is later in Ptolemy, but Hipparchus also likely used them (Steele 2004, 338).
[13] See pp. 159–160; 166–168.
[14] Lesher 2009.

on its own terms, not as an imitation of modern experiments and presupposing the modern relationship to scientific theory. However, that is not to suggest that there is *no* relationship between the experimental impulse in early Greek science and the experimental method of later epochs. Indeed, it can be demonstrated that the converse is true: that early Greek experiments influenced later scientists, and especially those at the beginning of the Scientific Revolution. Although we can do no more than touch upon the afterlife of early Greek experimentation here, it is important to do so to show that the tests treated in this study are not of mere antiquarian interest, but are of crucial importance to the history of science.

Among the Presocratics, we saw evidence for experiments, both in thought and performed. The former, of course, have had a very long life. Space, motion, and "vagueness" were all subjects that found expression in thought experiments of the Presocratics, and ancient philosophical discussions on these matters are still taken seriously.[15] From a more empirical standpoint, the use of experimental apparatus by Empedocles and Anaxagoras to demonstrate the corporeality of air finds an intriguing parallel in the work of the physicist Evangelista Torricelli's (1608–1647) invention of the barometer which uses the same principle, as noted by Maria Timpanaro-Cardini.[16]

As we move on to the other fields, the parallels become even stronger. As we have seen, the Hippocratic author of *On the Nature of the Child* undertook an experiment to crack open chicken eggs throughout the course of the embryos' development, observing the features as they developed at regular intervals. We have also noted that Aristotle was impressed enough by this

[15] Cf., for instance, Sainsbury 2009, 4–21 on Zeno's paradoxes and their modern reception.
[16] Timpanaro-Cardini 1958. Toricelli's barometer was used not only to prove the corporeality of air (like Anaxagoras used the *clepsydra*), but also that air was a body that had weight, and that the surrounding air's weight pushing against the liquid in the barometer (in this case mercury) is the cause of *horror vacui*, rather than a natural motion into available emptiness. Thus Torricelli's points were quite novel, but his demonstration used an apparatus which works on the same principle as the *clepsydra*.

test that he recorded it.[17] But we also find the same test in anatomists many years later, notably by the discoverer of circulation William Harvey (1578–1657) in his 1651 *Exercitationes de Generatione Animalium*. In the very beginning of the treatise, entitled *ab ovo gallinaceo cur ducatur exordium* (roughly, "why the [treatise] begins from a hen's egg"), he states:

> nos autem ab ovi historia exordiendum duximus, tum ob praedictas caussas; tum etiam, quia inde certiora dogmata mutuamur, quae (utpote notiora nobis) quorumlibet animalium generationis contemplationi lucem afferent. Ova enim cum parvo continent, omnique tempore, & loco in promptu sint; facile ex iis observatu est, quaenam sint clara & distincta generationis primordia…[18]
>
> I, however, have thought that I should begin from the investigation of the [hen's] egg for the aforementioned causes, then also because from that source we may obtain more certain doctrines, which (inasmuch as they are more known to us) will shed light upon the study of the generation of any animals we wish. For eggs are obtained for a small price, and are readily available at any time or place. From these, it is possible to observe easily what are the clear and distinct beginnings of generation...

He then goes on to describe the embryo contained within the hen's egg in great detail day-by-day.[19] Nor was he the only modern to do so to follow in the Hippocratic author's footsteps; as Harvey points out that the universal availability of eggs and their cheap price make them ideal for repeated experiments by many different investigators.[20] And so we find the same experiment performed by other early modern anatomists like Volcher Coiter (1534–1576), Ulisse Aldrovandi (1522–1605), and Hieronymus Fabricius (1537–1619).[21] To their minds Aristotle was the ultimate source of this experiment. Yet, as we have seen, he was most likely predated by the

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[17] pp. 102–103.
[18] Harvey 1651, 1.
[19] Ibid., 44–70.
[20] *Cur ab ovo gallinaceo…iampridem dictum est: nempe, quod illud parvo veniret, & ubique obvium esset;…nobis in rem ipsam accuratius inquirere liceret, & alii dictorum veritatem facilius tutiusque explorare possent*; "Why [we begin] from the hen's egg…has already been said: namely, because it is sold for cheap and is available everywhere;…it is permitted for us to inquire more accurately into the same matter, and other are able to more easily and safely explore the truth of what has been said" (Ibid., 214).
[21] Zubov 1959, 230 lists these and other instances. Harvey 1651, 42–44 also goes over his predecessors' attempts (including Aristotle).

Hippocratic author of *On the Nature of Child*. Although now nameless, he thus stands at the head of a long line of anatomists.

No less important from the standpoint of the history of science was the harmonic testing inaugurated by early Greek thinkers. The ancient tradition attributed this above all to Pythagoras, even though, as we have seen, this attribution may be doubted. What cannot be doubted, however, is that among early Pythagoreans harmonic testing reached a very high level. And this sophistication is reflected in how their understanding served as a basis for later researchers.[22]

Galileo Galilei (1564–1642) in his *Dialogues Concerning Two New Sciences* noted that stretching a string with weights corresponding to the harmonic ratios in fact does *not* produce the correct notes; rather one needs to square the tension in order to create the correct intervals.[23] This was demonstrated by Marin Mersenne (1588–1648), who experimentally proved Galileo's points and who gave his name to the laws governing the relationship between a vibrating string's length, tension, and thickness and its frequency.[24]

Furthermore, there is little doubt that Mersenne used ancient sources as an inspiration (albeit not a positive one) for this empirical research. In his *Traité de l'harmonie universelle* (1627), he noted that Pythagoras was said to have discovered music by weighing the hammers "entirely contrary to the truth and experience" and that it was "surprising that Macrobius, Boëthius, and other ancients[25]…have been so negligent that they did not undertake a single

[22] On which, cf. Cohen 1984, 85–114.
[23] "There are three different ways in which the tone of a string may be sharpened, namely, by shortening [the string], by stretching it and by making it thinner. If the tension and size of the string remain constant one obtains the octave by shortening it to one-half, i.e., by sounding first the open string and then one-half of it; but if length and size remain constant and one attempts to produce the octave by stretching he will find that it does not suffice to double the stretching weight; it must be quadrupled; so that, if the fundamental note is produced by a weight of one pound, four will be required to bring out the octave" (Galilei 1638/1914, 100, tr. Crew and de Salvio)
[24] Dostrovsky 1969, 133; Cohen 1984, 101.
[25] I.e., the ancient authors who report Pythagoras' discovery of the harmonic intervals and his use of tension as a variable (cf. p. 117, n. 40).

experiment to uncover the truth [i.e., about their report]."[26] But, as we have noted, these ancient reports are later versions of a "miracle story" which drew upon much earlier material that *did* correctly describe the physical phenomena. In that sense, Mersenne's criticism is actually aimed at a later period than that under study here. And, although one should not push this point too far, Mersenne can even be said to have been part of the Pythagorean tradition—even while correcting it—in that Mesrenne made the seemingly simple point to perform the experiment as designed in these later ancient sources!

Not only in harmonics did the experiments which did not "work" and whose reported results conflict with modern understanding command interest long after antiquity. Infamously, various kings actually carried out the experiment of Psammetichus in order to figure out whether there was a primordial language of humankind and, if so, its identity.[27] The Holy Roman Emperor Frederick II (1194–1250) is reported to have isolated infants along with nurses in order to see "whether they would have the Hebrew language (which was the first [language]) or Greek or Latin or Arabic, or at any rate the language of the parents from whom they were born."[28] However, the author reports that the infants died before any result could be obtained.

A similar experiment is attributed to the Mughal emperor of India, Akbar the Great (1542–1605) and to the Scottish king James IV (1473–1513). The court chronicle of Akbar, the *Akbarnāma*, relates that the emperor undertook the same experiment as Psammetichus, locking children in along with mute wet-nurses and coming to the (correct) conclusion that without

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[26] "[Q]ue Pythagore inventa la Musique en remarquant la pesanteur de ces marteaux; ce qui est entierement contraire à la verité et à l'experience…[e]t certes je m'étonne de ce que Macrobe, Boëce, & autres ancients…onte esté si negligens qu'ils n'ont pas fait une seule expérience pour découvir la verité" (Mersenne 1627, 447 as quoted by Dostrovsky 1969, 151).

[27] Gera 2000, 92–95; Stevens 2016.

[28] *Volebat enim cognoscere, utrum Hebream linguam haberent, qu*[*a*]*e prima fuerat, an Grecam vel Latinam vel Arabicam aut certe linguam parentum suorum, ex quibus nati fuissent*; "He wished to know whether they would have the Hebrew language, which was the first, or Greek or Latin or Arabic or at any rate the language of their parents from whom they had been born." The account is from the 13th century *Chronicles* of Salimbene de Adam (Bernini 1942, 517).

linguistic stimuli, children cannot learn how to speak.[29] The children sequestered by James IV, on the other hand, were said to speak "guid Hebrew" spontaneously, although the chronicler is, rightfully, a bit incredulous of the claim.[30]

Here we are justified in asking whether, indeed, these rulers took Herodotus' text as a starting point and had these linguistic experiments performed or whether they are simply literary artifacts. On the one hand, the chroniclers' interpretation of the results (save for that of Akbar's experiment) is not correct. However, on the other hand, we should not underestimate our ability to have our expectations influence seemingly objective evidence. A full answer cannot be attempted here, but we should note that even in antiquity there was a link between absolute power and experimentation on political subjects.[31]

It has traditionally been common to see the Scientific Revolution as a disavowal, or at least a radical reevaluation, of science inherited from the classical past. In no small part this idea is due to a conscious process of rejecting the ancients by scientists of that epoch like Bacon.[32] Yet, as this survey of experiments found in the early sources of *historia* has shown, important continuities exist. The earliest period of Greek science actually acted as a great store of inspiration for much later inquiry into nature as descriptions of experiments in Greek sources were re-interpreted in different historical and theoretical contexts. Furthermore, this productivity is not surprising, given the widespread and quite advanced idea of experimentation that we find in the sources for early Greek natural science.

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[29] Moosvi 1994, 90–91. The chronicler makes this experiment one of Akbar's own design, but the structural similarities to that contained in Herodotus are highly suggestive.

[30] "The king also caused tak ane dumb voman, and pat her in Inchkeith, and gave hir tuo bairnes [i.e., children] with hir, and gart furnisch hir in all necessares thingis perteaning to thair nourischment, desiring hierby to knaw quhat languages they had when they cam to the aige of perfyte speech. Some sayes they spak guid Hebrew, but I knaw not by authoris rehearse [i.e., report], etc." (Lindsay 1814, 249–250).

[31] I have in mind the case of human dissection (vivisection?) in Ptolemaic Egypt especially (cf. p. 79, n. 45).

[32] As one of many examples cf. *Novum Organum* 122: *rerum enim inventio a naturae luce petenda, non ab antiquitatis tenebris repetenda est*; "for the discovery of things must be sought from the light of nature, not recalled from the darkness of antiquity" (Bacon 1620/1900, 328).

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