Induction in the Socratic Tradition

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Abstract: Aristotle said that induction (*epagōgē*) is a proceeding from particulars to a universal, and the definition has been conventional ever since. But there is an ambiguity here. Induction in the Scholastic and the (so-called) Humean tradition has presumed that Aristotle meant going from particular statements to universal statements. But the alternate view, namely that Aristotle meant going from particular things to universal ideas, prevailed all through antiquity and then again from the time of Francis Bacon until the mid-nineteenth century. Recent scholarship is so steeped in the first-mentioned tradition that we have virtually forgotten the other. In this essay McCaskey seeks to recover that alternate tradition, a tradition whose leading theoreticians were William Whewell, Francis Bacon, Socrates, and in fact Aristotle himself. The examination is both historical and philosophical. The first part of the essay fills out the history. The latter part examines the most mature of the philosophies in the Socratic tradition, specifically Bacon's and Whewell's. After tracing out this tradition, McCaskey shows how this alternate view of induction is indeed employed in science, as exemplified by several instances taken from actual scientific practice. In this manner, McCaskey proposes to us that the Humean problem of induction is merely an artifact of a bad conception of induction and that a return to the Socratic conception might be warranted.

Introduction

Aristotle said that induction (*epagōgē*) is a proceeding from particulars to a universal, and the definition has been conventional ever since. But there is an ambiguity here. Did Aristotle mean particular things and universal ideas, or did he mean particular and universal statements? Induction in the Scholastic and the (so-called) Humean tradition has presumed the second. Recent scholarship is so steeped in this tradition that we have virtually forgotten the other. But the alternate view prevailed until late antiquity and then again from the time of Francis Bacon until the mid-nineteenth century. This essay seeks to recover that alternate tradition, a tradition whose leading theoreticians were William Whewell, Francis Bacon, Socrates, and in fact Aristotle himself. [1]

There have been times when philosophers were stressfully aware of the ambiguity. In 1439, Lorenzo Valla said that Socrates and Cicero had the correct view and Boethius was evil for promoting the other: Boethius was like a thief who steals a horse and tries to hide the crime by cutting and dyeing the horse's hair.[2] Rudolph Agricola (d. 1485) agreed that induction was the Socratic practice.[3] In a book of 1542, Agostino Nifo, in commentary on Aristotle's *Topics* 1.12, said there were now several open questions about what induction is.[4] In 1551, in the first edition of the first logic textbook published in English, Thomas Wilson took the Scholastic view, that induction was propositional inference made good by conversion to a syllogism. But in the second edition, "newly corrected," published only one year later, Wilson added a new section on the other kind of induction, "called … Socrates['] induction."[5] The debate waned after Bacon and his followers adopted the Socratic understanding, but it returned in the nineteenth century. The revisionist logician Richard Whately found it necessary to add to the fourth, 1831, edition of his *Elements of Logic* an acknowledgement that he was using the term "induction" in the Scholastic sense not in the "original and strict sense."[6] The whole Mill-Whewell debate over induction was essentially a disagreement over which of the two meanings was correct. In an 1874 textbook, Mill's follower Alexander Bain warned his students against the Baconian or Socratic usage. "By Induction, we arrive at *Propositions*, … [It is not Induction] where what we arrive at is a Notion or Definition."[7] Bain's students heeded his injunction—and most of

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[1] For comments on drafts of this paper, I thank Daniel Schwartz, Greg Salmieri, and Travis Norsen. None of them agrees with everything I say here.

[2] Lorenzo Valla, *Repastinatio dialectice et philosophie*, ed. Gianni Zippel (Padua: Antenore, 1982), pp. 345–52.

[3] Rudolph Agricola, *De Inventione Dialectica,* 2.18, p. 265.

[4] Agostino Nifo, *Aristotelis Stagiritae Topicorum* (Venice: Girolamo Scotto, 1557), f. 18r–v, first published 1542.

[5] Thomas Wilson, *The rule of reason, conteinyng the arte of logique, set forth in Englishe* (London: Richard Grafton, 1551), ff. 64v–68r; (London: Richard Grafton, 1552), f. 66r, f. 32v in subsequent editions.

[6] Richard Whately, *Elements of Logic*, 4th ed., bk. 4, ch. 1, sect. 1, n. 2. In later editions, this note was moved into the body of the text.

[7] Alexander Bain, "Meaning and Scope of Induction," *Logic*, bk. 3, ch. 1, sect. 1, p. 1. Italics in original. "Notion" was Bacon's technical term for a concept, the cognitive content corresponding to a word.

us have done the same. We take Aristotle to have meant that induction is a proceeding from particular statements to a universal statement—that is, a kind of propositional inference—not fundamentally a proceeding from observation of particular things or groups of things to an abstract concept.

But this is not what Aristotle meant.[8] He uses the term *epagōgē* frequently enough, but always without preface or preparation. He always assumes his student knows what he means. And what his student would have known by the term was that distinctive practice by which Socrates pursued the identifying characteristics that justify grouping things together as a class. When Aristotle said, "Two things may be fairly ascribed to Socrates—inductive reasoning and universal definition,"[9] Aristotle was not listing two unrelated inventions. He was describing two aspects of one project, what Valla, Agricola, and Wilson knew as "Socratic induction."

Unfortunately the word *epagōgē* (Cicero translated it as *inductio*) is not used in the Socratic dialogues, and so we are left to infer exactly which part of Socrates' practice Aristotle would have considered induction. I have argued elsewhere for the part that I presume here,[10] but the focus in this paper is philosophical, not historical. My goal is to sketch out what I believe is a promising approach to induction, and I will label the proposal as being for induction in the "Socratic tradition." But whether Aristotle, Cicero, Valla, Agricola, Wilson, Bacon, and I are right to give the historical Socrates credit will not be central to the presentation here. Moreover, not everyone working in this tradition agrees with all the others or with me. I will gather what I think are the most promising parts and say of their authors what we say of the generous colleagues from whom we learn: None has seen the final product, and none should be held responsible for its errors.[11]

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[8] I have argued this in detail in "Freeing Aristotelian *Epagōgē* from *Prior Analytics* II 23," *Apeiron: A Journal for Ancient Philosophy and Science* 40, no. 4 (December, 2007): 345–74.

[9] *Metaphysics,* M4 1078b24–29. Ross's translation, slightly modified. Cf. a similar passage in *Nicomachean Ethics,* bk. 6, ch. 3; 1139b26–33.

[10] "Freeing Aristotelian *Epagōgē*."

[11] For an entry to the sparse literature on Socratic induction, see Mark L. McPherran, "Socratic *Epagōgē* and Socratic Induction," *Journal of the History of Philosophy* 45.3 (2007): 347–64 and Hugh H. Benson, "Socratic Method," *Cambridge Companion to Socrates* (Cambridge: Cambridge University Press, 2010). Other scholars have not espied in Socratic *epagōgē* exactly what I have, but I think some have been hampered by looking for what those in the twentieth and early twenty-first centuries would call induction, not what Socrates' successors would have called *epagōgē*.

1 Socrates

Less contested than the nature and role of induction in Socrates is the importance there of the search for answers to the question, “What is it?” or, as we often say in this regard, “What is F-ness?” In the *Republic*, “What is justice?” In the *Laches*, “What is courage?” In the *Meno*, “What is Virtue?” Elsewhere, “What is beauty?” “What is it to be skilled?” “What is a good ruler?” “What is piety?” Consider this last, from the *Euthyphro*.[12]

Socrates asks: What is piety? Euthyphro replies that it is prosecuting a wrongdoer, even if the wrongdoer is one’s own father. Socrates does not dispute that this is an instance of piety but asks for something else: “I did not bid you tell me one or two of the many pious actions but *that form (*eidos*) itself that makes all pious actions pious*.”[13] Euthyphro appreciates the difference and proposes that piety is doing what pleases the gods. Socrates likes this proposal, but it is ambiguous: Which gods? After further discussion, they agree that what is pious is what pleases all the gods. Euthyphro and Socrates have reached some sort of definition. What pleases all the gods is pious, and whatever is pious pleases all the gods. The two sets are coextensive.

Socrates, however, is not satisfied. He does not just want a definition that marks out the boundaries of the concept. He wants rather to identify “*that form (*eidos*) itself that makes all pious actions pious*.” Which fact, he wants to know, *causes* the other? Euthyphro is at first confused, and Socrates explains. Euthyphro then appreciates the difference but realizes he is not sure which causes which. Socrates notes then, that even though what is loved by all gods may be pious and what is pious may be loved by all gods, “the god-loved is not the same as the pious.”[14]

Socrates suggests they start over. And where he starts is important: Piety, he proposes, is *a kind of* justice. All that is pious is of necessity (*anagkaion*) just, but not all that is just is pious. Socrates is proposing a genus. Euthyphro embraces the proposal, and Socrates calls for a differentia. “See what comes next: if the pious is a part of the just, we must it seems, find out what part of the just it is.”[15] Euthyphro proposes that piety is justice in service to the gods. The other part of justice is in service to men. The conversation now turns to understanding what would make

[12] *Euthyphro*, 5c–6e.
[13] *Euthyphro*, 6d, emphasis mine.
[14] *Euthyphro*, 10d.
[15] *Euthyphro*, 12d.

something of service to the gods. The question comes round very close to the original one. Euthyphro tires of the investigation and begs his leave.

Socrates has pursued not just a definition of piety, not, that is, just a delineation that identifies what is or is not pious. He demands to know what makes a pious thing pious. What is the form? What is the cause? What predicate fills the blank, "It is piety *because* it ____"? To answer this, Socrates proposes to survey some instances, accepting that they are indeed instances, and to repeatedly compare and contrast instances of the one sort with instances of other sorts. He decides that the best approach is to first identify a genus and then use more compare-and-contrast to find the distinguishing differentia.

Knowledge of such a form would be remarkably powerful. When, in *Hippias Major,* Socrates seeks the form of fineness (beauty, *kalon*), he says he wants to know "what when added to anything—whether to a stone or a plank or a man or a god or any action or any lesson—*anything* gets to be fine."[16] Note that it is not necessarily knowledge of a Platonic Form that Socrates seeks. As Aristotle reports, just after saying Socrates was concerned with inductive reasoning and universal definitions, "Socrates did not make the universals or the definitions exist apart; his successors, however, gave them separate existence, and this was the kind of thing they called Ideas."[17] The metaphysical status of a form is separate from its identification.

2 Francis Bacon

From Aristotle's time until late antiquity, *inductio* and *epagōgē* were as closely associated with Socrates as induction nowadays is with David Hume. After the mid-seventeenth century, that association shifted to Francis Bacon.

Bacon came to induction late. Though reared and trained for a lawyerly and courtly life, he always had an interest in natural philosophy and experimental science. Worldly explorations and the new sixteenth-century industries interested him as a boy.[18] In 1592, when he turned thirty-one, he expressed a wish that he could purge systematic knowledge of its errors by his own "industrious observations, grounded conclusions, and profitable

[16] *Hippias Major*, 292d, emphasis in Woodruff's translation.
[17] *Metaphysics*, bk. M, ch. 4; 1078b30–32. Translation by McPherran, after Barnes.
[18] Benjamin Farrington, *Francis Bacon: Philosopher of Industrial Science* (New York: Collier Books, 1961), ch. 2.

inventions and discoveries."[19] Later that decade, he would enjoy retreats outside London to an estate at Twickenham Park, where he could perform experiments.[20] Bacon's scientific discoveries did not in the end amount to much, but—to take just a few examples—his study of specific gravity was the result of commendably careful experimentation,[21] his theory of the tides earned Galileo's consideration,[22] and Robert Boyle modeled his early experimentation on Bacon's posthumously published natural history, *Sylva Sylvarum*.[23]

By around 1603, when Bacon was in his early forties, he had become engaged with a theoretical problem arising in the practice of natural philosophy:[24] How does one effect a property in materials that have never had that property? How does one attempt something never before done and know what will happen? The problem, Bacon decided, had two dimensions, what he called certainty and liberty. The first, Bacon thought, was easy enough if one ignored the second. It takes no great genius or much method to know that the next dollop of butter thrown on a hot skillet will melt.[25] We can continue doing what we have always done, and we know what will happen. But what of lard? What about cheese? Wax? Clay? What about a new artificial material, envisioned but not yet produced? As we exercise our liberty, as we try things increasingly dissimilar, we lose our certainty—at least without a proper method. Bacon wanted a method that would allow liberty without sacrificing certainty.

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[19] Letter to William Cecil, 1st Baron Burghley, *The Works of Francis Bacon*, ed., James Spedding, Robert Leslie Ellis, and Douglas Denon Heath (London: Longmans & Co., 1857), (hereafter "Spedding"), v. 8, p. 109.
[20] Lisa Jardine and Alan Stewart, *Hostage to Fortune: The Troubled Life of Francis Bacon* (New York: Hill and Wang, 1998), p. 138.
[21] *Historia densi et rari*, Spedding, v. 2, pp. 242–305; *History of Dense and Rare*, Spedding, v. 5, pp. 339–400.
[22] Letter to Bacon from Tobie Matthew, Spedding, v. 14 pp. 36–7; Jardine and Stewart, *Hostage to Fortune*, pp. 306–7; and Paolo Rossi, *Aspetti della rivoluzione scientifica* (Naples: Morano, 1971), pp. 163–9.
[23] "I must inform you that many of the Particulars which we are now considering, were in my first Designe collected in order to a Continuation of the Lord Verulam's *Sylva Sylvarum*, or Natural History. And that my intended Centuries might resemble his, to which they were to be annexed." Robert Boyle, "A Proemial Essay," *Certain physiological essays*, (London: 1661), p. 14.
[24] *Valerius Terminus*, ch. 11; Spedding, v. 3, pp. 235–41.
[25] My example, not Bacon's. His involved reproducing the color white in any material, including liquids.

To solve his problem Bacon turned to three concepts he found in Aristotle—*kata pantos*, *katholou proton*, and formal cause.[26] A property that is true *kata pantos* is true for *all* members of a class. But a property that is true *katholou proton*, is true of *all and only all* members of a class. Thus a proposition predicating a *katholou proton* property is convertible; that is, subject and predicate can be swapped. All triangles have angles that sum to 180°, and any plane polygon whose angles sum to 180° is a triangle. This suggests a rule: If you want a polygon whose angles sum to 180°, make a triangle. But even if the properties are *katholou proton,* a rule like that may not be useful. Even if you have found several properties that counter-predicate, you need to know which is "more original."[27] It is not enough to know that properties "cluster and concur,"[28] it is important to identify which is the cause. But which cause? Bacon dismissed the final cause as inapplicable in cases outside of human actions. And he thought knowing just the material and efficient causes can provide certainty but not liberty. Such knowledge would help only to "achieve new discoveries in material which is fairly similar."[29] What is needed, Bacon says, is to identify what is "formative,"[30] what is the "form or formal cause,"[31] what the "received philosophies" call the "true difference."[32]

To find this Form (the term is often capitalized in *Novum Organum*), this formal cause, Bacon proposes that the researcher first gather instances, and counter-instances against which they can be compared. Such comparisons are used to identify a genus. Further comparisons, especially those guided by some helpful rules, will identify the differentia and consequently the formal cause, the Form, that which makes something the kind of thing it is. When, as an example, Bacon investigates the Form of heat, he concludes

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[26] *Valerius Terminus*, ch. 11; Spedding, v. 3, pp. 236, "This notion Aristotle had in light, though not in use"; *Advancement of Learning*, bk. 1, sect. 17, para. 12; *De Augmentis Scientiarum*, bk. 6, ch. 2. In Latin, the first two went by the names *de omni* and *universaliter*, respectively, but Bacon preferred either the Greek, as in his published works, or the Ramist forms "rule of truth" and "rule of prudence," as in *Valerius Terminus*.
[27] *Valerius Terminus*, ch. 11; Spedding, v. 3, p. 240.
[28] *Valerius Terminus*, ch. 11; Spedding, v. 3, p. 240.
[29] *Novum Organum*, bk. 2, aph. 3, Silverthorne's translation.
[30] *Valerius Terminus*, ch. 11; Spedding, v. 3, p. 241
[31] *Valerius Terminus*, ch. 11; Spedding, v. 3, p. 239. Cf. *Novum Organum*, bk. 2, aph. 2.
[32] *Valerius Terminus*, ch. 11; Spedding, v. 3, p. 239. Cf. *Novum Organum*, bk. 2, aph. 1.

that heat is a kind of motion, "an expansive motion which is checked and restrained and acting through particles, expanding in all directions, [etc.]" Armed with this knowledge, he boldly claims,

If in any body you can arouse a motion ... [of this certain kind], you will certainly generate heat. It is irrelevant whether the body is elementary (so-called) or imbued with heavenly substances; whether luminous or opaque; whether rare or dense; whether spatially expanded or contained within the bounds of its first size; whether tending toward dissolution or in a steady state; whether animal, vegetable or mineral, or water, oil or air, or any other substance whatsoever.[33]

It is not that there will be this motion and the motion will then make some heat. It is that the motion *is* heat. If you arouse this motion, you will generate heat—because that is what heat *is*. This is a part of what Bacon means when he says that knowledge is power. Knowledge of formal cause provides both certainty and liberty. (Notice as well that the final cause in this case ends up being also a material cause and an effective cause, but it is qua formal cause that these provide certainty and liberty. Thus, one way to characterize Bacon's contribution to science is that he changed formal cause from being a substance to formal cause being reducible to one or more of efficient, material, or final cause.[34])

Bacon's conclusion is inescapable. If, in fact, that is what heat is, then if you effect that motion, you effect heat. If Socrates could find the form—the formal cause—of fineness (*kalon*), then wherever the cause was found, there would be fineness, whether in a stone or a plank or a man or a god or any action or any lesson—in *anything*. The conclusion becomes true *by the very definition of the term*, by the very essential nature of the concept (of the *notio* in Bacon's language).

Bacon, however, did not say his conclusion was true "by definition." Somewhere between writing his first notes in or around 1603 and others in 1607 and 1608, Bacon came to say his conclusion was trustworthy because

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[33] *Novum Organum*, bk. 2, aph. 21. Italics in Bacon's original.

[34] The proposal here should go a long way toward reconciling what many commentators have thought to be tensions or inconsistencies in Bacon's thought. I suggest that the tensions are really false dichotomies, artifacts created by scholars trying to put Bacon into their own this-or-that buckets rather than understand him as participating in a Renaissance conversation already underway about the nature of causes, induction, and productive powers. For a spirited cataloging of such artifactual problems, see "Francis Bacon and the Progress of Knowledge," *Journal of the History of Ideas*, 53, no. 3 (1992), by Brian Vickers, who is himself not immune to the siren of artifactual dichotomizing.

it was reached by "a true induction:" Bacon does not make the connection between his method and the term "induction" in *Valerius Terminus*, written in or around 1603. *The Advancement of Learning* of 1605 only hints in the direction. The association appears in the manuscript *Partis Instaurationis Secundae Delineatio et Argumentum* of 1607 and is strong in *Cogitata et Visa de Interpretatione Naturae*, also of 1607. I speculate that he picked up the term from interactions with William Harvey, who learned a similar method at the medical school of Padua, a method Harvey called *regula Socratis*, "the rule of Socrates." But whether from Harvey, Wilson, another humanist,[35] or even Aristotle,[36] Bacon came to the view that his universal claim was true by induction, and by that he meant a compare-and-contrast method that results in identifying the true cause, the essential nature, the Form of something. The identification does result in a definition, but a certain kind of definition, a causal, essential one, not just a nominal one.

Bacon was tracing the same steps Socrates had, and it was surely these to which he referred when he said, "[The correct procedure] has not yet been done, nor even certainly tried except only by Plato, who certainly makes use of this form of induction to some extent in settling on definitions and ideas."[37]

3 William Whewell

The last major induction theorist to work in the Socratic tradition was William Whewell. (I will here skip over but will return later to John F. W. Herschel. I will also skip Thomas Reid.) As with others in the tradition, for Whewell induction is a process of classifying and defining. He presumes, that is, that induction is a progression from particular things or groups of things to universal concepts, and only derivatively a progression from particular statements to universal statements. To understand his theory of induction, we must understand the basic outline and terminology of his overall theory of conceptual knowledge.

Whewell claims that his whole philosophy rests on recognition of the difference between *thoughts* and *things*. Our Thoughts are something which belongs to ourselves; something which takes place within us; they are what *we* think; they are actions of our minds. Things, on the contrary, are

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35 William Temple, England's leading Ramist, is another candidate.

36 Bacon knew his Aristotle more than he is given credit for. In about a page of introductory remarks to the *Novum Organum* (in the *Distributio Operis*), Bacon uses or cites technical terms or issues in recent Aristotelian scholarship forty-one times.

37 *Novum Organum*, bk. 1, aph. 105, Silverthorne's translation.

something different from ourselves and independent of us; something which is without us; they *are*; we see them, touch them, and thus know that they exist; but we do not make them by seeing or touching them, as we make our *Thoughts* by thinking them; we are passive, and *Things* act upon our organs of perception.[38]

These "organs of perception," however, do not themselves provide us with perceptions, merely with sensations. Sensations are given a perceptual form, automatically, by means of a few *fundamental ideas*, such as space and likeness, with the result that we perceive objects: "Perception is Sensation, along with such Ideas as make Sensation into an apprehension of Things or Objects."[39] From this apprehension of objects, knowledge is built up hierarchically, using *conceptions*.

We gather knowledge from the external world, when we are able to apply, to the facts which we observe, some ideal conception, which gives unity and connexion to multiplied and separate perceptions… Our *conceptions*, thus verified by *facts*, may themselves be united and connected by a new bond of the same nature; and… man may thus have to pursue his way from truth to truth through a long progression of discoveries, each resting on the preceding, and rising above it.

Each of these steps, in succession, is recorded, fixed, and made available, by some peculiar form of words; and such words, thus rendered precise in their meaning, and appropriated to the service of science, we may call *Technical Terms*.[40]

Thus, conceptions bind facts together, and words (or technical terms) fix those conceptions and make then usable. Finally, to round out Whewell's terminology of items in the cognitive hierarchy: A second conception, broader than another, is called an *idea*. The difference between conception and idea (when Whewell makes one), is hierarchically contextual, like that between species and genus. What is an idea at one level can be a conception at another. An idea, such as space or causality, broader than all or nearly all other conceptions is one of the above-mentioned *fundamental ideas*.

[38] *Philosophy of the Inductive Sciences*, 2nd ed. (London: John Parker, 1847), bk. 1, ch. 2, sect. 1, "Thoughts and Things"; v.1, p. 17. Whewell's emphases.
[39] *Philosophy*, 2nd ed., bk. 1, ch. 2, sect. 10, "The Fundamental Antithesis inseparable"; v. 1, p. 43. Cf. bk. 8, ch. 1, art. 2, "Unity of the Individual"; v. 1, pp. 467–8. Whewell's capitalization in text and title.
[40] *Philosophy*, 2nd ed., bk. 1, ch. 3, art. 1; v.1, p. 51. The first two emphases are mine, the latter Whewell's. The spelling is Whewell's.

The way in which perceptions, things, facts, conceptions, terms, ideas, and fundamental ideas are structured into a body of scientific knowledge involves two complementary processes, the *explication of conceptions* and the *colligation of facts*. Like analysis and synthesis, or differentiation and integration, explication and colligation are not necessarily sequential, either temporally or logically. They are simply two complementary, primary processes involved in scientific knowledge.

To *explicate* a conception is to clarify it by identifying what it contains, by "unfolding" it, as Whewell often says.[41] This may include, to begin, surveying and examining examples. When Whewell explicates the conception *symmetry*,[42] he lists as examples the right and left sides of animals and the three faces at the summit of some crystals. He also identifies several kinds of symmetry: simple, triangular, tetragonal, pentagonal, and oblong. To explicate is also to identify implications. One implication of symmetry is that symmetrical members are affected in like ways by like circumstances. An implication of the conception of the earth as a globe[43] is that the earth casts a circular shadow, as during a lunar eclipse. Another task of explication is to determine in what way a conception is an instance or modification of a more general idea. The result of all these considerations may be a definition. "The Definition gives the last stamp of distinctness to the Conception; and enables us to express, in a compact and lucid form, the … propositions into which the … Conception enters."[44] Note that the definition is the final, not the initial, step. "The Conception must be *formed* before it can be *defined*."[45] In fact, "though Definition may be subservient to a right explication of our conceptions, it is *not essential* to that process."[46] The essential part of explication is the identification of the constituent facts included in the conception.

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[41] *Philosophy*, 2nd ed., bk. 11, ch. 1–2, sect. 1; vol. 2, pp. 3–11.

[42] *Philosophy*, 2nd ed., bk. 7, ch. 1, art. 1, "Explication of the Idea of Symmetry"; v. 1, p. 439.

[43] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 11; v. 2, p. 84. Cf. also the fold-out "Inductive Table of Astronomy."

[44] *Of Induction, with Especial reference to Mr J. Stuart Mill's System of Logic* (London: 1849), reprinted in Butts, *Theory of Scientific Method*, ed. Robert E. Butts (Hackett, 1989) as "Mr. Mill's Logic," §35, p. 284. See also *Philosophy*, 2nd ed., bk 11, ch. 2, sect. 2, "Use of Definitions"; v. 2, pp. 11–16.

[45] *Mr. Mill's Logic*, Butts, p. 284. Whewell's emphasis.

[46] *Philosophy*, 2nd ed., bk. 11, ch. 2, art. 9; v. 2, pp.13–14. Whewell's emphasis. Fundamental Ideas cannot be defined. They are simply acknowledged in "self-evident

Colligation is the complementary process of "binding"[47] facts together. Whewell stresses that it is not just that "we find something in which the facts *resemble each other*."[48] A conception is not merely a binding of multiple instances of a common attribute. It is rather a cognitive binding of the facts themselves—not just the common attributes, not just the definition, but indeed all the attributes and even propositions associated therewith. The conception of universal gravitation, for example, *includes* the fact of heliocentric motion, *includes* the fact of the precession of the equinoxes, *includes* the conception of terrestrial weight, and so on.[49] This is why Whewell says explication is an unfolding. It is an exposing of what has already been bound together in the colligation.

The process of colligation is a normative process. It can be done properly or improperly, and Whewell calls the proper method *induction*. "*Induction* is a term applied to describe the *process* of a true Colligation of Facts by means of an exact and appropriate Conception."[50] The first step in an induction—in a successful colligation, a successful binding—is selection of the broader (possibly fundamental) idea that contains the facts under investigation. Before an induction of planetary observations can proceed, for example, it must be decided whether these observations are instances of physical motion or are instances of supernatural whim. Thus, an induction *presupposes* that all the observations are instances of one already known universal. An induction is not the creation of a new generalization per se. It is the narrowing of an already existing generalization. Every conception is, for Whewell, a modification of an existing (possibly axiomatic) idea. Ultimately, all conceptions are modifications of *space*, the inescapable, fundamental idea presupposed in the very act by which we perceive objects. Once the facts and the broader-level idea have been identified, the first step of colligation is complete.

The second step is the construction of the conception. This involves a creative act that Whewell calls *invention*. He observes that such invention is often performed by means of hypotheses—"by calling up before our minds

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truths," that Whewell calls "Axioms." *Philosophy*, 2nd ed., bk. 11, ch. 2, sect. 3, "Use of Axioms"; v. 2, p. 16–23. Also bk. 1, ch. 2, sect. 3; v. 1, p. 21.

[47] *Philosophy*, 2nd ed., bk. 11, ch. 1, 2:5. Also bk. 11, ch. 4, art. 1; v. 2, p.36. Also bk. 11, ch. 4, art. 11; v. 2, p. 45.

[48] *Mr. Mill's Logic*, Butts, p. 284. Whewell's emphasis.

[49] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 1; v. 2, p. 75. Whewell himself uses such italics when making this point.

[50] *Philosophy*, 2nd ed., "Aphorisms Concerning Science," aph. 13; v. 2, p. 468; Whewell's emphases.

several suppositions, and selecting that one which most agrees with what we know of the observed facts."[51] How does the discoverer select from among the invented hypotheses? Before Whewell answers this, he stresses that a colligation, the formation of a conception, can still be meritorious and useful even if erroneous. The task of the colligation is to bind the facts together so that they can be cognitively manipulated as a unit. He offers the example of *fuga vacui*, nature's abhorrence of a vacuum. Water rising in pumps, the operation of a bellows, an infant's sucking action, respiration in animals, and many other facts were usefully bound together by this conception, even though aspects of the conception were later found erroneous. With this preliminary made and stressed, Whewell proceeds to offer criteria for the testing of hypotheses.

His tests for hypotheses include the following. First, an induction must be consistent with the facts. This consistency must be overwhelming, but not necessarily absolute. Whewell cites the orbit of Uranus. "If we find that Uranus … deviates from Kepler's and Newton's laws, we do not infer that these laws must be false; we say that there must be some disturbing cause."[52] As mentioned above, a valid hypothesis must also be a modified instance of a broader idea. A valid hypothesis must also be consistent with whatever facts follow deductively from it.[53] Whewell furthermore claims that "our hypotheses ought to *foretel* phenomena which have not yet been observed; at least all phenomena of the same kind as those which the hypothesis was invented to explain."[54] For example, "the *Epicyclical Theory* of the heavens was confirmed by its *predicting* truly eclipses of the sun and moon, configurations of the planets, and other celestial phenomena."[55] But Whewell then, famously, goes further:

The evidence in favour of our induction is of a much higher and more forcible character when it enables us to explain and determine cases of a *kind different* from those which were contemplated in the formation of our hypothesis. The instances in which this has occurred, indeed, impress us with a conviction that the truth of our hypothesis is certain. No accident

[51] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 6; v. 2, p. 54.
[52] *Criticism of Aristotle's Account of Induction* (Cambridge: 1850), reprinted in Butts, pp. 315–6. John H. W. Herschel made the same point in *A Preliminary Discourse on the Study of Natural Philosophy* (London: 1830), p. 165.
[53] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 18; v. 2, p. 93.
[54] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 10; v. 2, pp. 62–3. Whewell's emphasis and spelling.
[55] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 10; v. 2, p. 63. Whewell's emphasis.

could give rise to such an extraordinary coincidence.[56]

Whewell gives a special name to this kind of evidence. He calls it "Consilience of Inductions." He gives as an example the fact that Newton's inverse-square law of universal gravitation, developed to explain orbits, turned out to explain something seemingly unrelated, the precession of the equinoxes.[57] Whewell believes consilience to be one of the most powerful confirmations that a hypothesis can have. He says consilience has never supported a hypothesis later found to be false.[58] Consilience gives rise to Whewell's final criteria, simplicity. One hypothesis that encompasses multiple, seemingly unrelated, phenomena is simpler and better than multiple independent hypotheses.

All these criteria—agreement with facts, prediction, consilience, simplicity—are not arbitrarily chosen. They are direct results of Whewell's theory that an induction is the successful construction of a conception. A conception, by the nature of its universality must include all facts of the class, not just those already observed; therefore a valid induction must be able to make predictions about the unobserved. Because a conception includes all attributes of a fact, including its relations, the conception must be consistent with deduced implications. The discovery of a consilience demonstrates that facts earlier included in two or more conceptions are in fact instances of a single conception, strengthening and broadening the conception and increasing simplicity and the unity that is the goal of the binding. Since an induction is a successful construction of a conception, Whewell's criteria for a valid induction follow from the nature of a conception.

Whewell frequently says that every valid induction is accompanied by a new properly formed conception. The "Inductive Step" *is* "the Invention of the Conception."[59] "In *every* inference by Induction, there is some Conception *superinduced* upon the Facts."[60] This conception includes the facts, but it is not merely the facts. Something is added, a bond that holds the facts together.[61] The group of facts is then "seen *in a new light*"[62]

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[56] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 11; v. 2, p. 65. Whewell's emphasis.
[57] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 11; v. 2, p. 66.
[58] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 11; v. 2, p. 67; *Mr. Mill's Logic*, Butts, p. 295.
[59] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 17; v. 2, p. 91.
[60] *Philosophy*, 2nd ed., bk. 11, ch. 5, art. 11; v. 2, p. 65. First emphasis mine, second Whewell's.
[61] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 3; v. 2, p. 77.
[62] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 12; v. 2, p. 85. Whewell's emphasis.

and takes on "a new shape."[63] The penultimate step (a definition may be the ultimate) is creation or new application of a word, phrase,[64] or technical term. Whewell offered ninety pages[65] on how such terms have been and should be formed. He himself coined several (including *scientist*, *physicist*, *anode*, *cathode*, and *ion*). It is by the creation of such conceptions—completed by creation or application of a word or phrase—that inductions, for Whewell, are performed.

4 Whewell, Bacon, Socrates

Note some similarities and differences between Whewell's system and those of Bacon and Socrates. The latter two took for granted that we already have a concept, that we can identify its instances, and that we can readily get a description (or overlapping descriptions) that provisionally function as a definition. Then, in order to remove ambiguity, add precision to our knowledge, and raise it to the level of scientific understanding—to the level of Aristotelian *epistēmē*—we use induction to identify the essence, the formal cause, of what we are studying. Once we have identified that essence, we can legitimately make some unqualified universal statements. Whewell, on the other hand, drew attention to the fact that, in much scientific inquiry, the researcher in fact does not begin with a ready-formed concept. The forming of the concept (or "conception") itself can, he claims, be a crucial part of scientific discovery. For example, Newton's integration of facts about falling apples, revolving moons, planetary orbits, tides, comets, and so on did not merely result in better definitions of old concepts such as *gravitas* but, more importantly, in the formation of the new concept *mass*. Newton had at hand some facts, but the facts were not cognitively held as a single unit. They were expressed in statements, paragraphs, lists, tables, even whole chapters and books. Newton's inductive breakthrough, Whewell says, was to integrate ("colligate") a variety of facts into a single cognitive unit, assign to it a term ("technical term"), and then, as the final step, identify its definition.

Bacon stresses the importance of forming one's concepts from the ground-up, rising slowly. Whewell, on the other hand, thinks all concepts are formed by filling in a conceptual hierarchy that has individual perceptible three-dimensional things at the bottom and axiomatically known

[63] *Philosophy*, 2nd ed., bk. 11, ch. 6, art. 3; v. 2, p. 77.
[64] *Mr. Mill's Logic*, Butts, p. 271.
[65] *Philosophy*, 2nd ed., "Aphorisms concerning the Language of Science"; v. 2, pp. 479–569.

concepts at the top. All definitions are then, for him, formed of genus and differentia, even if the genus is something as broad as "thing." We often speak this way: "What is that?" "Oh, it's something [genus] that … [differentia]."

For Whewell, more so than for Socrates and Bacon, the boundaries of concepts could be refined as a science matures. Socrates assumed (or played along as if to assume) that the men who were supposed courageous really were. Bacon assumed that, in seeking the definition of heat, we already knew what to include as instances and what to include as counter-instances. But Bacon included spicy food as an instance. We would not. He did not indicate how exactly, if at all, his theory could accommodate dropping spicy food from the class.[66] Whewell, on the other hand, thought it not only untroubling but positively necessary and useful that, in the process of induction, we clarify and sometimes even move the boundaries of our classifications. All inductions, for Whewell, end with forming—or reforming—a concept. Appropriately, then, he does not automatically abandon a concept when a counter-instance, or class of counter-instances, is discovered. Against the twentieth-century model, for Whewell, at least in some stages of a science's maturation, a counter-instance does not necessarily invalidate an inductive conclusion. He thought *fuga vacui* was a valuable concept on the road to our understanding of gases.[67]

A large difference between Socrates and (especially) Bacon is that Socrates gave no guidelines on how one should proceed in an inductive search for an essence. He merely frustrated his interlocutors until they walked off. Bacon provided explicit rules. But to appreciate the purpose of those rules and the context in which Bacon developed them, we must go back again to ancient Greece.

5 Handbooks on Induction

In ways obscure to us now, the back-and-forth, give-and-take that we see exemplified in Socratic dialogues evolved in Athens into a pedagogic, dialectical sport, something like our high-school debate competitions. Aristotle's early work, the *Topics*, is a handbook for those engaged in such competitions. The handbook is a catalog of maneuvers and the associated

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[66] Daniel Schwartz claimed to me, and I think rightly, that *Novum Organum* bk. 1, aph. 118 and bk. 2, aph. 25 indicate Bacon does believe his theory accommodates such changes.

[67] For John Herschel's insistence that one should not commit to classification boundaries too soon, see *Preliminary Discourse*, p. 138.

principles that make those maneuvers effective. Each maneuver-and-principle pair came to be called a *topos*, later, in Latin, a *locus*, literally a place. The reason for the name, too, is obscure, but because the term "topic" took on such specialized meaning, the etymology matters little. (I envision something as mundane as a teacher laying out on the ground potshards with notes, each in its place, its own *topos*, as we would place notecards on a table, and instructing a student to retrieve a particular notes-shard based on the competitive situation he confronted.)

Nowadays, the topics are often introduced by saying they are a kind of "informal logic" and noting that the strategies can be persuasive but often do not adhere to standards of formal logic. This is misleading if it suggests that topics-logic is sloppy logic, a kind of arguing that is not fully valid and is useful only for swaying the gullible. Aristotle did not see it this way. Much is made of Aristotle saying that, in dialectical reasoning, a premise need not be true. It can merely be what is widely believed. But normally, Aristotle's point is not that one should persuade the gullible by reasoning from premises they foolishly hold. His point is usually that a debate regularly begins with some opinion held by a majority or by those considered wise[68] and *then proceeds to test* whether that opinion leads to any contradiction. He says, without suggesting his view is unconventional, that the technique he presents in his handbook are equally applicable to conversations, to one's own mental training, and to philosophical science. The techniques allow one to discern "truth and falsehood on every point."[69]

At times, Aristotle's *Topics* seems like a repetitive grab-bag. At the highest-level, however, the organization is simple, plain, and profound. When one is faced with assessing the truth of any proposition, the nature of the predication is the primary issue. Aristotle identifies four types of predication: the predicate is an accident, a genus, an *idion* (later, *proprium* in Latin; distinguishing property), or a definition. In Aristotle's treatise, all of its eight books except the first and last, are organized around this fundamental division. Books 2 and 3 treat accidents, book 4 treats genus, and so on. Nothing is more fundamental to Aristotelian reasoning—whether in gymnastic debate, in one's own thinking, or in science—than identifying this aspect of a statement's predicate. For example, the very first *topos* is to check whether an opponent has predicated as an accident something whose relation is not in fact accidental.[70]

[68] *Topics*, bk. 1 ch. 1; 100b23.
[69] *Topics*, 101a26–7, a37.
[70] *Topics*, bk. 2, ch. 2; 109a34.

In the statement, “The sky is blue,” the nature of the predication is unstated. It must be supplied either by the context or by qualifiers. And the scope varies whether one says, “The sky is blue today,” “The sky is naturally blue,” “The sky is always blue,” or “The sky is blue, roses are red, bananas are yellow.” Like any cognitive content, predication is contextual. So, to evaluate Euthyphro’s claim that it is pious to prosecute wrongdoing, even if done by one’s own father, one must identify the nature of the predication. By considering the context, Socrates can see that Euthyphro has not actually proposed a definition of piety but has instead given an example. The predication—using the framework Aristotle describes in the *Topics* book 2—was that of a particular accident not of a universal accident, let alone that of a universal genus, *idion* (pl. *idia*), or definition.

But Socrates wants a different sort of predication. Euthyphro proposes, “Piety is what pleases the gods.” This has the potential to be predication of an *idion*, a characteristic distinctive to piety and only to piety, and Socrates begins subjecting it to some tests, tests like those that Aristotle codifies in the *Topics* book 5. Unfortunately for Euthyphro, the proposal fails the tests, because the predicate cannot be made unambiguous in the ways necessary. Socrates proposes that he and Euthyphro start over; he proposes they start with predication of a genus. Aristotle might later say to his students: Socrates and Euthyphro jumped too quickly from book 2 to book 5, too quickly from accidental predication to distinguishing predication; they should have first identified the genus. Socrates proposes that all acts of piety are just, that piety is a kind of justice. Euthyphro readily accedes and the interlocutors are ready to proceed to definitional predication—book 6 of the *Topics*—when Euthyphro decides he is no longer having fun and begs his leave.

I have argued elsewhere[71] that, for Aristotle, *epagōgē* is a compare-and-contrast method used to identify *idia*, the distinguishing characteristics that counter-predicate with their subjects. Maybe that is too narrow and the term covered the quest for universal accidents as well, or maybe my proposal is too broad and Aristotle (or at least others in antiquity) would have the method cover only the identification of defining characteristics. The evidence is too slight to be completely sure. But whatever the scope, *epagōgē* in antiquity was a logic of classification, a process of compare-and-contrast used to form, refine, and define one’s concepts, especially predicate concepts. Because it was so, it was the foundational method by which valid general and universal statements could be made. In the ancient

[71] “Freeing Aristotelian *Epagōgē*.”

world, Aristotle's *Prior Analytics* was a handbook for deductive logic, and the *Topics* a handbook for classificatory, or inductive, logic. Interest in this latter sort of logic waned after the Alexandrian Neoplatonists recast induction as a kind of propositional inference like but inferior to deduction and whose definitive treatment was supposedly *Prior Analytics* B 23. But later, especially after the 1540s, interest in induction and the *Topics*—and the *Posterior Analytics*, where the logic of definitions is central—increased. It was in this period that Nifo said there were now important questions about what induction is. In the next generation, Wilson documented the two kinds of induction. And in the next generation, William Harvey, studying under the new humanist Aristotelians in Padua, learned his compare-and-contrast method for identifying essences, the method he called the rule of Socrates.

Aristotle's *Topics* and *Posterior Analytics* were thus the main treatises on inductive logic until 1620, when Harvey's older contemporary Francis Bacon published his *Novum Organum*. Book 2 of that work replaced *Topics* book 5 as the most complete set of rules for identifying distinguishing characteristics and, as Bacon saw it, for going even further and identifying a Form, a formal cause, an essence, a definition.

As with so many momentous books, it is remarkable how large are the parts of *Novum Organum* seldom read anymore. We frequently enough reprint and re-read the sections in book 1 about the idols, but those sections merely fleshed out a known problem in Renaissance philosophy of mind.[72] Bacon's real innovation was to show how a valid solution to that problem would also allow man to make universal statements of practical use in (what we would call) science, technology, and engineering. That solution comes in the much longer book 2.

Book 2 begins with the claim that the goal of productive human activity is, primarily, to generate freely and with certainty some nature (*natura*) in a given body that does not have—and may never have had—that nature. The nature might be heat, transparency, strength in glass, a particular color. Bacon concurs with the common judgment of natural philosophers that effecting a given nature requires a knowledge of causes. But, he says, the usefulness of knowing merely efficient and material causes limits one's power to materials that are similar. And final causes are irrelevant in physical sciences. The key is to find the formal cause, or

[72] Concepts (*notiones*, *conceptus*) were conceived to be mental images or representations (*imagines*, *species*). An *idol* was a faulty representation, a "vain phantasm," a false image, a notion hastily made or ill-defined.

"Form, or true difference, or causative nature or the source of its coming-to-be."[73] Sadly, he says, others regard the search for formal causes as useless, and man's progress is thus limited. Bacon puts his call in italics: "*find another nature that is convertible with a given nature, and yet is a limitation of a better-known nature*, as of *a true genus*."[74] This is done by a "true and proper induction."[75]

In a work 313 pages long, Bacon's example of finding the nature of heat takes fifty-four pages. He has shown how comparing and contrasting can identify a genus and then identify the distinguishing differentiae. And as mentioned earlier, he then lays claim to a universal and indisputable statement: Whenever motion of the sort he describes is effected, heat is produced, because heat is that motion. But his example has been illustrative only. He finally gets to his specific guidelines for a true and proper induction. He provides 139 pages—over forty percent of the whole work—describing twenty-seven kinds of instances (more with all his subcategories) whose comparisons are particularly useful in performing such an induction: solitary instances, instances that have nothing in common with other particulars except for the one nature under investigation; parallel instances, such as feet in animals and fins in fish; instances of divergence, in which two properties usually found jointly, such as heat and light, appear by themselves; crucial instances, which can indicate which of two theories is correct; instances of dominance, of which there are nineteen kinds and which are motions that can be precisely measured.

Unfortunately, the handbook is incomplete. Bacon says that he has yet to add sections explaining aids to induction, how to refine an induction,[76] how to adapt induction to concrete subjects, and more. Yet what was completed was already unwieldy. In the early nineteenth century, one of Bacon's vigorous advocates, John Herschel, in his *Preliminary Discourse on the Study of Natural Philosophy*, gently mocked those who committed themselves too zealously to categorizing instances into Bacon's twenty-seven.[77] Herschel reordered and simplified Bacon's list and placed that list in a broader framework of inductive experimentation.

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[73] Book 2, aph. 1. "*autem naturae Formam, sive differentiam veram, sive naturam naturantem, sive fontem emanationis.*" "These are the words we have that come closest to describing the thing"; "*ista enim vocabula habemus, quae ad indicationem rei proxime accedunt*."
[74] *Novum Organum*, bk. 2, aph. 4.
[75] *Novum Organum*, bk. 2, aph. 10.
[76] See note 66 above.
[77] *Preliminary Discourse*, pp. 183–4.

For Herschel, induction has three steps. The first[78] is the observation of facts and collection of instances. And Herschel offered specific criteria, such as variety and reproducibility, for judging the value of facts. The facts need to be recorded, reviewed, and reduced to measurements, and imprecision in measurements has to be accounted for. Classification is the second step.[79] Names must be assigned, but initial classifications can and often should be tentative. The classifications will get finalized in the third step, the induction proper. The first stage[80] of that last step is identification of proximate causes and inductions of the lower levels. Here, Herschel expands Bacon's three tables a little but then reduces Bacon's twenty-seven types of prerogative instances to ten rules, such as to reject candidates that are not present, not rule out a cause just because its mechanism is not discernible, consider contrary facts, and isolate one factor and test with an experiment. The second stage of the third step is to extend the inductions to higher levels. Here the source material is not experiments and other direct sensory experience, but the results of the lower-level inductions. Herschel explains how to address problems distinct to these higher-level inductions. Among other things, he cautions against wanton hypothesizing. The frontispiece to Herschel's book included a portrait of Bacon, but Herschel did not just repeat Bacon's guidelines. He regularized them, made them more mathematical, and in general updated them. He had, after all, the benefit of looking back on two centuries of inductive science.

Though the procedure Herschel recommended was different than those recommended by Bacon or Aristotle, induction was for him as it was for them: the "juxta-position and comparison of ascertained classes, and marking their agreement and disagreement," so as to obtain a "just and accurate classification of particular facts, or individual objects, under general well considered heads," and continuing to do so with ever higher levels of generality until "at length, by considering the process, we arrive at axioms of the highest degree of generality of which science is capable."[81] These classifications make possible scientific laws when they are based on *verae causae*, causes that truly make something the kind of thing it is.

[78] *Preliminary Discourse*, ch. 4.
[79] *Preliminary Discourse*, ch. 5.
[80] *Preliminary Discourse*, ch. 6.
[81] *Preliminary Discourse*, p. 102. Herschel's hyphenation.

The treatise on induction by Herschel's good friend William Whewell[82] was the most theoretical in the Socratic line of induction, less of a step-by-step cookbook than Herschel's. Whewell's criteria for good inductions, such as consilience and factual agreement, are more grounded in a theory that relates the formation of concepts to the establishment of universal predication. The man after Herschel most famous for developing concrete guidelines for induction was not Whewell, but John Stuart Mill. Mill reduced inductive criteria to just four "methods of experimental inquiry," but he completely swapped out the theoretical foundations being developed by Herschel and Whewell, turned induction—as the medieval Scholastics had done—from a logic of classification back into a (usually defective) logic of propositional inference, and concluded that "anything like a scientific use of the method of experiments, in these complicated cases [he was discussing medicine but went on to list many others], is out of the question."[83] The better scientists of the future would, Mill was sure, be using deduction, not induction.

For a while, at least, those scientists stayed with what was working. In fact, the zenith of science in the Baconian framework was the period from Herschel in the early nineteenth century until, let us say, John Maynard Keynes in the early twentieth. Though Keynes is now better known for his work in economics in the 1930s, his 1921 *A Theory of Probability* made a major contribution to the turn away from the Baconian conception of induction. In the book, Keynes noted that even though people do not associate David Hume with induction, they should.[84]

6 Examples of Socratic Induction in Science

Whewell called his three-volume history a history of the *inductive* sciences; similarly with his three volumes on philosophy. But in all these volumes he found no need to discuss Hume, the uniformity principle, probability, Bayes, or white swans. These were just not part of his conception of induction or his intended readers'. One major difference between their conception and ours is that nowadays induction is taken, by its very essence, to be a kind of *uncertain* inference, yet Baconians thought it was

[82] On their relationship see Laura J. Snyder, *The Philosophical Breakfast Club* (New York: Crown, 2011).
[83] John Stuart Mill, *System of Logic, Ratiocinative and Inductive* (1843), bk. 3, ch. 10, sect. 8.
[84] John Maynard Keynes, *A Treatise on Probability* (London: Macmillan and Co, 1921), p. 272.

induction that provided scientific certainty. Baconians were always a little cautious about the syllogism, since it seemed to be about words and not things. (Note that while Mill was debating induction with Whewell, parallel conversations were underway elsewhere about whether the syllogism was a valid form of inference at all. See, for example, discussions about quantification of the predicate. Also, any inability to prove a uniformity principle was, at first, considered as much a threat to syllogistic inference as to induction.) Let me briefly review how, in four cases considered in the nineteenth century to be hallmarks of inductive science, induction produced unqualified certainty.[85]

For his textbook example of inductive science in action, Herschel chose William Charles Wells' investigation into the nature of dew, an investigation widely admired.[86] Wells began by limiting his subject to what is "properly … called dew."[87] Herschel describes that as "the spontaneous appearance of moisture on substances exposed in the open air when no rain or *visible* wet is falling."[88] Wells had a *nominal* definition, sought the cause of his subject (the "real cause" or "*vera causa,*" Hershel or Whewell would say), and could—once that cause was found—replace his nominal definition with a *causal* or *essential* one. Using a wide range of experiments, involving many temperatures, weather conditions, seasons, times of day, locations, and materials, and by recognizing that the cause is a specific instance of known general laws of heat, Wells was able to identify dew as a condensation of water vapor that occurs when the dewed surface is cooled by radiation faster than warmed by conduction. This explains dew's complex dependency on thermal conductivity, cloud cover, wind speed, and other factors. The boundaries drawn by the new causal definition allow more universal and certain claims than were possible with the earlier, nominal definition. It could now be said, for example, that dew cannot form on certain materials. If water was found there, it could not be what was now classed as dew. Sure enough, later in the nineteenth century, some botanists studied drops of water found on plants in the morning, superficially similar to dew. By the earlier classification, they were dew. But these drops, it was

[85] For more on three of these four, see John P. McCaskey, "When Induction Was About Concepts," *Concepts, Induction, and the Growth of Scientific Knowledge*, Richard Burian and Allan Gotthelf, editors (forthcoming).
[86] Preface to William Charles Wells, *An Essay on Dew and Several Appearances Connected with It*, edited, with annotations by L. P. Casella (London: 1866)
[87] Wells, *Dew*, pt. 1, sect. 1.
[88] Herschel, *Preliminary Discourse*, sect. 163. Herschel's emphasis.

discovered, had a different cause, the forcing of liquid out through pores. Botanists chose to call these drops not dew, but guttation.

Based on similarity of symptoms, certain ailments were, as early as Celsus (c. 25 BC–50 AD), identified as cholera. But into modern times, little was understood of the disease. General statements could be made about it, but few universal, unqualified, exceptionless ones could be. By the mid-nineteenth century, physicians were grouping cases of cholera into categories. The so-called Indian type of cholera was particularly severe, frequently fatal, and often epidemic. By the 1870s, it was thought to be caused by a "specific organic poison."[89] In 1884, the German Robert Koch claimed to have identified the poison: a particular bacillus shaped like a comma. But the truth of his theory depended on what one meant by "cholera." Koch himself very soon began distinguishing "real (*wirklich, echt*)" cholera from other diseases classified as cholera. By the early 1890s, reference works were adopting Koch's distinction and by 1910, the presence of Koch's comma bacillus, *Spirillum cholerae asiasticae*, was the defining characteristic of cholera. A nominal definition that allowed many general but few universal statements was replaced by a causal, essential (Aristotelian), formal (Baconian) definition. It became possible to say with complete certainty, without reservation or qualification, that if a person is kept away from *Spirillum cholerae asiasticae* the person positively will not, cannot contract cholera. He may get a bellyache, he may vomit, he may have diarrhea, he may spread his illness to others, and he may die of it, but if what he had was not caused by *Spirillum cholerae asiasticae,* then he did not have cholera. A host of universal, exceptionless, scientific statements about cholera could now be made.

Historians of electrical science say that Ohm's law, the law that resistance is the ratio of voltage to current, was discovered by Georg Ohm in the 1820s. But that can be misleading, for the three constituent concepts did not yet exist. At the time, one could report how many pairs of copper and zinc plates were in a Voltaic pile, how large each plate was, the dimensions of a wire joining the metals, and how far a nearby compass needle deflected. But the distinctions between electromotive force, voltage, potential, current, power, charge, charge density, and so on were still being worked out. Some conceptions proved inconsistent; some were too poorly defined to be useful. It took a couple decades for the concepts of voltage and current to reach some maturity. Only as they did could Ohm's theory about

[89] John M. Woodworth, *The Cholera Epidemic of 1873 in the United States* (Washington: Government Printing Office, 1875), p. 8.

the relationship between compass deflection, wire length, and dimensions of a battery take the form it did. In 1834, Michael Faraday called Ohm's proposal a beautiful theory but still called it just a theory. In 1843, Charles Wheatstone wrote, "It will soon be perceived how the clear ideas of electromotive forces and resistances, substituted for the vague notions of intensity and quantity which have been so long prevalent, enable us to give satisfactory explanations of the most important phenomena, the laws of which have hitherto been involved in obscurity and doubt."[90] By 1850, Ohm's theory was being called a scientific law. In 1873, James Clerk Maxwell summarized the history like this: "Here a new term is introduced, the Resistance of a conductor, which *is defined to be* the ratio of the electromotive force to the strength of the current."[91] Ohm's Law was now true *by definition*, resistance *defined to be* the ratio of voltage to current. Can one simply define scientific laws into existence? Maxwell continues: "The introduction of this term would have been of no scientific value unless Ohm had shewn, as he did experimentally, that it corresponds to a real physical quantity."[92] Ohm's Law was not established by an application of hypothetico-deductive experimentation. Rather, classifications were worked out, a conceptual framework was constructed, and essential definitions were formulated. To know whether the universal statement applies, we do not now say, "The resistance of this device obeys Ohm's Law; the resistance of that one does; so too does this other—does the resistance of all devices obey Ohm's Law?" Rather, we ask, "Is this device a resistor?" If what we are measuring does not obey Ohm's Law, then what we are measuring is not resistance. What was shown to be true by induction is what was shown to be true by definition.

Tides were long identified as the flux and reflux of the seas, and mariners had many general things to say about them. But their cause was, until Isaac Newton, unclear. And after Newton, it was another two centuries before mathematics and mathematical science had advanced enough to make practical use of Newton's discovery. These advances made possible highly valuable predictions of the rise and fall of the seas. The predictions, however, were not always highly accurate. For another problem presented

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[90] Charles Wheatstone, "The Bakerian Lecture: An Account of Several New Instruments and Processes for Determining the Constants of a Voltaic Circuit," *Philosophical Transactions of the Royal Society of London* 133 (1843), p. 304.
[91] James Clerk Maxwell, *Treatise on Electricity and Magnetism* (Oxford: Clarendon Press, 1873), p. 296, my emphasis.
[92] Maxwell, *Treatise*, p. 296. Maxwell's spelling.

itself. Newton accounted for the celestial factors, but many non-celestial factors can causes bodies of water to rise and fall regularly. There are daily temperature variations, barometric cycles, seasonal rain patterns, seiches, and even man-made causes such as ships' passages or industrial releases of water. On August 25, 1882, Lord Kelvin, who had by this time done much to promote the mathematical analysis of tides, began an evening lecture by saying, "The subject on which I have to speak this evening is the tides, and at the outset I feel in a curiously difficult position. If I were asked to tell what I mean by the Tides I should feel it exceedingly difficult to answer the question. The tides have something to do with motion of the sea. Rise and fall of the sea is sometimes called a tide; but ..." [93] He proceeded to cite many problems with this definition—with what we may call a nominal definition. Kelvin was here reflecting on the development of tidal science in the two hundred years since Newton proposed what causes the sea to rise and fall and Newton's successors worked out the physics, mathematics, and data-gathering techniques to make it possible to predict such risings and fallings. And Kelvin had to acknowledge that all that science left him unable to tell the sea-captain for sure where the water level will be at a certain time, because all that tidal science has left temperature variations, barometric cycles, and the coming and going of ships out of the equations. Kelvin returned to his theme, "What are the Tides?" and answered, "I will make a short cut, and assuming the cause without proving it, *define the thing by the cause*. I shall therefore define tides thus: Tides are motions of water on the earth, due to the attractions of the sun and of the moon."[94] Centuries of inductive research into what causes tides and Kelvin announces the result: A tide is, *by definition*, caused by attractions of the sun and of the moon. The sea may flux; the sea may reflux; but if some particular fluxing and refluxing has some other cause, it is by definition not a tide. Statements about tides need no longer be just generalizations. They could be unqualified, certain, universal. For they could be deduced from the very definition of a tide.

[93] Lord Kelvin (William Thomson), "The Tides: Evening Lecture to the British Association at the Southampton Meeting, Friday, August 25, 1882," *Harvard Classics* 30 (Collier and Son, 1910), pp. 287–314.
[94] Ibid. My emphases.

7 Certainty and the Maturity of Concepts[95]

It is by concepts that we organize our thinking. There is only so much we can do with poorly formed ones, as Socrates' interlocutors learned. Bacon was explicit: "The syllogism consists of propositions, propositions of words; and words are the tokens of notions. Therefore if the notions [*notiones,* concepts] themselves—this is the foundation—are confused and rashly abstracted from things, there is nothing firm to what is built above."[96] Concepts are also personal. They are cognitive products of individual minds. There are no concepts outside of minds, and no concept of yours is numerically identical to any concept of mine. There may be similarities, but yours is yours and mine is mine, Ohm's was his and Maxwell's his. Concepts are mental integrations of things we observe but their referents are more than the individuals we observed in forming the concept. Concepts, that is, are ampliative. When I say or think, "house," I am referring to all individual things sufficiently similar and yet sufficiently different from other things—and to all such things past, present, and future, actual and imagined. But concepts are not the referents or the open-ended sets. They are the cognitive processes and the results of those processes. They are mental integrations. As such, they change over time. As an infant, I had a certain concept of soap. Over time, my concept changed. The mental integrations grew wider, deeper, and stronger. I made connections I had not made earlier. I more sharply distinguished boundaries of inclusion. Little by little, I even altered those boundaries. I could have kept the old boundaries, but I got on better in life by doing otherwise. Whether your

[95] The reflections in this section have been heavily influenced by my understanding of Ayn Rand's theory of concepts. See Ayn Rand, *Introduction to Objectivist Epistemology,* expanded second edition, ed. H. Binswanger and L. Peikoff (New York: Meridian, 1990), first edition (1979). Although I believe my understanding is consistent with Rand's published work, some scholars more studied in her theories, including some who spoke with Rand about these topics, believe my understanding is flawed. For valuable treatments, see *Concepts and Their Role in Knowledge: Reflections on Objectivist Epistemology*, ed. Allan Gotthelf and James Lennox (Pittsburgh: University of Pittsburgh Press, 2012). For a theory of induction based on Rand's theory of concepts that does not rely on a distinction between general and universal statements, as my reflections here do, see David Harriman, *The Logical Leap: Induction in Physics* (NAL, 2010), especially ch. 1.

[96] *Novum Organum*, bk. 1 aph. 14, my translation. See comparable statements in *Advancement of Learning*, bk. 2, ch. 13, par. 4; *Instauratio Magna*, "Plan of the Work"; and *De Augmentis Scientiarum*, bk. 5, ch. 2, Spedding v. 1, p. 621. For a seventeenth-century translation and comment, see John Webster, *Academiarum examen* (London: 1654), ch. 4, par. 3, p. 34.

concept of soap includes precisely the same integrations, differentiations, classificatory boundaries, clarity, or distinctness as mine, I do not know. If my getting on in life requires that yours and mine are similar and I suspect they are not, I will suggest we each write down our definitions (or consult a third party's) so that our concepts have at least the same referents. If it serves me better, I might go on modifying mine without concerning myself much with that of anyone else. Koch did that with his concept of cholera.

When my concept was immature, there were things I could say about soap that were generally true, but not universally so. The more my concept advanced, the more general could be my statements. Truly exceptionless, unqualified, universal statements required mature concepts not only of my subject, soap, but of predicate concepts as well, of *clean, wash, soft, hard, solid, liquid, dissolve, salt, fat, dye*, and so on, and so also of my concepts of predication itself. I had to mature to the point where I could distinguish the difference between Aristotle's accident, genus, *idion*, and essence. I needed to learn advanced concepts such as *every, all, must,* and *always*. To say things that are universally true about soap, my knowledge needed to advance to where I knew something about what makes soap, soap, and to understand differences in kinds of predication. The more I knew of the essential nature, the formal cause, of soap, the larger could be the scope of my generalizations. Now that I have scientific knowledge of soap, now that I have Aristotelian *epistēmē*, I can make unqualified, exceptionless, universal statements about soap. My concept of soap is now so mature that I can make statements about soap that could be denied only on pain of contradicting my mature definition of soap. I have come to this maturity through many compare-and-contrast operations, ones I have done myself and ones I have heard from reliable informants. There are now unqualified statements I can make that are true by induction *and* true by definition. (I mean to leave open the possibility of similarly certain and universal statements based on *idia* that are not definitional.) On similar grounds, I can now make not only general statements, but universal statements, about bachelors, triangles, and prime numbers.

When Koch began his work, a physician in Missouri had a concept for the disease he called cholera. So too did a doctor in London. The concepts were similar but not numerically identical. In fact, the mental integrations were substantially different. Both physicians classed as cholera ailments involving nausea, vomiting, and diarrhea. But the London physician had formed strong mental connections to water wells, contagion, and ships from India, that is, to what he had thought were causally related. The

Missouri doctor, on the other hand, would immediately consider season and what the patient had eaten. Robert Koch would immediately consider bacteria.

By the time Koch discovered the comma bacillus, he had used the most rigorous standards of classificatory logic—the most rigorous standards of induction, standards that could be traced back through Whewell, Herschel, Bacon, Aristotle's *Topics*, and Socrates' haranguing—to conclude that for the physician to do his job well, he should have a concept for the intestinal disease caused by that bacteria. So many cases that the London physician knew as cholera were in fact caused by this bacteria, and so many of the symptoms, treatments, and courses were exactly as the Londoner knew them, that Koch was recommending that physicians not say, "But I have cases of cholera not caused by your comma bacillus, so your theory must be wrong," but to say, "If I just make some small changes to the boundaries of my classification, I can retain and use almost everything I know about cholera and begin making universal and not merely general statements about cholera. And I could become a better doctor." For the physician in Missouri, many more mental connections needed to be severed and many more new ones formed. But he too found the effort worthwhile. He—or at least his successors—reclassified cases, began making certain claims about how to prevent cholera, and cured more patients.

Notice Maxwell's statement above about Ohm's Law. Maxwell said "so many conductors have been tested that our assurance of the truth of Ohm's Law is now very high." This sounds to us like a claim that a sufficiently large number of experiments have been conducted and enough confirming instances have been found to warrant a high probability that some hypothesized relationship is true. But that is not the situation Maxwell describes in the sentences immediately preceding. He said that enough experiments had been conducted to suggest the value of forming a concept for a property "defined to be the ratio of the electromotive force to the strength of the current." He continued, "The introduction of this term would have been *of no scientific value* unless Ohm had shewn, as he did experimentally, that it corresponds to a real physical quantity" (my emphasis now added). When Maxwell then wraps up by saying, "so many conductors have been tested that our assurance of the truth of Ohm's Law is now very high," he does not mean that a sufficient number of experiments have provided a sufficiently high correlation. He means many conductors have been found that fit the definition and much good will come to the engineers who class these conductors as resistors.

On the first day of a course I teach on the history of scientific method, students read Robert Hooke's publication of what is now known as Hooke's Law: force exerted by a spring is proportional to the compression or extension of the spring. Students see that Hooke tested his theory on a remarkable range of materials, forces, and displacements, and students consider whether Hooke had conducted enough experiments, whether he could be certain, whether maybe the next spring might not obey the law. The philosophy students bring up swans and Bayes and Hume and uncertainty and try to outdo each other in their inductive skepticism. Eventually a physics student who had been puzzled and quiet and increasingly uncomfortable joins the discussion: "If it doesn't follow Hooke's Law, it's not a spring. Following Hooke's Law is what makes a spring a spring." A semester of philosophers and scientists trying to understand each other has begun, as has a long discussion about what Socrates' search for the definition of piety has to do with experimentation, scientific knowledge, induction, and certainty.

8 Two Conceptions of Induction

There are two conceptions of induction. By the first, which prevailed in antiquity and in the period from Bacon to Whewell, induction is a logic of classification. As such it is a logic by which we abstract and form our concepts. The second prevailed from late antiquity until the Renaissance and then again starting in the late nineteenth century. It holds that induction is a logic of propositional inference. By it we derive universal statements from particular statements. This second takes the work of the first for granted. It assumes we already have concepts of swans and water and soap and asks whether some universal statement about them can be legitimately inferred from particular statements about them. But there is simply no way to know whether all swans are white, all cardinals red, and all zebras striped without standards for classifying things as swan, cardinal, or zebra. The first conception of induction holds that propositions are only as good as the concepts on which they are based. Crude and immature concepts may enable statements that are generally true, but few that are universally so.

Propositions are *only* as good as their constituent concepts, but they can be *fully* as good as their constituent concepts. By the Scholastic and modern conception of induction, constituent concepts are taken for granted. But by the Socratic conception, concept-formation is a normative process.

It can be done poorly and it can be done well. If done well, universal propositions become extensions—explications, let us say—of what is contained in the concepts. Yes, evacuation of *Spirillum cholerae asiasticae* will always cure cholera. Yes, you can say that this is "just" true by the very definition of cholera and of *Spirillum cholerae asiasticae*. But those definitions were not chosen on whim. They were selected by human discretion for the objective benefits the classification bestowed on the classifiers. The classifications were not arbitrary.

Sufficiently good concepts can ground unqualified universal statements, but such concepts do not emerge ex nihilo. Scientists, nay all human beings, pull their cognitive selves up by their bootstraps. A simple concept of soap enables rough generalizations about cleaning, itself a crude concept at first. New observations about soap and about cleaning and about how other materials interact enable refinements to the mental integrations that are the concepts of soap and of cleaning. The process is iterative, or better, spiral. Eventually, a thinker sufficiently concerned with soap will so refine his conception that he can make many exceptionless universal statements about soap that he could never have made using his earlier concept. Concepts of increasing and better delimited scope enable propositions of greater generality and more universality—more freedom and more certainty, Bacon would say. This makes sense—predicate concepts are, after all, concepts themselves. And predication is a kind of classification.

Both conceptions of induction hold that one can justifiably infer universal statements from particular statements, but the Socratic conception grounds these universal statements in universal concepts. It holds that in human cognition, ampliation takes place—fundamentally and primarily—at the conceptual not the propositional level. Induction in the Socratic tradition is not exclusively, but is fundamentally and primarily, a logic of classification. It holds that if, and only if, one gets the concepts right can one make unqualified universal statements. The tradition, when it was still active, sought the criteria by which such mature concepts could be formed, their maturity marked, and universal statements therefrom derived.

The tradition deserves a revival.