

Explanation through Analogical Reasoning
in Aristotle's Natural Science

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Explanation through Analogical Reasoning in Aristotle's Natural Science

I. Introduction: Analogical Reasoning and Explanation in Aristotle's Science

Analogy features prominently in Aristotle's writing; yet, the scholarship rarely treats Aristotle's scientific use of analogy—or its use in any area—apart from its literary merits. The few works that do discuss analogy in Aristotle's scientific writings tend to make two simple characterizations. The first, the weaker reading, sees analogy as serving a didactic function only and as carrying no explanatory force. It takes analogy to be something along the lines of an example or illustration, something that supports or embellishes the argument or explanation, while not being integral to Aristotle's investigation or causal accounts. On this view, Aristotle uses analogy to comfort or instruct the reader rather than as part of his methods of inquiry.¹ The second, which offers a somewhat stronger reading, considers analogy to be a heuristic device towards the generation of genuine causal explanations. On this reading, analogy functions as something that guides Aristotle's investigation and discovery of an explanation but is not itself part of that explanation and, therefore, does not carry any explanatory force itself.² No doubt, both didactic and heuristic uses of analogies are part of Aristotle's writings and are quite common forms of analogy in his corpus. As I argue in the present essay, however, there is a third, largely overlooked type of analogy at play in Aristotle's scientific treatises, namely, reasoning by analogy. While didactic analogies illustrate a phenomenon that is explainable in other ways and heuristic analogies can help lead one to an explanation, in analogical reasoning, the analogy itself functions as the explanation. This makes reasoning by analogy a potentially powerful method of scientific investigation.³

¹ See, for instance, Sedley, ch. 6, § 2; Johnson 126 and *passim*; Broadie; Lennox 133–4, 184ff., 230–2.

² See, for instance, Leunissen 115–21, 130; Falcon and Leunissen.

³ M. Hesse, in her "Aristotle's Logic of Analogy," offers the only extensive discussion of the relevance of analogy as explanation in Aristotle's scientific investigation. Analogies, she contends, are useful scientific tools of inference

Analogical reasoning, as it concerns the present inquiry, is a kind of reasoning according to which one pulls certain causal elements from a source object, which is more familiar and better understood, and applies them to, or maps them onto, a target object, in the hopes of explaining the target through its similarity to the source. Reasoning by analogy is, here, a mode of causal inference. It works by postulating the existence of an ontological causal correspondence between certain elements of the objects of the two domains in question, such that the causal explanation that is available for the well-known source domain is transferable to the lesser-known target domain. That what is invoked in the postulation is an *ontological* causal correspondence is key, since analogical reasoning aims at causal explanation beyond stating the mere epistemic reason why. Generally, the two domains of the analogy must be significantly different in at least one respect (since otherwise the two domains would be identical in type), although the degree of difference may vary.

For the argument of the present essay, a basic understanding of the structure of analogy is sufficient. Analogy is a four-term comparison of the typical form A is to B as C is to D, with the A and B side being a familiar source domain or process and the C and D side being an unfamiliar target domain or process. What analogical reasoning has beyond the typical four-term analogy structure is the characteristic of allowing one to draw inferences. These inferences are initially directly from the A and B relation to the C and D relation, but they can extend further, if the analogy allows for such elaboration. This involves the supposition of sufficient similarity in the relevant ways between the source (the familiar side, A and B) and the target (the less familiar side, C and D). In the sort of analogical reasoning with which the present essay is most concerned—cases in which analogical reasoning contributes to Aristotle’s scientific

that Aristotle effectively employs. Further, she argues that this may be his most important and lasting contribution to science.

explanation—the affinities between source and target are principally causal. There is much discussion today around how to assess analogical affinity properly and determine appropriate inferences; however, the present essay concerns itself with the way Aristotle uses analogical reasoning in practice, since he leaves the matter untheorized.

The scholarship has often overlooked, misunderstood, and miscategorized this type of analogical reasoning; yet, Aristotle employs it to great effect in his works of natural science. Aristotle's causal language is rich, and his explanations are not confined to those consisting only of demonstrations. Aristotle especially turns to analogical reasoning when he is at the limit of empirical observation and where other types of explanation or other methods to arrive at explanations fall short. This is also why the type of analogical reasoning I am interested in appears relatively frequently in Aristotelian treatises that deal with empirically underdetermined domains, such as embryology.

Cases of analogical reasoning are those in which the causes postulated through the analogy were otherwise not immediately available in what is observable. Since the collection of helpful empirical data in that domain is usually either impossible or unlikely to happen, Aristotle sorts out the material and tries to explain it by way of analogical reasoning. Although Aristotle does not discuss it explicitly and does not develop a formal account of analogical reasoning in his scientific writings, the present essay maintains that analogical reasoning (and its key component of ontological causal inference) serves as explanation in a way that is already evident in Aristotle's works of natural science. Aristotle uses analogical reasoning to explain a phenomenon that is mostly hidden from empirical investigation. He does so by identifying a phenomenon that is well known and open to empirical investigation and that he thinks is somehow—structurally or causally—similar to the unknown domain. By identifying a relevant

source domain, it is possible—by drawing out the analogy between the target and the source domain—to explain the target domain. However, in doing this, the analogy itself *is* the explanation—there is nothing further to offer, nothing that would yield an explanation independent from the analogy. In lieu of relying on direct observation, analogical reasoning provides Aristotle with a way to continue his scientific investigations and to provide causal explanations.⁴

While Aristotle has his own theory of analogy (*analogia*), it is not immediately germane to the discussion of analogical reasoning, besides providing the four-term structure already explicated.⁵ The present essay's interest lies in the extent to which Aristotle uses analogies to infer causal similarities and thereby constitute explanations. Does the analogy that Aristotle uses as part of his scientific reasoning lead to a full-fledged scientific explanation or to something lesser, such as a mere reduction of puzzlement, or is it merely a dialectic move and something that does not carry any scientific significance at all? Given the richness of Aristotle's scientific treatises, it is likely possible to find examples of each of these cases. The thesis defended in this paper, however, is that there are a significant number of instances where analogical reasoning not only leads to the generation of a full-fledged scientific explanation, but where the analogical reasoning *itself* provides the only scientific explanation possible given the material at hand. Analogical reasoning yields or constitutes explanation insofar as it locates causes and spells them out in a way that squares with observations and follows the empirical trail, so to speak. This use

⁴ A loose characterization of Aristotle's so-called scientific method is useful to keep in mind: something needing explanation is identified (e.g. an *aporia*); observations, if available, are made and information collected (the stage of *historia*); correlations are expounded (if necessary, reasoning by analogy occurs here), and, from this, comes an explanation or, if nothing else, some kind of account that is supposed to reduce the puzzlement (the stage of *aitiai*).

⁵ That said, there may be deeper connections among Aristotle's theory of analogy (*analogia*), what it means for something to be an analogue (*analogon*), and analogical reasoning. Especially fruitful in connecting Aristotle's theories and other practices to analogical reasoning are Aristotle's use of homology (*homologia*), induction (*epagôgê*), and reasoning by likeness (*homoiotês*). The appendix of the present essay briefly explores each of these in an effort to lay the ground for future work.

of analogical thinking is not at all a weakness of Aristotle's method; rather, his appeal to these analogies is one of his greatest strengths and one of the elements of his science that has most endured. Moreover, it is a testament to his dedication to empirical knowledge and faith in the uniformity of nature and of the four underlying causes.

Section II introduces the sort of analogy under discussion and begins with an exemplary passage of analogical reasoning. The section also identifies what the present essay takes to be the characteristics of Aristotle's reasoning by analogy in scientific contexts. In the remainder of the present essay, I use these criteria when discussing specific instances of analogical reasoning. Section III gives the bulk of the evidence: it treats Aristotle's solution of puzzles (missing explanations) by way of analogical reasoning in specific passage from *De Generatione Animalium*. Section IV shows the wide-ranging scope of analogical reasoning: this section identifies one source domain, cooking, that is very rich and which Aristotle applies to a variety of targets. Evidence for this section comes from the *Meteorologica* and *De Partibus Animalium*. In this section, the emphasis is on the way in which many cases of Aristotle's scientific explanation, even when they are not directly cases of analogical reasoning, are underpinned by general inferences from the analogy between craft and nature, in particular the inferences about vital heat from the analogy to cooking. Thus, Aristotle does not have to state the analogy explicitly in every instance, since he has this host of analogical material on which to draw as needed.

II. Seeking Ontological Causes: Characteristics of Analogical Reasoning

In order to help differentiate cases of reasoning by analogy from those in which Aristotle uses analogy for discovery only (i.e. heuristically) or simply as an illustration or exemplification

(i.e. didactically), this section analyzes closely one seminal instance of analogical reasoning found in *De Generatione Animalium* II 4 739^b20–6. This example is valuable for fleshing out the characteristics of analogical reasoning. In this passage, Aristotle is discussing the process of fertilization in terms of how the male and female contribute to forming a new organism during insemination and how embryogenesis begins:

the material secreted by the female in the uterus has been fixed by the semen of the male (this acts in [almost (*paraplêision*)] the same way as rennet acts upon milk, for rennet is a kind of milk containing vital heat, which brings into one mass and fixes the similar material, and the relation of the semen to the menstrual blood in the same, milk and the menstrual blood being of the same nature)....⁶

The first hint in this passage is the language. On its own, *paraplêision* is insufficient to establish reasoning by analogy. *Paraplêision* is ambiguous and could mean either *in almost the same way as* or *in virtually the same way as*. But what *paraplêision* does do is help signal that Aristotle is bringing together two otherwise separate objects in the form of a comparison. A further contributing factor is the causal language, specifically regarding vital heat. Together, these two factors are helpful to alert the reader to a possible case of analogical reasoning.

The parenthetical explanation in the passage comes from the process of fertilization being almost the same as the setting of cheese. The analogy, at its core, is this: rennet is to the coagulation of milk as male seed is to the fixing of female secretion. Aristotle compares the cause in the solidification of curds to the cause in the solidification of the embryo, with the result that the analogy evinces rennet as performing almost the same efficient causal role as male semen. The causal connection is, first, that both rennet and male semen have a small amount of

⁶ The *paraplêision* is untranslated (omitted without note) in the standard edition of the text, but deserves reinsertion here.

liquid that has within it the heating power to set and solidify another specific material, and, second, the similarity of the materials with which the heat interacts.

At first glance, one can see that the image of cheese making illustrates and visualizes Aristotle's point. Yet, the analogy exceeds the function of exemplification, insofar as the analogy has helped sort out the puzzle of how it is that fertilization in living beings occurs. Aristotle could not have directly observed the fertilization process—at least, he would not have been able to see it in action. In order to generate an explanation, he needs another area of knowledge that he can apply to this particular case. The source domain is introduced by analogy, and, by identifying a relevant analogy, he essentially provides the explanation. Given that there is only limited empirical evidence about the phenomenon he is trying to explain, his ability to describe and explain the sort of mixing and fixation he thinks is at work in fertilization at all depends on being able to identify an analogy between a sufficiently relevant causally familiar process and the process that is the subject of the investigation.

One might object that Aristotle does have sufficient data to form an explanation and, thus, that the analogical passage is only illustrative. The likely candidate for providing such information is the famous experiment of the Hippocratics in which the observer opens fertilized eggs over multiple days. Thus, say those objecting, Aristotle could have observed the setting of the embryo in the way he describes. But this objection does not undermine the thrust of my point, since Aristotle cannot have observed *directly* whatever is actually doing the solidification (the process of fertilization) as it is occurring, only shortly after it has occurred. Nor could he determine from the eggs the elements responsible for the process just from this experiment. An explanation would still be absent. Therefore, while the experiment does provide Aristotle with more data than it may have seemed at first, it does not elide the need to infer based on analogy.

Aristotle aims at giving a causal account that relies on the action of vital heat as it also exists in the realm of cheese making.

Aristotle is, in this passage, engaged in analogical reasoning that aligns two causal processes to the effect that one explains the other. With respect to efficient cause and material cause (the formal cause is different in both domains), in both cheese making and fertilization, the causal functions are alike. In these processes, vital heat is acting on the curdling material, with the semen and rennet containing the sources of heat and the milk and menstrual material being the same curdled material. The materials are, at base, of the same sort, namely, of the kind subject to this particular solidification through the action of vital heat. Thus, the analogy is used to reason from a familiar case of curdling material and vital heat to one that is much less phenomenally familiar.⁷ It is not just that fertilization and cheese making are alike enough to give the reader a clear picture; rather, the similarity (sameness of the causality in question) established allows the elaboration of a point beyond what an illustration would allow. Here, Aristotle goes on to say, of both processes, “the more solid part comes together, the liquid is separated off from it, and as the earthy parts solidify membranes form all round it” (GA.II.4.739^b25–7). This is a continuation of the reasoning established in the analogy, a

⁷ Throughout *De Generatione Animalium*, Aristotle repeatedly refers to rennet’s coagulation of milk. For further analogical reasoning involving rennet and milk see, for instance, *De Generatione Animalium* I 20 729^a11–5, IV 4 771^b18–27. Many of the analogies in Aristotle’s biological works roughly follow examples of analogy already found in the ancient medical tradition recorded in the Hippocratic texts, insofar as Aristotle uses analogical reasoning to get at the explanation and bases the comparisons on a material similarity. In Aristotle, we find this throughout *De Generatione Animalium* (as discussed in the present and following sections), as well as in the repeated broad analogy to cooking and concoction (as discussed in section IV). Besides retaining their material-laden language, Aristotle also retains the sense of causal transference from the source to the target. In the same vein, Aristotle owes much to Archytas’s notions of analogy—namely, a wider and more causally near use than might otherwise be available—as evidenced in the passages from the *Topica* cited in the appendix, which are the very same analogies Archytas uses and with the same operating principle, definition by the use of similarity (see Huffman 489–507 for passages and discussion).

continuation that allows him to pursue his main explanation of *De Generatione Animalium* II 4, how the process of embryogenesis begins.

It is worth stressing how deeply founded is the analogy between the two processes—that is, the degree to which one description of the mechanics and material suffices as a causal account for both. The way Aristotle draws the analogy, the efficient causal processes are identical—or very nearly so—just operating on different types of material. On the general level, the descriptions of the actions of the materials involved are alike. This is why Aristotle thinks the explanation for both processes must be alike. In other words, if one does not specify the ratio of the elements, then there is nothing to differentiate the causal processes (at least given the information at hand). At the most basic chemical level—until one specifies the exact substances, not their elemental type—the processes of curdling cheese and forming embryos are the same.

We now have the necessary information to lay out the characteristics of Aristotle's analogical reasoning. The first key consideration is that of observability. In analogies where the phenomena of the source and target are both observable, it is plausible that the investigator reached the elements in the analogy by means other than analogical reasoning, namely, through direct empirical study. In this case, one could take the analogy as an illustration, one that gathers its strength from the comparison of two separately determined objects. Thus, the first characteristic of analogical reasoning: the analogy aims at explaining something that involves unobservable factors. Further, since analogical reasoning yields, as in the above instance from *De Generatione Animalium* II 4, a full-fledged scientific explanation, the analogy must involve causality; specifically, the analogical passage must be postulating a cause for the phenomenon picked out in the target domain. This postulation of a causal relation is the second characteristic of analogical reasoning in Aristotle's science. If the first consideration is useful for

distinguishing between analogical reasoning and analogy as illustration or exemplification (analogy used didactically), the third consideration aids in distinguishing between cases of analogical reasoning and cases of heuristic use of analogy. To wit, in instances of analogical reasoning, not only must the analogy involve causes, as specified by the second consideration, but these causes must be explained at the ontological level (although the analogy may also involve epistemological causes or result in an epistemological explanation in addition to an ontological one). The fourth characteristic is straightforward: the investigator must make an inference from the familiar to the unfamiliar; that is, it cannot just be that the familiar provides a model for thinking about the unfamiliar. Substantial inference is crucial. The inference is that of the causal elements—the affirmation of the hypothesized causal similarity—from the causally familiar to the causally unfamiliar.

These characteristics afford a further chance to distinguish analogical reasoning from the heuristic use of analogy and from the merely illustrative use of analogy. In the case of the heuristic use, Aristotle often appeals to reasonableness when imaging a comparison. Aristotle also tends to state mere reasons why, as opposed to offering causal explanations. While the ontological cause could later be determined in addition to this, it would require further observation. In cases of analogical reasoning, Aristotle states the similarity outright, introduced, often, with *paraplêsiôn*, sometimes coupled with *hôsper*, to indicate resemblance. An excellent example of heuristic analogy comes in *De Caelo* II 12, in which Aristotle invokes the comparison of the movement of the wayward stars to the movement of animals. As for the illustrative use of analogies, Aristotle's arguments allow the audience to arrive at the conclusion he has already reached by means other than the analogy; thus, he is using the analogy as an example to make the conclusion more intelligible or more accessible. Major examples of this are

some instances of the analogy between art and nature, such as that used in *Physica* II 8, where Aristotle makes multiple appeals to craft in order to illustrate the teleology of nature and concludes with the lines, “If, therefore, purpose is present in art, it is present also in nature. The best illustration is a doctor doctoring himself: nature is like that” (199^b26–30). Reasoning by analogy is distinct from both the heuristic and illustrative use: when Aristotle is in the process of reasoning by analogy, he uses the analogy as empirical evidence. While the relevant part of the target is not observed (hence, the need for the analogical inference), the subject is, nonetheless, something that is observable in principle. Besides the above analogical reasoning inferring from rennet and milk to semen and menses, there are many other examples, some of which I will discuss in the remaining sections.

III. Analogical Reasoning in *De Generatione Animalium*: The Evidence

The purpose of the present section is to provide evidence for the argument that there are instances of analogical reasoning in Aristotle’s natural science—instances in which the analogical reasoning itself provides the scientific explanation Aristotle seeks. The evidence takes the form of three representative uses of this kind of analogical reasoning.

One piece of evidence of analogical reasoning comes in *De Generatione Animalium* III 2 753^a16–29. Aristotle explains the process of eggs spoiling in an analogy that compares it to wine souring:

it is in the hot season, as we should expect, that the eggs are more apt to be spoilt and the so-called “uria” are produced; for just as wines turn sour in the heats from the sediment getting stirred up (for this is the cause of their being spoilt), so is it with the yolk in eggs, for the sediment and yolk are the earthy part in each case,

and that is why the wine becomes turbid when the sediment mixes with it, and the like applies to the eggs that are spoiling because of the yolk.

The key elements of the causal story are heat, the earthy elements, agitation, and spoilage. Heat agitates the earthy element that is the sediment in the wine, which spoils the wine. That is, Aristotle compares wine spoilage to egg spoilage in a way that identifies the same causal process: heat agitates the earthy element that is the yolk in the egg, which spoils the egg. The only substitutions in the elements of the analogy are the egg for the wine and the yoke of the egg for the sediment of the wine. The causal comparison is quite strong, and Aristotle makes it in the framework of strict analogy.

The case is one of analogical reasoning and fits the characteristics that I identify above, namely, that the phenomenon in need of explanation cannot be observed very well, that the analogy involves causality, that the explanation identifies real, ontological causes as opposed to mere epistemic ones, and that there is an inference from a causally familiar domain to causally unfamiliar domain. As for observability, the phenomenon of egg spoilage is unobservable as it occurs inside the shell, while wine spoilage is more easily observable and, this is key, much more causally familiar to Aristotle and his audience. Note that whether the causality Aristotle attributes to the familiar case is correct is not of great importance here; rather, what demands attention is the transfer of this causal explanation to the unfamiliar case. The major culprit for the lack of empirical evidence is the impossibility of his observing the stirring up of yolky sediment in the egg. As for locating the cause, Aristotle seeks to explain egg spoilage, since the reason for the spoilage is not readily apparent. As for inference, there are causal inferences drawn: wine spoilage is more familiar, the cause being readily available in what is observable. Lastly, as for the nature of the causes, the causes at which Aristotle aims are not merely epistemological, but

are also ontological. Notice further that there is no appeal to the reasonableness of the inference or an introduction that expresses doubt about the possibility of explaining the phenomenon at hand, as would be expected or characteristic in a heuristic use.

Let me, in support of my thesis, discuss two further paradigmatic examples of analogical reasoning in *De Generatione Animalium*. As I mentioned in my introduction, this is a treatise in which we especially expect to find such cases, since embryology is an empirically underdetermined domain relative to the other domains of natural investigation. The first passage of interest is *De Generatione Animalium* III 4 755^a13–26. Aristotle compares the rapid growth of certain eggs to the similar growth of what we now know as yeast:

The growth of the egg is like that of a grub, for those animals which produce grubs give birth to a small thing at first and this grows by itself and not through any attachment to the parent. The reason is similar [*paraplêsiôn*] to that of the growth of yeast, for yeast also grows great from a small beginning as the more solid part liquefies and the liquid is aerated. This is effected in animals by the nature of the vital heat, in yeasts by the heat of the juice commingled with them. The eggs then grow of necessity through this cause (for they have in them a yeasty residue), but also for the sake of what is better; for it is impossible for them to attain their whole growth in the uterus because these animals have so many eggs.

Note, first, that just as in the milk and rennet example from *De Generatione Animalium* II 4 that I discuss above, Aristotle uses *paraplêsiôn* to introduce a comparison. While the above noted caveats to the usage of *paraplêsiôn* still apply, the occurrence of this word supports the fact that Aristotle introduces an analogy. While both the source (yeast growth) and the target (rapid egg

growth) are, in many ways, observable, the mechanism that causes the rapid expansion of the number of egg is not. The motivation for the comparison is that Aristotle seeks the causes of the rapid growth of certain eggs, and the explanation is not immediately apparent from the observable instances. Thus, the analogical case of yeast functions to provide the causal explanation, namely, by indicating the action of the material: the “solid part liquefies and the liquid is aerated.” While, in stating that the process happens of necessity and for the best, Aristotle includes both a material and a teleological explanation, by introducing this analogy, he also identifies the efficient cause of the phenomenon, namely, the specific action of the heat of the juice. This is also, then, an inference of causality from the familiar to the unfamiliar: from the already explained action of heat on the yeast, the liquefying of the solid part and the aeration of the liquid part, Aristotle infers that the same process is happening in the case of the eggs, a case that was unexplained before this inference. This instance of analogical reasoning is in line with the rennet and milk passage analyzed in section II and does not deviate from the main points: the causal affinity between source and target is based on an equality of the underlying causes of heat and similar material composition. While this material focus testifies to the depth of the analogical similarity, there are other sorts of examples as well.

In *De Generatione Animalium* V 7 787^b20–788^a10, Aristotle uses analogical reasoning to yield an explanation, but this time the causal agent has nothing to do with vital heat and its action on conglomerations of materials. In this passage, Aristotle uses mechanics as his source domain and draws an analogy between weaving and the tension of fibers to vocal cord slackening:

All animals when castrated change to the female character, and utter a voice like that of the females because the sinewy strength in the principle of the voice is relaxed. This relaxation is just as if [*paraplesia*] one should stretch a string and

make it taut by hanging some weight on to it, as [*hôsper*] women do who weave at the loom, for they stretch the warp by attaching stone weights to it. For in this way are the testes attached to the seminal passages, and these again to the blood-vessel which takes its origin in the heart near the organ which sets the voice in motion. ... If the testes are removed the tension of the passages relaxes, as when the weight is taken off the string or the warp; as this relaxes, the principle which moves the voice is loosened in the same proportion. This, then, is the reason why the voice and the form generally change to the female character in castrated animals; it is because the principle is relaxed upon which depends the tension of the body....

Here, as elsewhere, there are linguistic signals: this time, *hôsper* (just as) accompanies *paraplesia*, giving us a hint to examine the case more carefully. Obviously, the phenomenon Aristotle wishes to explain, the voice change of male animals due to castration, is unobservable in its mechanism; what is unobservable is that which connects the castration to the voice change. Where his empirical purchase runs out, stopping at the correlation of castration and voice change, Aristotle seeks, by way of analogical reasoning, a causal account of the changing of voice to the female state in males after castration. One might insist, on the contrary, that, since Aristotle states the causes before giving the analogical components, what follows in the text is an illustration. However, it is apparent that the unobservability of the slackening corresponding to voice change prevents this line of argument. Aristotle goes on to infer causality from familiar to unfamiliar, from the loom and what happens in weaving to the castration process and slackening. And this causal explanation aims at the ontological: it provides an account of the way in which

castration affects voice change. In both source and target, the same principle of bodily tension is active and then made inactive.

Unlike the examples canvassed so far, this passage of analogical reasoning does not involve an organic to organic inference (sc. cheese making and fertilization, wine spoilage and egg spoilage, and yeast growth and egg growth). Additionally, while Aristotle reasons by material similarity, he discusses a different active cause than vital heat, namely, the principle of tautness. He also grounds his explanation in a general background of mechanics. These points of difference reveal a more significant similarity: much more important than organic to organic analogy or vital heat is the fact that this weaving analogy is an analogy between craft (here, mechanics or the inorganic) and nature (the organic), which has a long history in ancient Greek thought and is widely used by Aristotle. Moreover, we can understand the other examples cited in the present essay from this perspective of the analogy between craft and nature (sc. cheese making, wine making, and crafts that use yeast). It is with this broad craft analogy of Aristotle in mind that analogical reasoning takes on wider import: reasoning by analogical association lies at the heart of Aristotle's causal account and explanation of nature via craft.

IV. The Importance of Inferences from Craft to Nature: The Cooking Analogy in the *Meteorologica* and *De Partibus Animalium*

The analogy between craft and nature is one of the most pervasive, most important, and most talked about analogies in the Aristotelian corpus; yet, it is only ever discussed for its educational purposes. What I want to show, here, is that, in some cases, the analogy to craft is also used for explanatory purposes. The rich source material the craft analogy provides—in cheese making (*GA*.II.4.739^b20–6, the case of fertilization), wine making (*GA*.III.2.753^a16–29,

the case of wine souring and eggs spoiling), baking or brewing (*GA*.III.4.755^a13–26, the case of yeast and egg growth), and weaving (*GA*.V.7.787^b20–788^a10, the case of castration and vocal cord slackening), as we have seen already—offers much for individual cases of analogical reasoning, individual instances where observation no longer furnishes adequate information for Aristotle to generate explanations just on the basis of that. But this is not the end of its importance. The craft analogy also appears in many places that do not immediately fit the criteria of analogical reasoning used as explanation, such as the appeal in *De Generatione Animalium* II 6 743^b18–25 to nature being like a painter and drawing the outline of the organism before filling it in with the internal organs.⁸ Nevertheless, Aristotle does, at times, appeal to craft as an explanation of nature in a more general way that is consistent with analogical reasoning. One such appeal comes in the *Meteorologica* IV 1–3, which provides a source for Aristotle’s widely used cooking analogy, but here used in a non-embryological context. The importance, here, lies in the fact of how many meteorological phenomena can be explained by analogy to phenomena that involve cooking. The way in which Aristotle talks of concoction in *De Partibus Animalium* provides further evidence.⁹

Aristotle begins the fourth book of the *Meteorologica* by stating the sorts of changes the elements and their properties produce and their division into the active, the hot and the cold, and the passive, the dry and the moist. In line with my comments above about the similarity (or identity) of types of causal processes—for instance, recall how egg spoilage and wine souring

⁸ The full comparison of nature to a painter runs as follows: “The upper half of the body, then, is first marked out in the order of development; as time goes on the lower also reaches its full size in the sanguinea. All the parts are first marked out in their outlines and acquire later on their colour and softness or hardness, exactly as if nature were a painter producing a work of art, for painters, too, first sketch in the animal with lines and only after that put in the colours.”

⁹ While the English *cooking* and *concoction* refer to the same Greek *pepsis*, generally, throughout the present section, *cooking* is used to refer to the source domain and *concoction* is used to refer to the casual explanation that Aristotle transfers.

are indistinguishable without specifying the material, since the cause of both going bad is the working up of the earthy part (differentiated as yoke and sediment) by heat—Aristotle indicates the importance of the ratios of these materials (elements) for differentiating different sorts of objects. As he puts it, “Unqualified natural becoming is a change introduced by these powers into the matter underlying a given natural thing when they are in a certain ratio; and matter is the passive qualities we have mentioned” (378^b33–379^a1). At this point, Aristotle also discusses the case where the active principles are insufficient, inconcoction, the failure to heat the material properly, and uses language that refers to imperfect boiling.

In the second chapter, Aristotle introduces the successful sort of action on the passive; this process is concoction, which is due to heat: “Concoction is a process in which the natural and proper heat of an object perfects the corresponding passive qualities, which are the proper matter of any given object” (379^b18–20). Recall that most of the examples of analogical reasoning that constitute explanations in *De Generatione Animalium* identify this vital heat as the efficient cause of the phenomenon to be explained. The activity of vital heat is not directly observable, so it makes sense that this is an area where Aristotle uses analogies frequently. The classes of vital heat that make up concoction are established by analogy—Aristotle identifies species of concoction based on various methods of cooking: “We must recognize that the things are not properly denoted by these words: the various classes of similar objects have no names universally applicable to them; consequently we must think of the species enumerated as being not what those words denote but something like it” (379^b14–6). In the form Aristotle gives it here, he has obscured the analogical nature of the comparison. In its fully spelled out form, the instances of analogical inference from known cooking to unknown causal action (the action of the cause of vital heat in general, the concoction) become clear. Thus, cooking (the original

meaning of concoction) acts on various material cooked as vital heat (what Aristotle describes as concocting) acts on various material heated.

This is not a simple analogical inference either. The difference is not just in sorts of material heated—solid, liquid, sinew, and so on—but there are related differences in the sort of concocting that occurs. That is, just as cooking is divided into various sorts—ripening, boiling, broiling—so too is concoction; inconcoction, which is due to excess cold, is similarly differentiated, respectively into rawness, parboiling, scorching (379^b11–3). This is to say, the types of concoction are identified and described—their ontological character pinpointed—based on the categories and action of causes in cooking. Concoction (*pepsis*), as has been said, is the vital heat acting in proper natural proportion (379^b18–20). Aristotle states further, “Things that undergo a process of concoction necessarily become thicker and hotter; for the action of heat is to make things more compact, thicker, and drier” (380^a4–6).

The third chapter of the book contains further development of the species of concoction. While ripening (*pepansis*) obviously applies to fruit, Aristotle notes the same causal process occurs elsewhere: “the general character of the process [of ripening] being the same ... the word is applied by an extension of meaning” (380^a4–6). Ripening in this extended meaning gleaned from analogical inference (although no longer used strictly in the form of an analogy) is described as follows: “everything that ripens turns from an airy into a watery state, and from a watery into an earthy state, and in general from being rare becomes dense. In this process nature incorporates some of the matter in itself, and some it rejects” (380^a24–7). Boiling (*hepsêsis*) also has extended analogical meaning. While boiling is, generally, “a concoction by moist heat of the indeterminate matter contained in the moisture,” Aristotle notes, “the word is strictly applicable only to things boiled in the way of cooking” (380^b12–4). Nevertheless, the extent of material that

is boiled is great; food, drink, medicine, and others all might be acted upon by boiling (380^b36–381^a2). Even though Aristotle limits the scope at first, he concludes the definition of boiling with a very strong statement of the similarity between the craft (cooking) cases and the natural (concoction) cases: “the process is the same in an artificial and in a natural instrument, for the cause will be the same in every case” (381^a10–1). Broiling or roasting (*optêsis*) is heating that comes from a dry, external heat (381^a24). Again, to drive home the point of the similarity in the causal process of craft and nature, Aristotle says of both boiling and broiling, they are “artificial processes, but the same general kind of thing, as we said, is found in nature too” (381^b4–5). The types of inconcoction (*apepsia*)—rawness (*ômotês*), parboiling (*molunsis*), and scorching (*stateusis*)—are likewise based in the analogy to cooking and are failures of the respective processes.

Aristotle uses the notions of concoction, inconcoction, and their subspecies, as introduced in the *Meteorologica*, for particular explanations in *De Partibus Animalium* (as well as the *Historia Animalium* and, of course, in *De Generatione Animalium*). Surveying a few examples from *De Partibus Animalium* gives us a sense of just how ubiquitous Aristotle’s explanations of this sort are. Again, while many are not presented as analogical reasoning, the causal language used is the same as was theorized in the *Meteorologica*, theorizing which is based on the analogy between the development of food and other products by craft and the development of various substances by nature. The production and effects of blood are frequently explained in terms of concoction. One such instance comes in *De Partibus Animalium* II 4 651^a17–8: “The watery part of the blood is serum [*ichôr*]; and it is watery, either owing to its not being yet concocted, or owing to its having become corrupted or else watery blood....” Thus, it is the action of concoction (generally, by vital heat) that is responsible for the blood’s proper formation. The

spleen can help finish the job of concoction for bloodlike fluids, as Aristotle explains at *De Partibus Animalium* III 7 670^a27–670^b7: “the spleen attracts the residual humours from the stomach, and owing to its bloodlike character is enabled to assist in their concoction” (670^b4–6). The association with blood and concoction carries over, since it is because of the specific character of the residue, it being like blood, that the spleen can assist. The existence of the spleen in the animals that have spleens is explained by the existence of residues that need to be more fully formed. This working up of the matter is a sort of concoction and, as with the concoction described in the *Meteorologica*, this cooks off the watery part of the residue. In *De Partibus Animalium* III 14, there is much discussion that concerns the esophagus and stomach (and similar discussion continues in the next chapter and book).¹⁰ Digestion is, like blood, another place where the language of concoction typically appears. Here, the specific focus is on differentiating stomachs by the differences in concoction. Take one example: “When, however, an animal is of large size, and feeds on substances of so thorny and ligneous a character as to be difficult of concoction, it may in consequence have several stomachs, as for instance is the case with the camel” (674^a26–31). Thus, it is the particular nature of what needs to be concocted and the capabilities of concoction that explain the sort of stomach large animals have.

The diversity and frequency of Aristotle’s explanations by way of concoction have not gone entirely unnoticed, and G. E. R. Lloyd similarly sees them as based in the analogy to cooking (although he does not fit this into the framework of analogical reasoning). In “The master cook” in his *Aristotelian explorations*, Lloyd details—mentioning the above examples

¹⁰ In *De Partibus Animalium* III 15, we find another discussion of rennet and coagulation, which seems to have the unstated background of cheese making as a source: “It is the thick character of their milk which causes all these animals to have rennet; whereas in animals with a single stomach the milk is thin, and consequently no rennet is formed. That is why the milk of horned animals coagulates, while that of animals without horns does not. Rennet forms in the hare because it feeds on herbage that has juice like that of the fig; for juice of this kind coagulates the milk in the stomach of the sucklings” (676^a12–9).

and many others—how widespread this language is. Lloyd further sees it for the practical investigative tool it is, even if he has ultimate reservations about its legitimacy. As for its strength and flexibility, Lloyd writes of the use of concoction in Aristotle’s natural science, “The great strength of Aristotle’s use of the idea of concoction lies, in general, in the way it enables him to see the connections between widely disparate phenomena and processes” (95). This is precisely the power of analogical reasoning, to draw inference from an outside domain, which may have, at first, appeared unrelated. Lloyd then criticizes—in a way, rightly—Aristotle’s use for being less than rigorous: “But the corresponding weakness is in the very vagueness or generality of the concept—which is what allows him to suggest those connections. To put it another way, the connections he apprehends run ahead of the theoretical explanations he can offer” (95). Indeed, as Lloyd notes, even the fundamental categories of hot, cold, wet, and dry—which are employed to explain numerous processes in these appeals to concoction and elsewhere—are themselves open to interpretation and are insufficiently defined (96).

What is important is that Aristotle applies so widely these causal explanations derived originally from the analogy to cooking. Each of the above cases (and the plethora of examples not recounted here) is underpinned by the general inferences Aristotle has already made—inferences of the behavior of heat in various sorts of cooking applied to cases of various sorts of vital heat. Aristotle may apply these categories and the explanations they bring too vigorously, but this is a result of his scientific concern for the uniformity of explanation. Given the extent to which analogical inferences underwrite Aristotle’s general description of vital heat, we see it has a wider scope; that is, it extends to the cause of vital heat in general, since direct observation of the action of heat does not immediately provide an explanation for what the heat does in each case on each material. Aristotle has to turn to cooking for such an explanation—at the general

causal level, as in the *Meteorologica*, and in the specific explanations of ontological causes, as in *De Partibus Animalium*. This analogical reasoning extends beyond cases of particular explanation, since the action of vital heat itself is characterized by causal inferences.

V. Conclusion: The Importance of Analogy and Analogical Reasoning in Aristotle

In Aristotle's natural science, analogical reasoning plays a significant role. When direct observation fails, he is left with at least one way to produce an explanation—that is, if he can find the relevant familiar, ontologically causal cases from which to infer to the phenomenon that demands explanation. Especially in his *De Generatione Animalium*, analogical reasoning serves as explanation. But Aristotle, in *De Partibus Animalium* (among other treatises), also provides explanations that, while not strictly cases of analogical reasoning, are underpinned both generally and specifically by the analogy of cooking and concoction, which he explicates in the *Meteorologica*. This testifies to just how deep the analogical reasoning goes in Aristotle. Thus, analogical reasoning, while not directly theorized in Aristotle, is a key part of his scientific investigation.

Although, in the present essay, it has been necessary to distinguish sharply between cases of analogical reasoning and other cases of analogy in order to bring analogical reasoning into distinct relief, interesting advancements may come from focusing on the very way in which these categories of analogy are not strictly maintained in Aristotle's natural science. That is, once the possibility for causality and explanation are understood as real valences of the analogies that have been treated here as instances of reasoning by analogy, much more terrain is opened up for a broader, fuller, and more dynamic understanding of analogy in Aristotle's natural science. Another area for future research is the way in which areas Aristotle has theorized more fully

might be brought into dialogue with the sorts of explanation Aristotle generates with the causal inference that analogy allows (see the appendix for gestures in this direction). Despite the myriad of other sorts of comparisons and uses of analogy, however, it remains important to grasp analogical reasoning as a significant, substantial, and enduring part of Aristotle's natural science, one that persists in scientific practice today.

Appendix

I. Homology (*Homologia*)

Homology is worth examining because it shares an important feature with analogical reasoning. The existence or absence of a part or function can be used to explain the behavior of another part or function (or why it is absent) in a way similar to the inference of causality (although not the inference of a full explanation) from a source to a target domain.

In homology (*homologia*)—the case where things are analogues, although their causes are not related by generic similarity—the final cause is typically the same, while the other causes may require additional explanation. For example, lungs and gills fulfill the same function of being for warmth, but explanation of how the gills come to be is different from that of the lungs. These cases (as with heuristic cases) relate to an assessment by reasonableness: the homology comes from a source domain in a way that sets up what one might expect to find in a very near target domain. This is obvious by a sort of negative example, those cases where Aristotle finds something is absent from an animal where it might otherwise be expected. These often are of a mode in which the expectation is incorrect; thus, the homology picks out the absence of something in the target object. These analogies have substantial weight, since it is often due to such homologies that Aristotle feels compelled to explain the absence. Aristotle commonly uses this mode of investigation in *De Incessu Animalium* and *De Partibus Animalium*, such as when he investigates why snakes have no feet though the rest of the sanguine land-dwellers are footed or when Aristotle needs to explain why birds have no outer ears though all other sanguine quadruped ovi- and vivipara have outer ears (*IA*.8.708^a9–20, *PA*.II.12.657^a19–25; see Leunissen 115 and Lennox 214).

II. Induction (*Epagôgê*)

As for induction (*epagôgê*) or the examples on which one performs the induction, Aristotle sometimes speaks of induction in conjunction with analogy, as in *Metaphysica* Λ 5. While this is different from the sense of analogy discussed in the present essay, the inductive move resembles the initial inference in cases of analogy.

In Aristotle's use, one inducts from analogue cases to a higher principle that is evidenced in the similarity of the analogues. These are analogies in which concrete examples are given in the source domain, and one is invited to abstract from these examples and move up to a target domain that belongs to a higher level of generality; this target object is the general form of the analogical commonality. Aristotle usually uses this type of analogy when it looks like there is no other reasonable way to get a grasp on the target domain, because, for instance, definition of it is impossible. Take *Metaphysica* Θ 6, where Aristotle is trying to get his reader to get a grasp of the notions of actuality (*energeia*): "What we wish to say is clear by induction from particular cases, and we must not look for a definition of everything, but be able to comprehend the analogy" (1048^a35–7). The elements from which one abstracts include seeing and walking. There really is no other way to gain an understanding of these notions except by providing this series of examples. In this case, we actually have an example of typical Aristotelian analogy: as walking is to the capacity to walk, so actuality is to potentiality; as seeing is to the capacity to see, so actuality is to potentiality. In the analogies, the universals function as particulars, in that they are compared to particular instances. The induction accompanies this, however, in that we are to grasp actuality–potentiality universally. There are also cases in which induction serves alongside other possible evidence. For example, in *De Partibus Animalium* II 1 646^a25–31, which compares house building to the order of development and the order of substance and which

speaks of the comparison as induction, Aristotle also indicates the conclusion, “For that which is posterior in the order of development is antecedent in the order of nature, and that is genetically last which in nature is first,” can also be shown by argument.

III. Likeness (*Homoiotês*)

The core argument defended in this paper—that Aristotle uses analogical reasoning to find ontological causes and explain phenomena therewith—does not require Aristotle to have given a formal account of analogical reasoning. However, Aristotle’s arguments from likeness (*homoiotês*) may have characteristics similar to analogical reasoning.¹¹

Even though there is no account of analogical reasoning given in the *Analytica Posteriora*, for example, that does not mean that analogical reasoning is not in Aristotle’s scientific repertoire, as evidenced throughout the present essay. Nonetheless, Aristotle’s use of analogical reasoning is compatible with, and is possibly partially derivable from, Aristotle’s own theory of arguments from likeness. This is most directly discussed in *Topica* I 17. While Aristotle’s account of *analogia* mostly deals with establishing (primarily) four-term proportional relation, his brief account of *homoiotês*—an account that clearly involves analogies—can be read as alluding to inference and explanation. Aristotle provides a very brief formal account of arguments from likeness that outline the general contours of an argument from analogy. He gives the formula for alike things that are of different genera at *Topica* I 17 108^a6–10:¹²

¹¹ Other useful passages provide evidence for further connection. These include Aristotle’s theory of analogy as a subspecies of metaphor (*Poetica* 21) and its relation to his theory of discrete analogies of four terms (outlined in *Ethica Nicomachea* V 3, along with continuous analogies of three terms, *Metaphysica* Δ 6, and *Topica* 17). Also informative is Aristotle’s discussion of argument from example (*paradeigma*). Relevant passages on argument from example include *Rhetorica* II 25 1402^b14–7 and *Analytica Priora* II 24 68^b1–20.

¹² He states the other sort of investigation of likeness, that of things belonging to the same genus, next in the chapter: “We should also look at things which belong to the same genus, to see if any identical attribute belongs to them all, e.g. to a man and a horse and a dog; for in so far as they have any identical attribute, in so far they are alike” (*Top.I.17.108^a13–7*).

as one is to one thing, so is another to another (e.g. as knowledge stands to the object of knowledge, so is perception related to the object of perception), or: as one is in one thing, so is another in another (e.g. as sight is in the eye, so is intellect in the soul, and as is a calm in the sea, so is windlessness in the air).

While this formal account does come in the context of discussing dialectic, one should not be too hasty to discount it as having a possible theoretical tie to the scientific practice of analogical reasoning (nor should one discount out of hand the coexistence dialectic and scientific investigation). The examples Aristotle gives are very telling. These analogies are all of the discrete analogy form, A is to B as C is to D (as opposed to the continuous analogy form, A is to B as C is to B), and they relate properties and objects. The first analogy, “as knowledge stands to the object of knowledge, so is perception related to the object of perception,” establishes analogy by a subject–object relation. The second analogy, “as sight is in the eye, so is intellect in the soul,” uses a capacity–actualizer relation. And the third analogy, “as is a calm in the sea, so is windlessness in the air,” relies on a likeness of property with respect to material. What is striking about these examples is that—while they are not full-fledged explanations and are much more of a description than a case of analogical reasoning—if one of the sides of the analogy involved an unfamiliar process, it would be much clearer how this relates to analogical reasoning, since Aristotle would then be making an inference. There are, then, important structural similarities between Aristotle’s account of *homoiotês* here and his use of analogical reasoning in the scientific treatises. Aristotle’s comment in *Topica* VIII 1 156^b10–16 supports this point:

the universal involved is less patent [in arguments from likeness]; e.g. that as knowledge and ignorance of contraries is the same, so too perception of contraries is the same.... This argument resembles induction, but is not the same thing; for

in induction it is the universal whose admission is secured from the particulars, whereas in arguments from likeness, what is secured is not the universal under which all the like cases fall.

In successful arguments from likeness, the arguer secures a sort of local induction, the one case abstracted in the relevant way and applied to the other. This resembles closely the inferences of analogical reasoning. The universal is involved but is not readily apparent or the final object of the comparison. The general principle is a sort of midway point that unites the side of the analogy. For example, as examined above, in the case of the coagulation of milk by rennet and menses by semen, the two cases are analogous in that both are instances of vital heat working up matter that can be formed in this way. In cases of arguments from likeness, the aim is to secure the acceptance of the target case as relevantly alike. Analogical reasoning goes a step further, in that it is not a technique of dialectic; it is, rather, a technique of science for arriving at ontological causes. In a strong sense, then, the causes singled out in the inferential operation do not stand or fall on any interlocutor's acceptance or denial of them. Once identified, the causes and the explanation they produce stand on their own.

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