

Abduction, Complex Inferences, and Emergent Heuristics of Scientific Inquiry

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abstract:

The roles of abductive inference in dynamic heuristics allows scientific methodologies to test novel explanations for the world's ways. Deliberate reasoning often follows abductive patterns, as well as patterns dominated by deduction and induction, but complex mixtures of these three modes of inference are crucial for scientific explanation. All possible mixed inferences are formulated and categorized using a novel typology and nomenclature. Twenty five possible combinations among abduction, induction, and deduction are assembled and analyzed in order of complexity. There are five primary categories for sorting these inferential procedures: fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics.

Experimental sciences use abductions in the course of their methodologies. The involvement of abductive inferences in many kinds of dynamic heuristics allows scientific methodologies to consider and test novel explanations for curious matters, and to gradually increase information about the world's ways.

Science didn't invent abductive inference; it was borrowed. Deliberate reasoning in general – accepting conclusions due to their discerned relationships with relied-upon beliefs – frequently follows abductive patterns as well as deductive and inductive patterns. Deeper cognitive processes such as perception, concept formation, and shifting habits of thought likely modes of abduction.¹ To the extent that the experimental sciences contribute increases in knowledge, they have applied some abduction as well as induction and deduction. The power of scientific explanation does not reside within any of these inferential modes alone. Understanding roles for abduction in satisfactory explanation should look to complex mixtures of these three modes.

A preliminary exploration of those modes, organized by increasing complexity and categorized with a typology, maps out some prominent features of this inferential landscape. Five primary categories emerge for the twenty-five combinatorial possibilities among deduction, induction, and abduction. These inferential procedures can be sorted into fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics. Among these procedures are core methodologies inherent to metaphysical and theological worldviews, and their accurate classification helps to reveal their close relationships with proto-scientific thinking.

Why Abduction?

Deduction reasoning alone may be sufficient to intelligibly relate all knowledge already possessed. Alan Musgrave defends deductivism by pointing out how any generalization appearing to arise from non-deductive reasoning can be re-cast afterwards as a deductive inference with just the right premises added. After showing how to do this with a typical form of generalization, he adds,

“The same applies to all the other patterns of inductive or ampliative reasoning. All can be reconstructed as deductive arguments with suppressed factual or epistemic premises.”²

Reconstructed deductive arguments are useful in their own way, after new information has been established. Of course, knowledge arises (for humans, at least) from learning, and we must figure out which factual or epistemic premises are just the right ones. Being told that some extra fact about the world will convert non-deductive support for a conclusion into its deductive support isn't helpful for learning. Learners want to acquire precisely which fact, when supposed, will turn out to be the right support.³

Inquiry crucially relies on abduction, so that proposed matters can become believable supposed facts. Abduction, by itself, is a blatant fallacy – yet there appears to be no way to avoid it. Neither deduction (necessary inference) nor induction (probable inference) can increase the real amount of information beyond what is already accepted, but abduction (possible inference) can.

If these are the three primary modes of inference, with abduction playing a needed but insufficient role, then abduction may be transcending mere fallacy through its application in concert with deduction and/or induction. Charles Peirce, abduction's 'discoverer', typically situated abduction alongside deduction and abduction in the proper functioning of scientific inquiry. His 1903 Harvard Lectures on Pragmatism is an example:

Abduction merely suggests that something may be. Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction, and that, if we are ever to learn anything or to understand phenomena at all, it must be by abduction that this is to be brought about.⁴

Peirce placed immense confidence in abduction's explanatory powers, so long as it played a helpful role in cooperation with the other modes of inference.⁵

Here, we explore how patterns of procedural abduction – combinations of these three inferential modes executed over time towards some conclusion – can simultaneously reduce the fallacious character of abductions, increase the credibility deserved by their conclusions, and yield increasing information about the world. This preliminary work is concerned with methodologies within empirical inquiry, not about the overall strengths and weaknesses to "inference to the best explanation" or debates over scientific realism.⁶ It delineates, identifies, and evaluates many combinations of deduction, induction, and abduction, from simpler forms to quite complex patterns. Some intricate combinations rise to the level of utility for experimental scientific inquiry. Along the way, non-scientific and pseudo-scientific procedures are exposed as well, which suggests why they can be relevant to the perennial demarcation problem.

Procedural abduction plays a significant role within some phases of proto-scientific and fully scientific methods. Its patterns may be most recognizable in the ordinary inquiries people undertake daily to sort and select simple explanations behind encountered events. Understanding the merits and risks inherent to procedural abduction would not be out of place in an effort to improve critical thinking. Science is by no means 'common sense' enlarged, although continuities are present.

It must be firmly noted from the outset that these patterns cannot be the "essence" of scientific methodology, if there could be such a thing. Nor are these patterns even capable of characterizing the more important inferential methods applied in the sciences. Some of the most complex abductive patterns do begin to resemble what have been called 'heuristics' to scientific inquiry, as later sections note. Science surely gets vastly more complicated than even the most convoluted inferential patterns categorized here. Nevertheless, in these procedural abductions, some of science's proto-methodical 'building blocks' can be discerned, and distinguished from inferential patterns on paths tending to diverge away or run parallel to science.

Abduction Basics

Begin with abduction in its simplest form:

Q
 If A then Q
 So, A ["Simple abduction" – the 'affirming the consequent' fallacy]

Because we are only considering deliberate inferences, and such cognitions are extended in time, this three-part inference is to be understood as displaying temporal phases that matter to the acceptability of any conclusion. Here, 'Q' is learned first, and 'If A then Q' is considered after Q is already in mind, with the conclusion following in both temporality and plausibility (if any may pertain). After acquaintance with all three parts, they may be kept in mind as a single whole for further consideration, just as all the notes of a simple tune may be sustained together in the imagination without having to sing it over and over. Just as the original order of a tune's notes still matter all the same (the same notes in another ordering would form a different tune), the original order of a certain abductive procedure matters to its plausibility. Rearrange the order, and a different abductive procedure is formed. This temporality to abductive inquiry shall remain a presumption for the rest of the procedures discussed in this article.

This abduction fallacy concludes with some candidate 'A' for credibility, though that candidate must be deemed logically unacceptable here. The phrase "Therefore, A" fits well with deduction, and by convention, to induction. Instead of using 'therefore' with abduction, we shall use 'so' to indicate only an intended linkage between premises and tentative conclusion. Hence, "So, A" can only mean something like, "So, it appears that A is plausible," or "So, perhaps A is believable." In the realm of abduction, "So, A" is entirely compatible with "You shouldn't regard A to be credible, since ..." Where abduction is involved, inferences retain their conjectural and fallible status to some degree or another.

There are two intuitive reasons why this simple 'affirming the consequent' is a fallacy. First, almost no credibility can be given to an explanation when innumerable equally explanatory options (B, C, D, etc.) are available, since they haven't been ruled out by Q or any other considerations. Call this the "Explanatory Plenitude Problem". For example, if I blame a roaming raccoon for that sound heard outside my window late at night, I have arbitrarily picked one of many possible causes for that sound. Second, almost no credibility can be given to an explanation when simply positing some imagined A to be responsible for Q supplies no conception of the relationship between A and Q to make responsibility plausible. (And asserting "A is responsible!" is not a conception of the alleged relationship.) Think about it: why would a raccoon be causing such a noise? Call this the "Explanatory Responsibility Problem".

Greatest confidence in A would be earned if we could arrive at: Only if A then Q, and Q, so A. Asserting "Only If A then Q" is an assertion both that no other B, C, etc. can explain Q, and the absence of other explanations is due to the way that the conceived ground of the relationship between A and Q that makes A responsible for Q is so concrete and compelling that A of necessity is responsible for Q. Then A would truly be the best explanation. Of course, that result is gained by effectively replacing abduction with deduction. The distance between simple abduction and straightforward deduction is vast indeed. How can that gap be narrowed?

With simple abduction, so far, some B (or C or D etc.) could be imagined easily to imply Q just like A. We are very far from "Only if A then Q."

What if we prevented any other optional explanations from becoming conceivable?

Q

Only If A then Q [because no other B, C, D, etc. seem thinkable, or if thinkable, they don't feel relevant]
So, A ["Deducible abduction"]

This is the conceptual conversion of "If A then Q" to "Only if A then Q" by psychological means. If B, C, D (etc.) can be made to seem unthinkable and impossible, then A appears to be the forced preference. But this tactic is only about biasing the mind, not learning about reality. Adjusting or interfering with people's minds to cause mental poverty or ignorance in a group cannot be a reasonable way to rule out the existence of alternative possible explanations. Deduction is a dangerous method to apply to substantial matters without caution. Conceivability may be a sign of real possibility, but inconceivability should never be taken to be a sure sign of impossibility about material matters. Limiting your knowledge to only what you find currently conceivable will prevent further learning. Nevertheless, a principle that "Foreign explanations are inconceivable among us!" – let this be labeled as the "Social Inconceivability of Options" principle – often operates among social groups.

More brains thinking just like us can't really increase deserved credibility. Back to observations then, so we need more Qs.

Q1
 If A then Qs
 Q2, Q3, ... [induction]
 So, A ["Inducible abduction"]

A seems to reliably predict lots of Qs, and more Qs keep coming. If one is primed for spotting more Qs as they occur, A can seem so predictive. But what about some rival explanation B? If B, then Q, and Q1, Q2, ..., So B! And what about C or D as well, explaining those Qs that have been already observed? When all that has been observed is a reliable pattern of Qs, no A or B (etc.) seems to really put to any explanatory test. Just taking a series of Qs to be good evidence for A leaves one prone to a simply confirmation bias. However, where equally successful 'explanations' can proliferate just by imagination, the credibility for any single explanation falls towards zero.

So far, we have combined simple abduction with deduction and induction, without making much progress towards discovering a procedure deserving credibility. However, we do see where deduction and induction can be combined with abduction. Those two combinations can dominate abduction so that the procedure really isn't abductive anymore, but instead primarily deductive or inductive in nature. The three basic forms are:

ABDUCTION, because it is accounting for a surprising fact which is doing most of the credibility work.
 Q !
 If A then Q
 So, A

INDUCTION upon abduction, because it is the iteration which is doing most of the credibility work.
 If A then Q, and Q
 If A then R, and R
 If A then T, and T
 So, A

DEDUCTION upon abduction, because it is the definition of A which is doing most of the credibility work.
 Q !
 If A's definition is suitably changed, then Q
 So, A

Returning to our analysis of Inducible abduction, what about rival explanation B? If B, then Q, and Q1, Q2, ..., So B!
 And what about C or D as well, explaining those Qs that have been already observed?

We need to look at more than Qs. Two primary options open up at this stage.

EITHER

Qs, and If A then Qs
 Rs, and If A then Rs
 Ss, and If A then Ss
 Ts, and If A then Ts
 ...
 So, A [abductive induction – "Iterative Abduction" – a sequence of similar abductions of things]

OR

Both Qs and Rs have feature F1
 If A then Qs and Rs would have F1 [after defining A to 'effect' that analogous F1 displayed by both Qs and Rs]

Both Qs and Rs have feature F2

If A then Qs and Rs would have F2 [A's definition also 'effects' that analogous F2 in both Qs and Rs]

...

So, A [abductive deduction – "Coduction" – an abduction of similar features in things]

Let's discuss Coduction first. Although it applies abduction, it really is a kind of deduction. Deducing similar phenomena, these analogous features in both Qs and Rs, from A's definition is actually doing the plausibility work. This A can 'effect' – can 'be responsible for' – a curious series of analogous features (they only need be similar/analogous, not identical features) in two otherwise different things. There can be great intuitive plausibility attached to an A which can account for why separate things would display analogous features. We suspect some hidden thing responsible for the similar features to otherwise separate matters. We rely heavily on this basic Coduction in our human world, for example. When we visit a neighboring house and compare that house with our own, we might notice how that house has the same-sized kitchen to the left of the dining room, which also open up to the right onto the same-sized living room just as ours does, and the stairs proceed from that room up to two bedrooms just like our own house has, and so on, we soon will be thinking that both houses probably were designed by the same architect.

The detection of similar features across different things is a core intellectual capacity, and 'coduction' points at the inherent plausibility awarded to an explanation able to be responsible for that detected correlation. However, two main problems arise to severely limit the reasonableness of Coduction. First, the Explanatory Plenitude Problem will persist, since rival explanations B, C, D (etc.) will also try to be responsible for the same Fs of Qs, Rs (etc.). That opens the door for the second main problem: as rival A, B, C (etc.) set off to account for more and more analogous features among Qs, Rs, Ss, and even more things, our cognitive capacity to 'detect' similarities across disparate things will get powerfully exercised. We are too good at this capacity, though. Cognitive biases again make their influence felt, especially in our tendency to attend closely to coincidences and perceive strong patterns where only weak ones really exist. We can find analogous features in about any two different things with enough imaginative creativity. Our efforts will go into detecting analogous (we imagine) features of things, and not into the proposed connecting relationships between explanation A and feature Fs. This Explanatory Relationship Problem, as we can label it, will only grow. However, Coduction does show powerful explanatory power, even if controlling that power is evidently crucial. We will re-engage with Coduction after some detailed explorations into Abduction.

Next, concerning Iterative Abduction, while it applies abduction it really is a kind of induction. Intuitive plausibility can attach to an A which can account for why separate things display their detected frequency patterns after those patterns are discovered. A simple example illustrates the degree of plausibility that Iterative Abduction deserves. When I am upset to find that the garbage can behind the house has been overturned and garbage is littered about, I imagine a raccoon getting a midnight snack. The next day, not only has the garbage can been overturned and pillaged again, my neighbor's garbage can has also pillaged. After several similar incidents, I can't help but think that a raccoon has found a congenial picnic location.

There is a degenerate form of Iterative Abduction, where A is used to repeatedly 'explain' a series of features to Qs:

Qs have F1, and If A then Qs have F1

Qs have F2, and If A then Qs have F2

Qs have F3, and If A then Qs have F3

...

So, A [limited abductive induction – "Singular Iterative Abduction"]

This narrower form can helpfully focus attention on a plausible explanation, but its explanatory power is severely limited. To continue my earlier example, I might notice how only certain kinds of food wastes left in my garbage appear to be consumed each night – just waste from foods containing nuts, peanut butter, or seeds. Every time that my garbage is invaded, I notice how either nuts, seeds, or peanut butter products appear targeted, so my suspicions turn towards a squirrel instead of a raccoon.

For both Iterative Abduction and Singular Iterative Abduction, some alternative explanation B could keep pace with similarly explaining the features of many Qs, or the series of Qs, Rs, Ss, etc., just as well as A. There is an additional risk that as more explanations C, D (etc.) also try to keep up, they become explanatorily empty. However, Singular Iterative Abduction in the long run, if perpetually successful, may arouse the suggestion that A and Qs may not be separate matters. If every significant feature of all Qs is 'reliably' effectuated by A, and A does not possess any of its own capacities not busily effectuating Qs, then the conceptual distinction between A and Qs fades. Perhaps Qs simply are manifestations of A from various 'perspectives'. For example, I still recall my astonishment as a child upon being told that traveling through fog is just like traveling through a cloud. Later, I learned why: there is hardly a difference between fog and cloud except altitude; one could fairly say that fog is just a cloud down upon the ground.

The "Principle of Identity of Effects" serves as a label for the proposal that where an explanatory thing always effects the same phenomena and never effects anything else, then those phenomena are just manifestations of that explaining thing. This principle can be very useful, but it must be applied cautiously, as discussions of more complex procedures shall illustrate.

Why wait to see what kind of A can keep predicting each and every thing that comes along? Perhaps we can define A more carefully up front. What if A can effect ... everything!

[everything – all observed 'Zs' where a Z could be anything]

There is no Z such that If A then not-Z [by defining A just right and then deducing this second premise]

So, A [extreme deducible abduction – "Panoptical abduction" – abduction by everything observed]

While uncommon, this extremely imaginative sort of 'explanation' isn't alien to human thinking. When people long ago mostly lived in isolated villages, rooted to their local agricultural life, childish questions asking why the sky displays its bright lights, or why the landscape has its peculiar features, or why the people do the daily tasks they do, might (depending on local tradition) all be answered with ancient lore about a single high god who turns out to always be responsible for arranging all matters. Seeing "the hand of god" in all things remains an explanatory tactic available to theology to this day. Yet this tactic remains vulnerable to local ignorance; its plausibility relates to the "Social Inconceivability of Options" principle often operating among social groups. That vulnerability is exposed when one village discovers how the neighboring village credits everything to a different deity. That's the risk to crediting a lone A for all that explanatory work – what about some imaginatively defined B that can explain everything too?

Deduction is needed again. What we need is an additional principle to add to the deduction process.

There is no Z such that If A then not-Z [deduced from A's definition]

There is no Z such that If B then not-Z [deduced from B's definition]

[everything]

If X is responsible for a set of things and Y is responsible for precisely that same set of things, then X=Y

[Principle of Identity of Responsibles]

So, A ["Reductive panoptical abduction"]

The Principle of Identity of Responsibles has some intuitive power because one commonsensically doesn't expect some Z to really be entirely caused by both A and B, so only one is probably involved. For example, two neighboring villages, or two entire religions, may suspect that fewer than two deities are fully responsible for all creation (so they instead argue over the correct name for that singular supreme deity). However, that helpful intuition cannot logically identify which one, A or B, is actually responsible, or whether some unknown C might really be responsible. This Principle of Identity of Responsibles can't be generally valid. It only seems to be valid so long as there is nothing that could ever be unexplainable by A or B. Under those extraordinary conditions, we can't conceive of a difference that makes a difference. As Peirce judged, no logical difference remains between two hypotheses permanently having the same empirical consequences.⁷ We can decide that the A/B distinction is just semantic, and we reduce them to each other so that only one explanation is really involved. In this atypical context alone, the Principle may be admitted.

But what about the way that it could still be the case that even “If A then [everything]”, each particular Z never depends on A? Defining A “just right” to be logically compatible with all Z does not permit the inference that Z every actually depends on A. In fact, the vaguer A gets by definition to stay compatible with everything in the world, the less we are able to conceive of the grounds for a dependency relationship of any Z to A. A is assigned fewer and fewer traits and the remaining traits get more and more abstract. There is less and less in common between A and any particular thing, to the point where A shares almost nothing or nothing in common with things and cannot be understandably relatable to all things. (Theologians are familiar with the way that metaphysical conceptions of God can easily get vaguer the more that God is unlike creation.) The “Explanatory Relationship Problem” arises in the long run, in a new form. The claim that “A is responsible for each and every thing” can become explanatorily vacuous and the conception of A becomes empty. Label this as the “Explanatory Emptiness Problem.”

In order to avoid that explanatory dead end, we must return to a stage before deduction was allowed to tempt us to define A with excessive ‘explanatory’ power. We therefore return to this stage:

Qs, and If A then Qs

Rs, and If A then Rs

Ss, and If A then Ss

Ts, and If A then Ts

...

So, A [abductive induction – “Iterative Abduction” – a sequence of similar abductions of things]

Yet it is still the case that some alternative B might keep up with explaining Qs, Rs, Ss, etc. That possibility of competition should not get ruled out. So we must restrain our conception of A in advance.

Abduction Controls

Let’s try to control the definition of A so that it only has a delimited amount of traits and powers.

Qs, Rs, Ss, and Ts !

If A then Qs

If A then Rs

If A then Ss

If A then Ts [and given A’s definition, by deduction we see that there are no more things for A to explain]

So, A [deduced abductive induction]

All the same, we won’t wait long for some B, C, and D to show up to explain Qs, Rs, Ss, and Ts too. It’s too easy to conceive of some new B (etc.) such that E ‘explains’ a given list of Qs, Rs, Ss, and Ts already observed. (A cat or a dog, rather than a raccoon, may be getting into each house’s garbage cans on my street.) If many conceivable causes for the same observed phenomena can be considered, what can be called the “Explanatory Plenitude Problem” arises to diminish confidence in any of the possible A, B, C, D, etc.

Delimiting the conception of A up front was too hasty. We must limit the explanatory responsibilities of A without delimiting them too much up front. Our answer is this: we shall permit A (and B, etc.) to be defined generously up front, permitting it to potentially be responsible for matters not yet observed.

Qs !

If A then Qs

Rs !

If A then Rs [given A’s definition, by deduction we see how Rs would be expected from A]

So, A [“limited iterative abduction”]

Of course, some alternative explanation B could also turn out to expect Rs too. What could throw the advantage to A again?

A's advantage would be due to greater explanatory reach. How many novel phenomena might A be able to 'predict' after their discovery – how much can A 'retrodict' in the long run?

Qs !
 If A then Qs
 Rs !
 If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]
 Ss !
 If A then Ss [given A's definition, by deduction we see how Ss would be expected from A]
 ...
 So, A [deducibly abductive induction – "Retrodicted Abduction"]

This procedure can continue for a long time, depending on the initial definition of A and how many kinds of phenomena can be elicited from it. (If only a dog would knock over lots of garbage cans, and eat all of the food waste, and dig a hole nearby to bury a steak bone, etc., then suspicions turn towards blaming a dog.)

There is a similar inductive version to Retrodicted abduction, "Retrodicted Induction":

Qs !
 Suppose that If A then Qs [after designing A's definition quite vaguely, to expect Qs along with plenty of other unspecified matters]
 Rs !
 Suppose that If A then Rs [now expecting Rs from A's vague definition too]
 Ss !
 Suppose that If A then Ss [now expecting Ss from A's vague definition too]
 ...
 So, A [abducibly deductive induction – "Retrodicted Induction"]

Retrodicted Induction superficially looks like an abductive procedure. It surely is far more suspicious, because A's definition is designed in advance to 'explain' not just some initial Qs but also plenty of other vaguely indicated matters, so that any chosen Rs, Ss, and Ts (etc.) can get 'explained' when they show up later. (If my partner gets fearfully convinced that a bear is roaming the neighborhood, without knowing much about bears, that suspicion gets stronger every day that a mess is discovered, because "That's apparently just what a bear would do!") Retrodicted Abduction seems less suspicious by comparison, because at least A has the modestly greater merit of not being pre-designed to vaguely fit with some selected set of phenomena observed later on.

For an explanation A supported by either procedure, some rival explanations B, C, and D will try to keep pace, but a failure rate will build up among them. It is possible that some E will outpace all other explanations tried so far, by retrodicting more explained phenomena than the rest without exhausting its explanatory powers.

If two explanations, E and F, have explained all surprising Qs, Rs, ..., Zs without signs of explanatory exhaustion, perhaps E and F are really about the same thing? Apply the Principle of Identity of Responsibilities here: If X is responsible for a set of things and Y is responsible for precisely that same set of things, then X=Y. However, that Principle is not valid in this context, where it is not known whether their sets of explained phenomena will remain the same, so therefore E and F cannot be known to be identical to each other.

Furthermore, conceptions of E and F becoming vaguer as they repeatedly come up with post-hoc ways to 'explain' what gets observed. By the Principle of Explanatory Emptiness, explanations E and F (etc.) risk becoming vacuous as they race each other to maximize phenomena explained. It seems to be a dead end to expect maximal retrodictions from explanations.

More pressure must be put on the explanations A, B, C etc. by the things Q, R, S (etc.) that they are supposed to be responsible for. Two primary options emerge and diverge at this stage.

The “Predicted Independent Phenomena” scenario, in which the definition of A gets induced to expect an iteration of Qs, Rs, etc.:

If A then Qs [given A’s definition, by deduction we see how Qs would be expected from A]

A pattern of Qs gets discovered !

If A then Rs [given A’s definition, by deduction we see how Rs would be expected from A]

A pattern of Rs gets discovered !

...

So, A [deduced inductive abduction – “Predicted Abduction”]

OR

The “Predicted Analogous Phenomena” scenario, in which the definition of A is used to deduce features, and a iterated series of Fs are predicted for Qs and Rs:

If A then Qs and Rs have F1 [from A’s definition, by deduction feature F1 is expected in both Qs and Rs]

Qs and Rs have F1 !

If A then Qs and Rs have F2 [from A’s definition, by deduction feature F2 is expected in both Qs and Rs]

Qs and Rs have F2 !

...

So, A [induced deductive abduction – “Predicted Coduction”]

Predicted Abduction is the first procedure in this development which genuinely deserves some credibility. It combines two important features. First, the definition of A remains stable throughout the iterations of abductions (this will become highly significant), so iterations are deduced from the same definition to A. Second, the definition of A is applied to make “novel” predictions about what would be discovered, and those discoveries are made. This is abductive risk, which should not get lost. (Knowing more about dogs than bears, I can predict further signs of canine scavenging around the neighborhood, and watch for confirmations.) So long as the iterated pattern of successful predictions can continue, A can enjoy some deserved credibility. How much credibility? Well, we mustn’t get too attached to A, because its run of explanatory luck may not be long, especially because the definition of A is inflexibly rigid. How much can A really keep predicting?

We consider Predicted Coduction next. Like its simpler version already considered, this procedure must eventually suffer from the Explanatory Relationship Problem. Recalling my neighbor’s house, sharing striking features to its floor plan with my own house, we might notice further similarities as we get more convinced that one architect designed both houses, while overlooking major dissimilarities and ignoring the possibility that two different architects coincidentally designed similar plans. All the same, an explanation A using Predicted Coduction will resist its dismissal, on the grounds that it has impressive explanatory power, by accounting for surprising similar features to different matters. That impressive ability to focus attention only on similarities, in the long run, is exactly what should erode its credibility upon reflection.

As A is applied for finding expanding analogous features to separate phenomena, great pressure will compel the conception of A to change and develop, so that it can ‘effect’ additional features to new things while still accounting for already explained features.

Abduction Inflation

If Predicted Coduction is applied in a more flexible manner, then it will actually look like this in practice:

The “Predictably Analogous Phenomena” procedure:

If A then Qs have features F1 [given A’s definition, by deducing how Qs having F1 are expected]

Qs have F1 !

If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]

Rs have F2 !

...

So, A [inducibly deductive abduction – "Predictable Coduction"]

This flexible procedure of Predictable Coduction deserves its name, because after a while this mode of explaining gets somewhat predictable. Primed by an initial supposition of A, our cognitive capacities search out novel features of curious matters, and then we ponder adjusting our conception of A just right to 'predict' some analogous feature to those matters getting explored. For example, suppose my friend makes his first visit to a foreign country and barely understands its language. Overhearing native speakers warn against the 'zumzum' (names have been changed to protect the innocent species), my friend infers that this zumzum is a nasty thing to watch out for. That night, noises against the window disturb her rest, she notices a red bite mark on her ankle the next day, and on the third day she catches a glimpse of something small crawling on her sandwich. She now thinks that a single insect is behind these manifestations: this 'zumzum' is a flying bug, that seems to also be a bug that flies onto people to bite them, as well as a hungry biting bug that lands on food. Confident that she has identified what this zumzum is, after blaming it for a series of incidents "bugging" her, she would be surprised to learn from local inhabitants that 'zumzum' doesn't actually refer to any of those things.

The abduction aspect to Predictable Coduction inflates the conception of A to keep up with whatever evidence is brought before it. We simultaneously 'guess' at what A should be conceived as while we try to detect just those suitable analogous features which will 'fit' well enough with a revised conception of A. After those features are 'found', then we 'confirm' that revised conception to A, and even higher credibility gets assigned to A. There is no lack of cleverness to this procedure, since it may be difficult to simultaneously imagine a modified A that can 'effect' just the right analogous features to some new matter still getting explored. This sort of procedure can be productive at the 'cutting edge' of new knowledge, where features of poorly understood things are not clear at all. That's why the 'detection' of 'predicted' features can happen more easily, and 'confirmations' to A are more frequently available than with any well-established subject matter. This also explains why, despite the difficulties to 'predicting' novel features to things, rival explanations B, C (etc.) can manage to compete and survive alongside A.

As suspicious as this flexibility to A (and B, C, etc.) must be, Predictable Coduction marks a needed transition in the development of explanatory inference, precisely because A's conception is changing to respond to more and more evidence. Not only is the conception of explanation A central to the evaluation of these inferences, a feature of any material inference, any potential growth for a material inference's explanatory power lies in the deliberate inquiry-led modification to explanations. Down that road lies the full explanatory power of material inferences harnessed to inquiry-driven evidence gathering.⁸

Although Predictable Coduction displays some explanatory potential, a degenerate form of Predictable Coduction refuses to make specific predictions about what phenomena would be observed. Instead, this procedure first notices unusual features to newly discovered things, and then adjusts its explanation A so that those features 'fit' a pattern of analogy with previously explained features to other phenomena.

The "Deducibly Analogous Phenomena" procedure:

Qs have F1 !

If A then Qs have features F1 [given A's definition, by deducing how Qs having F1 are expected]

Rs have F2 !

If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]

Ss have F3 !

If A then Ss also have analogous features F3 [after adjusting A's definition again, then deducing how Ss having F3 are expected, while still deducing Rs with F2 and Qs with F1 too]

...

So, A [deducibly abductive induction – “Iterative Coduction”]

Iterative Coduction can attract even more credulous believers than Predictable Coduction, because this procedure can be repeated and applied to almost anything novel and somewhat mysterious, making it appear that A is endlessly ‘explaining’ many new curious matters and yielding explanatory connections among them. As A conceptually inflates, its believability seems to grow. This attractive credulity is the reason why fascination with the “uncanny” linked with oft-repeated superstition is prevalent across human societies. For example, faulting malevolent spirit(s) for all sorts of human miseries is not a common custom of only pre-modern times. (Societies accustomed to such ‘explanations’ typically host ‘experts’ predicting and negotiating with these hidden powers.) Iterative Coduction is a procedure utilized by mythic thinking, because it is both scalable and hierarchical. It can be broadened endlessly across ranges of phenomena, and higher-level explanations can superstructurally be “Coduced” to unify important features displayed by lower level explanations.

Claude Lévi-Strauss located the divide between scientific and nonscientific mentality here. Both care for evidence and explanation, but mythic mentality spins its intense practical obsession with everything in the environment into all-encompassing explanatory webs.⁹ It is unnecessary to appeal to Lévi-Strauss’s controversial theses; a reliance of mythic cosmology on Iterative Coduction is evident. When a single and supremely explanatory web uniting all explanatory webs is creatively developed, the realm of mythic cosmogony emerges, perhaps including agent deities or at least supreme powers. Where a grand mythic web of explanation is sustained by structured inculcation across generations, it acquires features commonly associated with religion.

The second and third intellectual strategies both lead to the same desired result, a guarantee that A will be the ‘best’ and final explanation, amounting to a procedure which we label as Deduced Coduction.

Qs have F1, and If A then Qs have F1

Rs have F2, and If modified-A then Rs have F2

Ss have F3, and If modified-A then Ss have F3

...

Principle of Explanatory Fertility / Principle of Identity of Responsibilities

So, A [inducibly abductive deduction - Deduced Coduction, by pan-fertility or by pan-responsibility]

In addition, recalling the procedure of Panoptical Abduction, a third strategy to ‘guarantee’ that A is the best and final explanation can be rationalized. This third way is called “Reductive Pancosmism” because everything that can ever be in the cosmos is reduced to an effect of a single ultimate explanation.

There is no Z such that If A then not-Z [deducible from A’s flexible definition]

[everything]

Principle of Explanatory Fertility / Principle of Identity of Responsibilities

So, A [abducible inductive deduction, Reduced Pancosmism, by pan-fertility or by pan-responsibility]

Metaphysical systems, some idealistic and others materialistic, can resort to Deduced Coduction and Reduced Pancosmism, as the history of philosophy displays. Core differences among kinds of theologies are also traceable back to these procedures.

Materialisms tend to prefer Deduced Coduction while idealisms typically rely on Reduced Pancosmism. Four primary types of ‘mono-theology’ also distinguish themselves here. The development from magical and superstitious imagination towards mythic ideas about hidden agents and guiding powers reaches its culmination in cosmogonic religions and rationalizing theologies. Hinduism’s Upanishads and Advaita Vedanta relied on Reduced Pancosmism by pan-fertility, as the transcendent reality endlessly generates (perceptibly or imperceptibly) all dualities and natural entities. Christianity’s monotheism relied on Reduced Pancosmism by pan-responsibility, as the lone Creator effected (directly or indirectly) each natural thing. Greek polytheism produced a theology that can be called “panpolytheism” which declared that other nations’ pantheons apply their local names to the one true set of gods genuinely responsible for all events, hence relying on Deduced Coduction by pan-responsibility. Roman

Stoicism relied on Deduced Coduction by pan-fertility, by attributing to uniquely supreme powers ('deities') the responsibilities for harmonizing all of nature's generative cycles and supportive habitats.

Abduction Development

Let us return back to two procedures already enumerated, positioned before mythic thinking branched away: the Predicted Independent Phenomena scenario and the Predictably Coductive Abduction procedure. To recall:

The "Predicted Independent Phenomena" scenario:

If A then Qs [given A's definition, by deduction we see how Qs would be expected from A]

A pattern of Qs gets discovered !

If A then Rs [given A's definition, by deduction we see how Rs would be expected from A]

A pattern of Rs gets discovered !

...

So, A [deduced inductive abduction – "Predicted Abduction"]

AND

The "Predictably Analogous Phenomena" procedure:

If A then Qs have features F1 [given A's definition, by deducing how Qs having F1 are expected]

Qs have F1 !

If A then Rs also have analogous features F2 [after adjusting A's definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]

Rs have F2 !

...

So, A [induced deductive abduction – "Predictable Coduction"]

Predictable Coduction enjoys an enormous advantage over Predicted Abduction: its definition of A is permitted to developmentally change. Turning to an example from physiology, the heart was long ago connected to the flow of red blood. If the heart by definition rhythmically puts red blood out through the arteries for consumption by the body, then further events would be observed; the ancient Greek physician Galen noted pulsing red blood from cut arteries of the limbs, and hearts pumping blood from its chambers during vivisection. Galen's delimited definition for the heart allowed centuries of physicians to ponder how the heart makes red blood, why heart valves restrict blood flow direction, where blue blood comes from, why some arteries are conveying blue blood, and many more mysteries. Harvey's seventeenth century discoveries about the heart and circulatory systems were predicated on flexibly defining the heart differently. The heart does not make blood and blood isn't consumed but only transformed, as the blood is pumped out through arteries, back towards the heart through veins, and cooled by the air in the lungs during a side trip (he was unprepared for reconceiving the lungs).¹⁰

Admirers of Predicted Abduction might point to its definitional rigidity to endorse its higher credibility, since A doesn't receive post-hoc modifications suspiciously capable of predicting new phenomena. It is the case that Predictable Coduction's flexibility exposes this procedure to the high risk of degenerating into post-hoc pseudo-explanations, explanatory vacuousness, and superstitious thinking. However, puritanical admiration for Predicted Abduction would be misguided. After all, the definition of A just to explain the initial Qs had to be forged from available prior notions, and A's conception is almost always some modified older idea. Furthermore, revolutionary theories in the history of science always undergo modification and development as they are extended to wider and disparate phenomena. It is very difficult to identify some useful hypothesis which never changed at all from its initial conception to its fullest utility. Nor does theoretical rigidity serve as a reliable predictor of scientific success – many of best confirmed scientific theories underwent dramatic development in the

course of their thorough testing. Indeed, theoretical rigidity seems to always part of the regrettable story to discredited explanations.

Let us honestly admit that explanatory rigidity is no safe path towards credibility. Permitting explanatory flexibility, we next generate the procedure of Predictable Abduction:

The “Predictable Independent Phenomena” procedure:

If A then Qs [given A’s definition, by deduction we see how Qs would be expected from A]

A pattern of Qs gets discovered !

If A then Rs [after adjusting A’s definition, then deducing how Rs would be expected from A, while still deducing Qs too]

A pattern of Rs gets discovered !

...

So, A [deducibly inductive abduction – “Predictable Abduction”]

At this stage, with two tentatively viable procedures, we can see how far we have come all the way from simple abduction to inducibly deductive abduction and deducibly inductive abduction.

Both procedures flexibly alter an explanation in the course of anticipating and predicting novel patterns to things or novel features to things. As we discussed, Predictable Coduction is a dangerous procedure to explore. Unless strict controls are placed upon modifying A in the process, A soon enjoys vast explanatory fertility at the cost of becoming explanatorily vacuous and/or A only ‘explains’ things as they get discovered, generating myths. All the same, discerning an explanation behind the prediction of analogous features to otherwise separate things feels familiar to us and possesses an undeniably powerful cognitive appeal. Things really are more deeply connected that they may appear, as a natural matter. The tougher question is how to develop this Coductive procedure in order to weed out poor explanations from better ones. Let’s set this issue aside, for now.

Predictable Abduction also look familiar and compelling, for obvious reasons. Let’s try to develop this Abductive procedure in order to weed out poor explanations from better ones. We should first admit that good explanations try to explain already curious matters. We should also admit that if we will be permitting conceptions of explanations to get set down and also modified, those explanatory features should have the capacity (somehow) to effectuate Qs, Rs, and so on, so that there is some conceivability to A (A at least has its set of capacities C1, C2, etc.), and also some conceivability to the basis for the effective relationship between the explanation and the phenomena getting explained.

This next procedure controls the set of capacities so that they are immediately put to use to explain how Qs, Rs etc. get effectuated.

This AIA procedure: A and its capacities Cs are abductively related, and then that relation is induced to effect Qs, Rs, etc.

Qs !

(If A then C1), then Qs would be effected from C1

(If A then C2 too), then Rs would be effected from C2

Rs !

(If A then C3 too), then Ss would be effected from C3

Ss !

...

So, A(Cs) [abductively inductive abduction - AIA]

The problem with AIA is that crediting A with multiple capacities, accumulating to account for more and more phenomena, leave the conception of A with a set of otherwise unrelated and ad hoc capacities. Looking to the history of science, the example of germ theory illustrates AIA’s potential and limits. The hypothesis that tiny living forms or ‘germs’ are involved with sepsis and pestilence traces back to the seventeenth century. Over

subsequent centuries, germs were occasionally raised by speculative physicians and botanists to account for very different phenomena from infections, boils, and fevers to plagues among humans and livestock, and even to afflictions to plants and crops. The concept of ‘germ’ was left far too vague, and related to varying phenomena in an ad hoc manner, leaving little solid information for researchers to work with. By the late nineteenth century, biologists were distinguishing bacteria, molds, fungi, worms and other parasites, and many more kinds of microorganisms, permitting scientists to link specific pathogens with certain maladies. AIA by itself credits A with various capacities ‘generated’ from A, but not because we really understand A, but only because they would conveniently produce the phenomena. There’s no reason given why A would have these Cs, or how they relate to each other. Instead of the Explanatory Vacuousness problem, there is a mysterious Capacity Overload problem. Furthermore, any rival explanation B, C, (etc.) can keep pace by including those capacities too, so no explanation can really gain any advantage over sufficiently imaginative rivals even in the long run.

To avoid the appearance of arbitrariness where Cs are gradually elicited from the conception of A, it is possible to first list all the Cs that the explanation should have, and then check to see if those capacities do effectuate further Rs, Ss, etc.

This IAA procedure: A and its capacities Cs are inducibly related, and then that relation is abductively effectuating Qs, Rs, etc.

C1, C2, C3 ... imply A which has these Cs, and Qs would be effected from C1

Qs would be effected from C1

Qs !

Rs would be effected from C2

Rs !

Ss would be effected from C3

Ss !

...

So, A(Cs) [induced abductive abduction - IAA]

The problem with IAA is that the initial list of capacities for A would have to be amazingly predictive of not just the initial Qs, but also the Rs, Ss (etc.) in advance. It would require the most extraordinary guessing at just the right needed capacities to accomplish this procedure successfully for very long. If that amazing guessing feels somehow believable to someone, that person would find A extremely credible. But more skepticism is recommended. This procedure can work well on someone ignorant about Qs, Rs, Ss, etc., so that the fraudulent claim is made that this explanation A arose long ago before all these Zs were discovered but A still managed to ‘predict’ them. For example, the attraction to “Ancient Wisdom” that amazingly anticipates today’s matters and recently discovered phenomena falls into this category of intellectual fraud. Of course, that explanation A was actually invented recently after all those Zs had been discovered, and so this procedure effectively collapses into IAD, Deduced Coduction, which is a ‘theological’ procedure.

A similarly suspicious procedure, IIA, simply assigns a set of Cs to an A which are capably of effecting any number of Zs of some general character.

This IIA procedure: A and its capacities Cs are inducibly related, and then that relation is inductively / effectuating Qs, Rs, etc.

C1, C2, C3 ... imply A which has these Cs, so that various Zs would be effected from one or another of the Cs

Qs !

Rs !

Ss !

...

So, A(Cs) [induced inductive abduction – Elicited Abduction]

The way that Elicited Abduction won't say in advance much about what specific sorts of phenomena these Zs will be must arouse suspicion and skepticism. When specific Rs, Ss (etc.) get detected and elicited into service, it would be too easy to say that those are the among the Zs 'predicted' by A having those Cs. For example, a pseudo-scientific theory such as astrology relies on this Elicited Abduction procedure, in which the capacities of heavenly bodies are supposed laid down by the theory, and they in turn are responsible for vague sorts of elicited Zs noteworthy here on earth. When interesting things do happen on earth, such as Rs and Ss (you are born with a certain temperament, or specific things happen to you today) then the astrologer announces that those Rs and Ss were indeed among the Zs "foretold" in the heavens. This procedure is most plausible to people who are already quite susceptible to confirmation biases.¹¹

Instead of specifying A's Cs in advance, we could return to a method that adjusts the Cs possessed by A gradually, as the procedure goes along from prediction to prediction.

The ADA procedure: A and its capacities Cs are abductively related, and then that relation is deductively applied to imply analogous features to Qs, Rs, etc.

Qs have F1 !

Supposing (If A then C1), then Qs would have feature F1

Supposing (If A then C2 too), then Rs would have feature F2

Rs have F2 !

Supposing (If A then C3 too), then Ss would have feature F3

Ss have F3 !

...

So, A(Cn) [abductively deductive abduction – ADA – Abductive Coduction]

Abductive Coduction manifests a tendency, also seen in IIA, towards a strong resistance to any disconfirmation. Suppose that after supposing that A has C4 and expecting some Ts with feature F4, those Ts aren't showing up as predicted. Has A suffered from a disconfirmation, so that doubt instead of credulity is earned here? No, the proponent of A will explain, all that has happened is that the fallible abduction that A has C4 was hasty and mistaken. A hasn't been disconfirmed at all – only C4. In fact, this bad prediction has yielded credible information about A, that it lacks C4. But A's existence remains a secure matter, we will be assured. Over time, by this selective procedure, A will acquire capacities (let's say) C1, C2, C3, C6, C12, C15, C19, C23, and C37. Look at how many capacities of A have been "confirmed"!

Although Abductive Coduction is minimally proto-scientific, since it is at least imaginatively experimental, reliance on this procedure would be unwise. The danger is that devout conviction that A is real can be sustained in foolishly credulous people for a long time by applying this hit-or-miss method. Conspiracy theorists rely on selective Abduction Coduction; they imagine that important events are really the outcomes of plots by a secretive organization, let's say. Which events? That's the puzzle-solving fun to being a conspiracy theorist – only the truly significant events would occupy such a powerful and secret organization, so one must weed through each year's worth of notable events to discern just the ones that could and would be accomplished by this secret organization (using their money? their threats? their political machinations? their overseas support? and so on) in a timely and effective manner.

The logical fact remains that A would not be seriously tested by Abductive Coduction, although whoever is assigning Cs to A and garnering some confirmations would be a very good guesser. Good guessing could also be displayed by proponents of a rival explanation B, C (etc.), as well. There could be something real about A and its confirmed capacities, but this is a poor procedure for credibly figuring out what is really the best explanation. There are fewer fruitless debates than those between adherents of rival conspiracy theories.

Abductive Coduction is hence susceptible to degeneration into hasty judgment, cognitive bias, fallacious inference, and even outright trickery. It is the method preferred by a fraud who might fool spectators into thinking that he or she possesses extraordinary powers. With enough imagined 'capacities' for making forecasts, diagnosing illnesses, reading others' thoughts, doing impossible feats, and so on, the busily risk-taking fraud can luckily (or

skillfully, with some magic tricks) accomplish some unexpected results once in a while before surprised onlookers. When the credulous people in the crowd have “seen with their own eyes” just a handful of ‘successful’ confirmations to this fraud’s amazing capacities, they don’t attend as much to the disconfirmations. This risk of degeneration into the “Fraudulent Powers” problem leaves Abductive Coduction in generally poor repute.

Abduction Evolution

We proceed to a more complex stage, for working out procedures that exercise stricter controls on the capacities assigned to the conception of A. The next procedure in the sequence is DAA.

The DAA procedure: A’s capacities are deduced from A’s definition, but then they are abductively related to Qs, Rs, Ss (etc.)

Qs !

Suppose (only if A has C1), then Qs

Suppose (only if A has C1-2), then Qs & Rs

Rs !

Suppose (only if A has C1-3), then Qs, Rs & Ss

Ss !

...

So, A(Cn) [deducibly abductive abduction – “Strict Abduction”]

Unlike the simpler suspicious procedures AIA, IAA, IIA, and ADA, which run into their troubles by not strictly controlling the capacities assigned to A’s definition, DAA exercises very strict control over modestly modifying the conception of A. Only the capacities required to account for the phenomena are attributed to A, and whatever the definition of A may be, that definition is only permitted to be compatible with those Cs applied in the procedure. No other conceptions of A, beyond those Cs proposed to account for Qs, Rs, Ss (etc.) are regarded as relevant. DAA has similarities with the simpler procedure of Predictable Abduction. However, instead of allowing the definition of A to be as broad as desired and adjusting it whenever it is convenient to predict some Rs, Ss (etc.), as Predictable Abduction allows, DAA does not permit the definition of A to range beyond whatever is minimally necessary for it to have its explanatory capacities. That is why we may label DAA as Strict Abduction.

Strict Abduction has five additional merits. First, whenever it being used, any particular time the conception of A has only one clear definition and set of capacities. Second, due to this bounded clarity, a community of inquirers can apply A together and everyone can agree upon what the explanation is and what it so far entails. Third, although a community will disagree over what new capacities A should have for increasing its predictive range, both the current definition of A and the presently assigned capacities place compatibility constraints on the sort of new capacities that can be assigned to A. Fourth, if a new prediction goes badly, only the relevant implicated capacity of A must be doubted, and not the rest of the capacities of A, preserving what explanatory power A had already earned. Fifth, the expansion of A’s capacities and its explanatory range can halt whenever the community finds no work for A to do presently, but A can be put to work again in the future.

Comets can illustrate Strict Abduction. During the late 1500s, astronomer Tycho Brahe’s observations suggested that comets are celestial (not atmospheric) bodies due to their observed trajectories; if celestial, they would be distant from the earth, and Brahe’s parallax measurements indeed indicated their immense distance and vast size. By 1604 Johannes Kepler added that the sun’s rays cause a comet’s head to expel a stream of nebular material shining by the sun’s light; his idea fit well with the usually overlooked way that a comet’s tail always points away from the sun. This celestial, naturalistic, and causal explanation for comets hasn’t essentially changed, but only supplemented. If comets journey between the planets, their paths must also be affected by the sun. By the late 1600s, Isaac Newton determined that a comet approaches the sun, swings around behind it, and departs away from the sun, and he explained why a parabolic path due to gravity would be typical for many comets. Also, Newton suggested that the sun would heat a close comet to incredible temperatures, so the head of a comet must

be dense while the tail would be vaporous. Later investigations confirmed these hypotheses, completing the basic theory of comets.¹²

The transition from Predictable Abduction to Strict Abduction marks the boundary into scientific reasoning. Predictable Abduction, Predictable Coduction, and even Abductive Coduction are proto-scientific. They also can be put to use for pseudo-scientific and theological ends, as the proto-scientific is simultaneously logical, mythological, theological, and scientific. All four procedures are cohabitants of a broad realm of “speculative” thinking, or what the ancient Greeks called “inquiry into nature” (not excepting the cosmic gods), which is an arrival place of many simpler methods and a departure point for complex procedures going in different directions. Several civilizations arrived at this generative nexus of the proto-scientific and proto-theological.¹³

Only Strict Abduction ventures on into fully scientific methodology. That journey leaves behind preferences for vaguely conceived yet richly imagined explanations that elicit credulity by appealing to familiar notions, cognitive biases, and selected evidence than genuine predictive power. A scientific hypothesis restricts the capacities (properties, powers, etc.) of a hypothesized thing to some fairly delimited set, and those capacities are stable and habitual. The logic of testing hypotheses requires such features; specific predictions must be made and confirmed, so postulated entities must behave in patterned ways under specified conditions. That is why science has an innate preference for proposing constant impersonal capacities to explain observed regularities and mundane matters, leaving mythic and religious thinking to imagine less than predictable (fickle and willful) agents to account for singular extraordinary events.

A close variant to Strict Abduction is DDA - Deducible Coduction - in which A and its capacities Cs are deducibly related, and then that relation is deductively applied to imply analogous features to Qs and Rs.

DDA:

Qs and Rs have F1 !

Only if A then C1, then Qs and Rs would have feature F1

Only if A then C2, then Qs and Rs would have feature F2

Qs and Rs have F2 !

Only if A then C3, then Qs and Rs would have feature F3

Qs and Rs have F3 !

...

So, A(Cn) [deducibly deductive abduction – DDA – Deducible Coduction]

Deducible Coduction is also a basic, but soundly scientific procedure. Its utility is limited to the investigation of two different kinds of things which share in many common features. Recalling how fog banks are practically low clouds, their common manner of refracting and obscuring light (F1) is due to their composition of tiny water droplets (A). With enough water particles suspended in the air (C1), both clouds and fog banks would obscure light in their characteristic way. Water particles condense from water vapor (C2) when just a few degrees separate the air temperature and the dew point, so both clouds and fog would form when those conditions prevail (F2), regardless of altitude (although wind matters). Further properties of condensed water vapor account for additional common features to both clouds and fog.

In the long run, Deducible Coduction can permit a long iteration of successful predictions that Qs and Rs share in every significant feature. If there seems to be no significant feature that Qs and Rs do not share and A's capacities have predicted all of them, a further inference seems plausible: the genuine connection between Qs, Rs, and A must be far tighter than originally postulated. Perhaps Qs and Rs are simply two ways for A to effectively manifest itself (so that A and Qs aren't really two separate matters, nor are A and Rs – e.g. fog *is* cloud *is* amassed water droplets). Alternatively, going even further, there really was no A in the first place because Qs and Rs really are the same thing understood from two different ‘perspectives’.

The first suggestion amounts to a “Principle of Identity of Effectables” while the second suggestion amounts to a “Principle of Identity of Correlatables”. The Identity of Effectables means that Qs and Rs are dual manifestations (or ‘properties’, etc.) of one single underlying A. The Identity of Correlatables means that there never really was any A, since it is now deemed explanatory eliminable, so that Qs and Rs were really the same

thing all along. (Further inquiry could next determine if R has ontological priority so that Q is 'actually' just R, or the reverse). These two Principles would function in two different procedures as follows:

Application of the Principle of Identity of Effectables

Qs and Rs have F1 !

Only if A then C1, then Qs and Rs would have feature F1

Only if A then C2, then Qs and Rs would have feature F2

Qs and Rs have F2 !

...

For all significant Fs of Qs and Fs of Rs, each Fn of Qs = some Fn of Rs [by inductive searching and discovery – "Identity of Features"]

Principle of Identity of Effectables – Where all of A's capacities effectuate Qs & Rs Identity of Features, then A = Qs and A = Rs

So, A(Cn) = Qs & Rs [Maximal Coduction]

OR

Application of the Principle of Identity of Correlatables

Qs and Rs have F1 !

Only if A then C1, then Qs and Rs would have feature F1

Only if A then C2, then Qs and Rs would have feature F2

Qs and Rs have F2 !

...

For all significant Fs of Qs and Fs of Rs, each Fn of Qs = some Fn of Rs [by inductive searching and discovery – "Identity of Features"]

Principle of Identity of Correlatables – Where all of A's capacities effectuate Qs & Rs Identity of Features, then Qs = Rs

So, Qs = Rs [Maximal Reduction]

Only each scientific field of inquiry can be responsible for judging the circumstances and background knowledge that permit the application of either Maximal Coduction or Maximal Reduction. These are fallible applications under the best of circumstances, since the possibility of rival explanations doing an even better job of explaining Qs and Rs, or a different job of relating Qs and Rs to other phenomena, cannot be ruled out in advance. Regarding banks of fog as just low-lying clouds because their composition and conditions for formation are so similar is an illustration of Maximal Coduction. An illustration of Maximal Reduction is the fate of Lavoisier's 'caloric fluid', an elemental gaseous substance within all bodies which flows from hotter to cooler regions. Chemists solved many experimental problems using caloric theory, while pondering how caloric fluid would also be the basis for the kinetic motion of molecules responsible for temperature. By the mid-1800s, Rudolf Clausius and James Clerk Maxwell demonstrated that the transfer of heat is just the redistribution of molecular kinetic energy obeying the principle of conservation of energy, so 'caloric fluid' was discarded.

There is one more procedure to this stage, AAA, which combines the merits of Strict Abduction with those of Deducible Coduction.

The AAA procedure: A's capacities Cs are abductively proposed from A's prior explanatory successes, and then they are abductively related to Qs, Rs, Ss (etc.). Let W(1-n) and Y(1-n) stand for any related series of Qs, Rs, Ss, Ts...Ns. Also, we define W(1-n) and Y(1-n) as an "analogous series" where common features found among all members of W(1-n) are also found, in analogous form, among all of Y(1-n).

If (Only if A's Cs have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))
 Y(1-n) !
 So, A [abductively abductive abduction – "Productive Abduction"]

For Productive Abduction, the C's of A are a "model" applied to the impressive effectuation of one "structure" – a series of W(1-n) – and that model additionally permits the successful prediction of another analogous structure of Y(1-n). To illustrate Productive Abduction, consider the development of cell theory in biology. Seeking the fundamental basis of life, the idea of a cell having its own cell wall and internal organic processes led botanists towards confirmations from studying microorganisms and plants. By the 1830s, this model was successfully applied to animal tissues, where cells displayed a similar construction and physiological functionings, and the cell was confirmed as the basic organic unit for all life forms.

Explanations confirmed by Productive Abduction deserve credibility. This procedure exploring the explanatory productivity of models is respectably scientific, while remaining naturally fallible.

Abduction Heuristics

Iterations of Productive Abduction (IAAA) can increase credibility, especially if no other rival explanation is also having that same degree of success. Furthermore, Deduced Productive Abduction (DAAA) can expand the explanatory power of A to additional structures if definite expansions to A's capacities are envisioned.

Iterated Productive Abduction:

If (Only if A's capacities Cs have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))
 Y(1-n) !
 If (Only if A's capacities Cs have predicted W(1-n) & Y(1-n)) then (another analogous series of unexpected Z(1-n))
 Z(1-n) !
 ...
 So, A(Cs) [IAAA – "Iterated Productive Abduction"]

OR

Deduced Productive Abduction:

If (Only if A's capacities C(n) have predicted a series of unexpected W(1-n)) then (an analogous series of unexpected Y(1-n))
 Y(1-n) !
 If (Only if A's capacities C(n+1) have predicted W(1-n) & Y(1-n)) then (another analogous series of unexpected Z(1-n))
 Z(1-n) !
 ...
 So, A(Cn+) [DAAA – "Deduced Productive Abduction"]

Both Iterated Productive Abduction and Deduced Productive Abduction can be powerfully credible for scientific explanation. An illustration for the first procedure comes from Maxwell's theory of electromagnetic radiation, which explained the properties of light as manifestations of the same radiating energy found at shorter and longer frequencies (confirmed with radio waves), and explained the properties of both electric and magnetic

forces as well, so that a single theory of oscillating electric/magnetic energy obeying a few equations eventually explained a wide range of phenomena. To illustrate the second procedure, consider the concept of the gene, which underwent drastic development during the 20th century. Proposed as the basic unit of heredity passed on the offspring via reproduction, a gene's capacity for transmission and combination with other genes to produce traits in all organisms could additionally explain how a cell's internal processes are regulated if genes also have the ability to control metabolic reactions, suggesting chemical properties for genes. Seeking out those properties in chromosomes, James Watson and Francis Crick ascertained that genes would be stretches of the DNA discovered by X-ray crystallography. Later research has made the concept of 'gene' more complex, as their susceptibility to mutation, reliance on regulatory regions, encoding for multiple proteins, working alongside epigenetic influences, making horizontal transfers (and so on), have explained in succession many puzzling features to cellular activity.

These two procedures are powerful, yet they do go deeper into risky territory. The same problem that emerged with Coduction can arise here for Iterated Productive Abduction: the Explanatory Relationship Problem. We can find analogous features in two distinct matters with enough imaginative creativity. Our efforts might go more into detecting analogous (we imagine) features of structure, and not into the proposed connecting relationships between A, its many capacities, and structures W, Y, Z (etc.). As for Deduced Productive Abduction, matters may be worse because A's capacities are growing during the procedure, so the Explanatory Emptiness Problem can emerge again. If we ignore the issue of maintain coherent conceptions of the relationships among A and its capacities, this explanatory model may become explanatorily vacuous, and the conception of A eventually seems paradoxical, irredeemably vague, or oddly empty. (The old paradigm of the gene as the unique carrier of information and the powerful initiator of biochemistry is practically extinct, while interest in systems biology and postgenomics grows.¹⁴) There is no trick to preventing these difficulties in advance. Communities of inquirers must experimentally explore the consequences to expanding an explanation's capacities for the sake of growing its explanatory power, because there is no higher logical method for dictating theoretical modification.

Because there is no higher inferential procedure for dictating modifications to explanations, besides letting them suffer the fate of their own predictive productivity, one way or the other, we are now entirely within the realm of hypothesis experimentation. Each scientific field must rely on the accumulated wisdom of skilled practitioners and useful heuristics for smartly adjusting procedures as inquiries proceed. This is especially the case when a network of interconnected hypotheses form a theory which must undergo further explanatory expansion and testing by risky predictions. The familiar problems of deciding which hypotheses within a theory must suffer credibility diminishment or even disconfirmation when things go badly are a matter of scientific heuristics, a higher meta-level problem beyond the scope of strict inferential reasoning.

In the realm of theories – networks of hypothetical explanations about a common matter – the next procedure of Abductive Productive Abduction may be applied, but it is more of an optional heuristic than a required procedure.

AAAA:

Structures W, Y, and Z under experimental conditions EC1 !
 If (Model A(Cs) can produce W, Y, Z under EC1) then W, Y, and Z
 If (Model A(Cs) can produce analogous W, Y, Z under EC2) then analogous W, Y, Z
 Analogous W, Y, Z !
 ...
 So, model A(Cs) [AAAA: Abductive Productive Abduction]

With this sketch to AAAA, our stages of procedures must arbitrarily halt to conclude this article. Additional heuristics for modifications to networked models are combinatorially possible. Their patterns can be constructed from the earlier inferential procedures outlines above, by returning to the start of this discussion and letting each instance of 'A' for Abduction stand for Procedural Abduction. Thus, to transform IDA, insert Productive Abduction for that instance of 'A' in 'IDA' to form "inducibly deductive abductively abductive abduction" or just Inducibly Deductive Productive Abduction. A typical scientific field may find a few of these additional heuristics to be practically useful, as it struggles with updating theoretical paradigms and coordinating ontologies with neighboring

fields. However useful these advanced heuristics may be, they all still suffer from their characteristic problems and degenerate forms, as warned in previous sections.

Conclusion

To summarize, there are five primary categories for sorting the inferential procedures covered by this investigation into the combinatorial possibilities among deduction, induction, and abduction: fallacies, non-scientific procedures, quasi-scientific procedures, scientific procedures, and scientific heuristics. Among the non-scientific and quasi-scientific procedures are found the basic types of mythic thinking and pseudo-scientific thinking, although a separate discussion about sorting them adequately requires separate treatment.

Fallacies:

- A, simple abduction
- DA, deducible abduction
- IA, inducible abduction

Non-scientific procedures:

- AI, abductive induction - Iterative Abduction
- AD, abductive deduction - Coduction
- DAI, deducibly abductive induction - Retrodicted abduction
- ADI, abducibly deductive induction - Retrodicted induction
- DIA, deduced inductive abduction - Predicted Abduction
- IDA, inducibly deductive abduction - Predictable Coduction
- DIA, deducibly inductive abduction - Predictable Abduction
- DAI, deducibly abductive induction - Iterative Coduction - religion
- IAD, inducibly abductive deduction - Deduced Coduction - theology
- AID, abducibly inductive deduction - Reduced Pancosmism - theology

Quasi-scientific procedures:

- IDA, inducibly deductive abduction - Predictable Coduction
- DIA, deducibly inductive abduction - Predictable Abduction
- AIA, abductively inductive abduction - Capacity Overload problem
- IAA, induced abductive abduction - degenerates to Deduced Coduction
- IIA, induced inductive abduction - Elicited Abduction, Confirmation Biases problem
- ADA, abductively deductive abduction - Coductive Abduction, Fraudulent Powers problem

Scientific procedures and heuristics:

- DAA, deducibly abductive abduction - Strict Abduction
- DDA, deducibly deductive abduction - Deducible Coduction
- AAA, abductively abductive abduction - Productive Abduction
- IAAA, Iterated Productive Abduction
- DAAA, Deduced Productive Abduction
- AAAA, Abductive Productive Abduction
- (etc.)

NOTES

1. Ordinary abduction is evidently habitual in practice for humans, and habits can be brought under reflective review for deliberation, especially if they are acquired in learning (Magnani [1]). No “instinct or inference” dichotomy about abduction is forced upon us, as if learning must be rigid and automatic. It is a debatable question whether something akin to abduction is instinctive for non-human animals (Park [2]).
2. Musgrave [3], p. 127.
3. P. Kyle Stanford [4] makes a similar point regarding the supposed self-sufficiency of Bayesian confirmation.
4. Peirce [5], para. 171-172.
5. A handful of recent philosophers of science have appreciated Peirce and abduction’s significant role. Consult for example McMullin [6], Niiniluoto [7], and Psillos [8]. A recent examination of Peirce’s mature logic of scientific methodology is by Pietarinen and Bellucci [9].
6. Campos [10] distinguishes Peirce’s abduction apart from inference to the best explanation. For broader explorations of abduction’s role in procedures of explanatory reasoning, consult Flach and Kakas [11], Lipton [12], Paavola [13], Aliseda [14], Pizzi [15], Schurz [16], Gauderis and De Putte [17], Gauderis [18], Aliseda and Beirlaen [19], and Velázquez-Quesada [20].
7. See Psillos [8], 135.
8. Consult Brigandt [21].
9. Lévi-Strauss [22].
10. See Shackelford [23], chap. 2.
11. On pseudo-science in general, the reader may begin by consulting Pigliucci and Boudry [24].
12. Heidarzadeh [25], chap. 4.
13. On that Greek nexus, consult Buxton [26], Morgan [27], Wians [28], and Mikalson [29].
14. Consult Richardson and Stevens [30].

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Abduction, the Logic of Scientific Creativity, and Scientific Realism

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abstract:

A fundamental question for philosophy of science asks, How is knowledge of the world created? A pragmatist approach is constructed to show how discovery and justification are tightly related during the creation of scientific knowledge. Procedural abduction, at the scientific level of Strict Abduction and higher, integrates the learnable (postulations undergoing conceptual development) and the logical (hypotheses undergoing rational scrutiny) quite thoroughly. Discovery and justification are functionally fused together within the organized process of procedural abduction by scientific communities. Four questions posed at the start are answered by this pragmatist philosophy of science as follows. (1) Is scientific creativity methodologically related to scientific justification? Answer: scientific creativity is integral to abductive procedures yielding scientific justification. (2) Can a distinction between genuine science and pseudo-science be clearly defined? Answer: genuine science is distinguished by the application of procedural abduction at the level of Strict Abduction or higher. (3) Does scientific knowledge achieve the legitimacy of scientific realism? Answer: procedural abduction legitimates the credibility of highly-confirmed hypotheses and hence justifies scientific realism. (4) How are scientific communities responsible for establishing scientific knowledge? Answer: scientific communities using procedural abduction realize (in both cognitive and constructive senses) scientific knowledge.

How is knowledge of the world created? Four longstanding issues involved with addressing this general question are usually treated separately by philosophy of science. From a pragmatist approach, there are resolutions to certain issues which additionally yield solutions to the others, and thus all four can be resolved together. These key issues can be expressed as four problematic questions, listed in the order that they are discussed in this chapter.

1. Is scientific creativity methodologically related to scientific justification?
2. Can a distinction between genuine science and pseudo-science be clearly defined?
3. Does scientific knowledge achieve the legitimacy of scientific realism?
4. How are scientific communities responsible for establishing scientific knowledge?

An inadequate answer to one of these problems contributes to making the other problems intractable. Only an examination into the abductive logic of scientific inquiry can show how to resolve all four. The key to these interconnected issues lies with scientific creativity. During the 19th and 20th centuries, dominant theories of scientific methodology ignored creativity or placed creativity's contribution beyond the inferential thinking undergirding scientific credibility. Fixated only on deductive and

inductive logic, abductive logic and its creativity has been only thinly considered in epistemology [1] and philosophy of science [2].

Abductive inference has been linked with conjectural creativity in scientific inquiry from its inception with Charles S. Peirce's logical investigations to its elaboration in recent investigations.¹ The pragmatic logic of abductive discovery – with *discovery* bearing the twinned sense of discovering hypotheses having plausibility and discovering that hypothesized entities have reality – requires creativity at every stage from postulation to confirmation. That pervasive role for creativity shows the pragmatist way towards resolving the four issues listed above. Scientific creativity is *integral* to scientific justification; genuine science is distinguished by *procedural* abduction; procedural abduction *legitimizes* scientific realism; and scientific communities using procedural abduction *realize* (in both cognitive and constructive senses) scientific knowledge.

Types of Scientific Creativity

At the least, scientific creativity is not mere novelty. Like artistic or technical creativity, where innovation develops from earlier forms and designs, the creativity to scientific learning has a largely constructive character. The history of science displays does not amount to just a loose sequence of novel ideas lacking in cohesion. A plenitude of hypotheses do arise over time, with paradigms twisting and shifting, but a scientific field continually enlarges through discoveries building on discoveries. The culmination of scientific creativity cannot stop short of appreciation and adoption into the growing body of scientific knowledge. Original learning can be surprisingly revelatory but new knowledge must be thoroughly reasonable. Creating knowledge is difficult, and rightly so.

Different types of creativity play important roles in science. On the surface, it is obvious that the knowledge sought by scientific investigators, established as original discoveries, has to be created. Anything empirically known has to be first learned by curious inquirers responsible for learning something new. That learning is created by learners, to supplement and amend knowledge, and then to be subsequently taught as part of that established knowledge. Those instructed learners do not feel so creative; receptivity and flexibility characterize their adoption of knowledge that is new to them. Receptive learning is not a defining component of science itself; creative learning is essential to science. How is scientific knowledge created? A deeper mode of creativity is involved.

Scientific inquiry at minimum enlarges and improves the factual evidence to be considered during an investigation. A body of reliable evidence, no matter how compendious and categorized, needs to be expanded. Investigators can go out to explore and gather fresh material for their study, and they can also return to accumulated evidence for re-inspection and re-interpretation by applying better methods of scrutiny. Both routes exemplify that enlargement of evidence. What seemed evident in the past may later appear less meaningful later, or what seemed uninteresting acquires more significance as overlooked features come into view. Even if already-collected materials are untouched and unchanged, their status as evidence relevant to further inquiry surely changes. New facts are able to arise from old evidence as well as from fresh evidence.

Material evidence, no matter how substantial and abundant, cannot inferentially bear upon justifying any validity to hypotheses – only credible facts could do so. Evidence is “uncovered” as though it pre-

¹ An entryway into the literature could start by consulting Magnani [3], Paavola [4], Barrena and Nubiola [5], and Park [6].

exists; interesting facts are surely created. (Pre-existing facts, due to their inadequacy and insufficiency, only provoke those new investigations.) Discovery and creativity are contraries, if their primary meanings are set in direct contrast. What is genuinely discovered cannot also be authentically created – the created thing cannot already exist prior to its creation, while a thing getting discovered must already exist prior to its discovery. And yet, we observe creativity and discovery blending together and intertwining with justification during empirical phases of scientific investigations. Scientific knowledge is created through the process of creating relevant evidence, a process which requires creative engagements with the observable world.

Surprising evidential facts are indispensable, often impelling new thinking and compelling revaluations of older theorizing. Methodical efforts undertaken during the conduct of inquiry create new facts within scientific fields. This view upon creating facts looks contrary to empirical science, which prides itself upon objective methods hostile to human-manufactured “evidence.” That much-prized objectivity still involves the creation of new learning, the learning of new facts from enlarging accessible evidence. Furthermore, objectivity implies a reduction of subjectivity, where individual biases flourish. Genuine discovery cannot be merely a fantasy in the mind or a fixation on familiar ground. As an enterprise of discovery, scientific inquiry instead constructs novel conditions where new empirical facts for learning about modeled causes can be openly generated and recorded.² This experimental creativity, when accomplished properly, is far from subjective. Reproducibility, repeatability, and robustness across a group of competent investigators are key signs of factual reliability.

Creating scientific knowledge relies on creating relevant evidence, which depends on creating experimental conditions that in turn create objective facts – important facts implicated in the creation of credible hypotheses able to creatively accommodate them. During each phase of this discernment of new knowledge through an appreciation of fresh facts and an appraisal of novel hypotheses, a reach of imaginative creativity beyond what is already familiar must be attained. At every level, what has been realistically conceivable, so far, is no longer adequate. Yet, at the same time, whatever is becoming conceivable is also responsible for being reasonable. It is impossible for conception and ratiocination to function in scientific inquiry without continual coordination. That coordination, within procedural abduction, is actually due to their fundamental fusion.

Discovery and Justification

How is knowledge of the world created? That creation presumes an integration of what is learnable with what is logical. If learning and logic have nothing in common, not only does their cooperation remain puzzling, but the place for creativity could be divided apart, as if imaginative creativity must stay separated from logical creativity. That manner of subdividing creativity sounds dubious indeed – what gets assigned to “logical creativity” so long as logic is no place for fancy? More commonly, creative discovery gets assigned exclusively to the processes of learning. Intuition, inspiration, imagination – by whatever name, such bursts of creativity seem very different from strict rationality.

As the previous section’s tour through primary phases of empirical inquiry has suggested, however, imaginative discovery and inferential justification should be organically unified during the creation of scientific knowledge. If learning and logic are integrated in that common goal of knowledge creation, creativity could not be isolated from reasoning. Each would find its scientific purpose in the other.

² Prominent philosophers of science who stress the epistemic link between realistic modelling and controlled experimental conditions include Hacking [7], Geire [8], and Cartwright [9].

Creativity would be reasonable, and reasoning would be creative, where a body of scientists are growing a body of knowledge over time.

However timeless the forms of inference may seem, processes of human judgment must be temporal, especially during consideration, consultation, and collaboration. Thinking is temporal through durations; all thoughts have histories. Theories earning their credibility have origins and courses, and even their demises have durable effects in fertilization or fossilization. A scientific body, as a replenishing organization of co-functioning scientists investigating theories over decades and centuries, displays both imaginative creativity and methodic rationality intertwined in intricate harmonies.

A sharp dichotomy between learning and logic establishes a dualism dismembering that organic unity within science. It divides discovery from justification, with spontaneous creativity on one side and strict reasoning on the other side. Creativity would at most have only an external association with logic, leaving their fruitful relationship as a deep mystery. Why should inferential justification accept intuitive notions as initial inputs for premises, and how would reasoning choose sensible inputs from a plenitude of fancies? Deduction proceeds towards conclusions after initial propositions are granted; it is no business of deduction what ideas get premised. Induction at least demands an array of observed facts before proceeding towards generalizations. Scientific creativity remains a problem where the relationship between learning and logic is a mystery.

Nevertheless, philosophy of science continually distinguishes the context of discovery from the context of justification and then struggles to re-connect them.³ The post-Kantian separation of empirical contingencies apart from apriori necessities enforced rationalism's dichotomy, and 19th century empiricism was no less strict. William Whewell's *The Philosophy of the Inductive Sciences* asserted that the first step beyond the evidence can only be "some happy thought, of which we cannot trace the origin; some fortunate cast of intellect, rising above all rules. No maxims can be given which inevitably lead to discovery. No precepts will elevate a man of ordinary endowments to the level of a man of genius: nor will an inquirer of truly inventive mind need to come to the teacher of inductive philosophy to learn how to exercise the faculties which nature has given him."⁴ For Whewell, and so many empiricists claiming expertise over the psychology of knowledge, the insight of a naturally imaginative mind is just an inspirational phase; only logically rigorous inferences can discern true discovery.

Neo-Kantianism and logical empiricism conveyed this view into the early 20th century, exemplified by Karl Popper. In *The Logic of Scientific Discovery* he stated that "every discovery contains an 'irrational element', or 'a creative intuition'."⁵ He expanded on this crucial distinction in this way:

The initial state, the act of conceiving or inventing a theory, seems to me neither to call for logical analysis nor to be susceptible of it. The question how it happens that a new idea occurs to a man—whether it is a musical theme, a dramatic conflict, or a scientific theory—may be of great interest to empirical psychology; but it is irrelevant to the logical analysis of scientific knowledge. This latter is concerned not with questions of fact (Kant's *quid facti?*), but only with questions of justification or validity (Kant's *quid juris?*). Its questions are of the following kind. Can a statement be justified? And if so, how? Is it testable? Is it logically dependent on certain other statements? Or does it perhaps contradict them? ... Accordingly I shall distinguish sharply

³ See Nickels [10], Snyder [11], and Schickore and Steinle [12].

⁴ Whewell [13], vol. 2, p. 186.

⁵ Popper [14], p. 32.

between the process of conceiving a new idea, and the methods and results of examining it logically. As to the task of the logic of knowledge—in contradistinction to the psychology of knowledge—I shall proceed on the assumption that it consists solely in investigating the methods employed in those systematic tests to which every new idea must be subjected if it is to be seriously entertained.⁶

The demise of logical empiricism did not doom Popper's distinction. The larger lesson was amplified: attaining an initial conception is unlike and unrelated to reaching a final conclusion. In general, philosophy must insist that what happens to be *believable* cannot be identified with what should be *credible*. Believability and credibility rest on two separate grounds. Imagining ideas to inspire learning is one process, while justifying learning to count as knowledge is another process. Reducing knowing down to learning violates that distinction and puts psychology in charge of logic (and hence of knowledge and truth too). As Popper well understood, philosophy of science was but one field affected by the broader problem of "psychologism" for philosophical logic [15] and theories of knowledge [20]. Learning is supposed to occur entirely within *natural* psychology while logic is liberated from psychologism by *normative* rationalism.

Narratives about the history of science typically appeal to this creation-justification distinction. One scientist gets credit for first thinking of a new hypothesis, while another scientist is credited with later confirming that hypothesis. Historians of science now understand how scientific advances could not have been so simplistic. The genesis of a hypothesis has receded in significance as theoretical models became more complex, and those abstract models resemble observable things less and less. That oversized role for an individual scientist has also diminished. Behind a complex hypothesis there stands a number of scientists who developed it over time, and teams of scientists are needed for gathering confirmations of that hypothesis. Furthermore, those two processes typically blend and share more in common. The period of development overlaps, and gets involved with, the period of confirmation. Some scientists help to redevelop hypotheses while they participate in designing rounds of experimental trials. A growing body of scientists consult together about the eventual rejection or acceptance of a hypothesis, contributing to the body of knowledge either way.

Allowing how many scientists are typically involved with phases of inquiry, philosophy of science is at least convinced that there is a distinctive logic of justification. In itself, logical justification is not so problematic. Science sets its standards of reasonable inference, to test and justify acceptable hypotheses. On the other hand, the idea of a "logic of discovery" in isolation is harder to conceptualize. Could there be any such thing as a "logic of discovery"?

The Learnable and the Logical

The disputed question whether there is a logic of scientific discovery, and wondering how it could relate to the logic of scientific justification, is rooted in the perennial tension between psychology and logic [17]. Modern logic renounced any entanglement with psychology; an understanding of logic requires avoiding the prime fallacy of psychologism. Logic is concerned for the ways that knowledge should be recognized among beliefs. Divorcing the context of discovery from the logic of justification echoes the age-old divide separating learning (temporally psychological) from reasoning (timelessly logical). Actual beliefs and how they happen to form is not supposed to be in logic's department. Knowing, in short, is more than believing. Believed ideas are learned by individuals through the passage of time; known

⁶ Popper [14], pp. 7-8.

truths are justified by inferences through unchanging norms. How a new idea could inspire original learning must be, it has been claimed, a very different process from the way that an attempt at learning should be justified as knowledge. Intuition, inspiration, imagination – by whatever name, that genesis of creativity by an actual mind seems irreducible to methodical steps for a generic reasoner.

Let logic protest that it truly does guide learning. It is the case that logic must deal indirectly with beliefs, since anything known must at least be believed. For logic, what should be believed is what is learnable, and what is learned should approach knowledge. (What is not knowable, such as the false or mysterious, cannot be learned now, and perhaps never learned.) What is knowable has already been learned, of course – unless something was learned, how could it now be known by anyone?

A. What is knowable must already be learned.

B. What is learned must already be knowable.

If logic has guidance about how knowledge should be learned, how would its guidance be used? It seems as if the known is already the learned, and the learned is already the known – and therefore logic is useless except for its survey of systematized instruction. The object of knowledge is what is already known by some number of minds. This is the basis for deduction: the right conclusion is dependent on reasons, reasons premised and already understood to be acceptable, which reliably guide one's thoughts to the conclusion. The premises must be both familiar and acceptable to one's mind.

C. What is learnable is already conceivable.

Where acceptable premises are to be obtained is not deduction's responsibility. Only premises already accepted as true can yield a knowable conclusion. (Merely hypothetical relations among propositions do not yield known conclusions about something's existence.) The objective of learning is already fully conceived from the start, since a deduction's conclusion is given with the premises. The object of knowledge – indicated by the 'subject' term in the conclusion – is set in the premises, and one's conception of it cannot change while learning from a deduction.

Tenet A can be disputed, for "knowable" has two senses: the knowable is what might become known; or the knowable is already established as known. (When is a river navigable? Only after someone has successfully navigated the length of its waters? Or, is a river navigable before anyone tries? The grammar of '-able' allows both senses.) Potential knowability is distinct from confirmed knowability.

A2. What is potentially knowable may become learned.

B2. What is learned must already be confirmably knowable.

As for logic, it now has a function for learning. What is potentially knowable can become learned through logic's guidance, but that guidance must be cognizant of knowledge's object to some degree. Guidance is no guidance without a conceptualized objective, even if only in vague outline. Furthermore, that guidance must relate this object with information accessible to the learner. Permitting the knowable object to be entirely unlike and unrelated to accessible information is nothing like guidance.

C2. What is potentially knowable is presently conceivable.

If the knowable object is conceived in terms of features evident in accessible information, that conceivability responds to the body of accessible information. If the relevant information changes over time during a period of learning, then the conception of the knowable object can also change. Indeed, intelligent learning modifies conceptions of the knowable object as more and more relevant evidence is gathered. Only unintelligent thought refuses to re-conceive what it is trying to understand.

Deduction, Induction, Abduction

If deduction is taken for the paradigmatic mode of inference for knowledge, there can be no logic of discovery. In a sound deduction, the subject of the conclusion – the object to be known – is already accepted as existing when the premises are accepted. Where and why premises are accepted as believable is not deduction's concern. Furthermore, that object of knowledge cannot be changed from the premises to the conclusion; a different 'subject' in the subject-predicate conclusion invalidates a deduction. The pre-given and static status of deduction's object of knowledge explains why deduction yields little learning and no discovery.

Deduction is about learning what is already known, not about the original discovery of something by initial learners. Deduction leads to conclusions of propositional learning about the terms in the premises. This is not empirical learning. Deduction does not conclude anything about the existential discovery of anything. Anything's existence must be presumed in premises. Although a reasoner learns propositions that are new to that learner, only propositions are "discovered." The terms of the conclusion are not new to the reasoner, since the premises must first be understood. Novelty to a term's meaning is unwanted, since a term's meaning should not change between premises and the conclusion. Terms must not change meanings if more premises are added. Through deduction, a term is not discovered, nor is a term's meaning discovered or altered, and nothing that a term may refer to can be discovered. At most, deduction's propositional learning draw attention to relations among understood terms.

Deduction about empirical matters has further restrictions. A learner accepting a conclusion as known accepts the premises as accurate, and accepting an empirical premise involves taking its terms to be about existing matters. Learning an empirical conclusion by deduction is not about discovering a premised term or discovering that a premised thing exists. Nothing in the world is discovered during deductive reasoning.

Induction is, by reputation and results, supposed to be the mode of inference that specializes in original discovery. Learning, if it involves some logicity, requires inferences about (a) objects not already known to exist and (b) not rigidly pre-conceived. Modes of induction partially satisfy these two criteria for logical learning. Inductive generalizations can anticipate future matters not yet encountered, and they can suggest modified conceptions of things already encountered when conjoined with fresh evidence. For example, the early idea of a microorganism gradually gained specificity as sub-types (such as bacteria, protozoa, and viruses) came into microscopic view, and those classifications themselves developed as more and more organisms were discovered. Induction is restricted by its inability to warrant conceptions of entities impossible to observe by any instrumental means, and limited by its impotence to suggest conceptions of matters quite unlike what has already been observed. Scientific theorizing about non-observable entities, with properties unlike phenomenal qualities, cannot have an entirely inductive basis.

Abductive reasoning is a better model for learning about objects not already known to exist and not familiarly pre-conceived. Abduction introduces and justifies the credibility of fresh hypotheses about unknown things with novel properties, so scientific methodologies require productively abductive theorizing [18] and not just inferences to “the best explanation” [19]. Peirce accordingly claimed that only the original postulations of abduction allows for scientific explanation, with this basic schema:

The surprising fact, C, is observed
But if A were true, C would be a matter of course
Hence, there is reason to suspect that A is true. ([20], 5.189)

This schema only serves as a comparison with basic forms of deduction and induction. In schematic form, abduction lacks credibility in actual empirical usage, as Peirce himself warned [21]. Abduction in iterative and procedural forms (sketched in following sections) does deliver serious credibility to hypotheses. That credibility can never attain certainty or even confident probability. Valid deduction discerns necessary relations between a conclusion and given premises, while strong induction detects probable conclusions from accumulated premises. Abductive credibility attaches to a surmised conjecture that expects a postulated cause to be responsible for observable effects. Peirce accordingly refers to “deductive necessity,” “inductive probability,” and “abductive expectability” ([20], 5.194).

The creativity inherent to abductive postulation, as Peirce repeatedly explained, allows for a genuine logic of discovery [22]. In this logic for learning, that static “Discovery-Justification” dichotomy separating learning from logic is replaced by a functional “Postulation-Confirmation” distinction within a unified process of reasoned discovery.

Abduction and Postulation

In 1878, Peirce published the sixth part of his “Illustrations of the Logic of Science” titled “Deduction, Induction, and Hypothesis.” By “hypothesis” Peirce was referring to what he also called “retroduction” and later labeled as abduction [23]. On deduction, Peirce points out that it “adds nothing to the premises, but only out of the various facts represented in the premises selects one and brings the attention down to it” ([20], 2.643). Comparing induction with hypothesis (abduction), he writes,

By induction, we conclude that facts, similar to the observed facts, are true in cases not examined. By hypothesis, we conclude the existence of a fact quite different from anything observed, from which, according to known laws, something observed would necessarily result. The former, is reasoning from particulars to the general law; the latter, from effect to cause. ([20], 2.536)

Induction can ascertain patterns and regularities among things sharing similarities. Discovering a not-yet-observed explanation responsible for those matters asks creative thinking to go beyond induction.

As Peirce refined and enlarged his approach to abduction, he continually emphasized science’s essential dependence on abduction’s creativity, transcending any observational reach.

All the ideas of science come to it by way of abduction. Abduction consists in studying facts and devising a theory to explain them. ([20], 5.145)

Abduction is the process of forming explanatory hypotheses. It is the only logical operation which introduces any new idea. ([20], 5.172)

The relationship of abduction's creativity with confirmation is left unclear by these brief statements.

The simplest formulation of abduction is, as Peirce well knew, just a formal fallacy of affirming the consequent. That concise schema only mentions the postulated entity once in the second premise: "But if A were true, C would be a matter of course." Where does that conception of A come from? It does not arrive from somewhere beyond abduction since it is a component of abductive reasoning. Yet its singular mention in the premises makes it look like it descends from clouds of imagination.

Peirce does say that "the abductive suggestion comes to us like a flash. It is an act of insight" ([20] 5.181). However, Peirce treats this "insight" more like an informed guess [24] that arises in various guises *during* inferential reasoning [25]. He wrote, "It must be remembered that abduction, although it is very little hampered by logical rules, nevertheless is a logical inference asserting its conclusion only problematically or conjecturally, it is true, but nevertheless having a perfectly definite logical form" ([20] 5:188). There is no contradiction between these two statements about abduction, unless one (wrongly) presumes that an initial insight is never modified throughout the process of abductive reasoning towards its eventual conclusion. That presumption is essential to valid deduction (avoiding the fallacy of four terms), but Peirce did not reduce abduction to a sort of deductive argument.

Abduction in the hands of scientific inquiry is never just simple abduction in pure form. Induction and abduction (hypothesis) cooperate in concert, according to Peirce.

The great difference between induction and hypothesis is, that the former infers the existence of phenomena such as we have observed in cases which are similar, while hypothesis supposes something of a different kind from what we have directly observed, and frequently something which it would be impossible for us to observe directly. Accordingly, when we stretch an induction quite beyond the limits of our observation, the inference partakes of the nature of hypothesis. It would be absurd to say that we have no inductive warrant for a generalization extending a little beyond the limits of experience, and there is no line to be drawn beyond which we cannot push our inference; only it becomes weaker the further it is pushed. Yet, if an induction be pushed very far, we cannot give it much credence unless we find that such an extension explains some fact which we can and do observe. Here, then, we have a kind of mixture of induction and hypothesis supporting one another; and of this kind are most of the theories of physics. ([20] 2.640.)

Furthermore, the explanatory power of abduction also includes deduction:

Abduction is the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea; for induction does nothing but determine a value and deduction merely evolves the necessary consequences of a pure hypothesis. Deduction proves that something *must* be, Induction shows that something *actually is* operative, Abduction merely suggests that something *may be*. Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction and that, if we are ever to learn anything or to understand phenomena at all, it must be by abduction that this is to be brought about. ([20] 5:171)

Reaching a conclusion earning abductive credibility is the result of prolonged inquiry incorporating phases of creative postulation together with induction and deduction.

A closer examination of abductive procedures for science, first elaborated in Shook [26] and sketched in the next section, reveals how they require a dynamic relationship between the accumulation of new empirical evidence and the alterations needed to the conception of the object of knowledge proposed in a hypothesis. That dynamic relationship between evidence and hypothesis accounts for the scientific realism that arises from abduction. Successful confirmations from abductive procedures yield conclusions credibly affirming the real existence of their hypothesized objects of knowledge.

Abduction and Confirmation

Deduction, induction, and abduction can be simplistically formulated in their pure timeless forms. Imitating Peirce's examples, consider the fruit of a particular tree.

Deduction - Atemporal

Fruits from that tree are red.
These fruits are from that tree.
Therefore, these fruits are (surely) red.

Induction - Atemporal

These fruits are from that tree.
These fruits are red.
Therefore, fruits from that tree are (probably) red.

Abduction - Atemporal

That tree's fruit is red.
If these fruits are from that tree, then they are red.
Therefore, these red fruits are (possibly) from that tree.

Their atemporal forms allow for schematic comparison, to show how none of them are reducible to another form.

Treating abduction only as a straightforward sort of premise-to-conclusion reasoning with but two premises is misleading. During the procedures of complex types of abduction, the object of the conclusion is re-conceived during the consideration and re-consideration of additional sought-for premises. The point of abductive reasoning is to improve conceptions of that postulated object in its capacity to be causally responsible for observed effects, while the plausibility of its efficacious reality grows in relation to an enlarging evidence base. The eventually discovered object is not already fully conceived from the start.

Peirce expected that the three kinds of inference – deduction, induction, and abduction, should cooperate in empirical discovery. His 1903 Harvard *Lectures on Pragmatism* says:

Abduction merely suggests that something may be. Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction, and that, if we are ever to learn anything or to understand phenomena at all, it must be by abduction that this is to be brought about. ([20] 5.17)

Peirce occasionally referred to “mixed” reasonings and inferences ([20] 2.774, 2.787, 7.218). He emphasized how deduction, induction, and abduction are distinct components in science, unable to perform another’s inferential work.

Nothing has so much contributed to present chaotic or erroneous ideas of the logic of science as failure to distinguish the essentially different characters of different elements of scientific reasoning; and one of the worst of these confusions, as well as one of the commonest, consists in regarding abduction and induction taken together (often mixed also with deduction) as a simple argument. Abduction and induction have, to be sure, this common feature, that both lead to the acceptance of a hypothesis because observed facts are such as would necessarily or probably result as consequences of that hypothesis. But for all that, they are the opposite poles of reason, the one the most ineffective, the other the most effective of arguments. The method of either is the very reverse of the other’s. Abduction makes its start from the facts, without, at the outset, having any particular theory in view, though it is motivated by the feeling that a theory is needed to explain the surprising facts. Induction makes its start from a hypothesis which seems to recommend itself, without at the outset having any particular facts in view, though it feels the need of facts to support the theory. Abduction seeks a theory. Induction seeks for facts. In abduction the consideration of the facts suggests the hypothesis. In induction the study of the hypothesis suggests the experiments which bring to light the very facts to which the hypothesis had pointed. ([20] 7.218)

Deduction, induction, and abduction have very different inferential characters and results. That is why each needs the other for productive and predictive inquiries. For example, Peirce recounts how abduction and induction can cooperate during investigations into explanations for empirical patterns:

Presumption, or, more precisely, abduction ... furnishes the reasoner with the problematic theory which induction verifies. Upon finding himself confronted with a phenomenon unlike what he would have expected under the circumstances, he looks over its features and notices some remarkable character or relation among them, which he at once recognizes as being characteristic of some conception with which his mind is already stored, so that a theory is suggested which would explain (that is, render necessary) that which is surprising in the phenomena. ([20] 2.776)

In a 1902 manuscript, after declaring that “arguments are either deductions, inductions, abductions, or mixed arguments,” Peirce describes a thoughtful process that mixes abduction with induction.

Suppose, then, that, being seated in a street car, I remark a man opposite to me whose appearance and behavior unite characters which I am surprised to find together in the same person. I ask myself, How can this be? Suppose I find this problematic reply: Perhaps he is an ex-priest. He is the very image of such a person; he presents an icon of an ex-priest. Here is an iconic argument, or abduction of it. Secondly, it now occurs to me that if he is an ex-priest, he should be tonsured; and in order to test this, I say something to him calculated to make him take off his hat. He does so, and I find that he is indeed tonsured. Here at last is an indication

that my theory is correct. I can now say that he is presumably an ex-priest, although it would be inaccurate to say that there is any definite probability that he is so, since I do not know how often I might find a man tonsured who was not an ex-priest, though evidently far oftener than he would be one. The supposition is, however, now supported by an inductive induction, a weak form of symptomatic or indexical argument. It stands on a widely different basis from that on which it stood before my little experiment. Before, it rested on the flimsy support of similarity, or agreement in "flavor." Now, facts have been constrained to yield confirmation to it by bearing out a prediction based upon it. Belief in the theory rests now on factual reaction to the theory. [27]

Peirce's story illustrates an inquiry that generates new evidence from an abductive guess which in turn supports the plausibility of that hypothesis. Confirming evidence is not independent from the postulated hypothesis; that evidence may never have been sought and found without such a hypothesis in mind. The notion of a hypothesis generating its own evidence must look suspicious from the standpoint of static deductive logic or sequenced inductive logic. Abductive reasoning is circular, in the sense that the growing quality of the evidence is the responsibility of the hypothesis's greater explanatory power. Atemporal reasoning schemas cannot reproduce or license such a mutually supportive relationship between postulation and confirmation stages.

Learning takes time; learning through reasoning is assuredly temporal. Imagining, thinking, and predicting are mental processes having durations. Peirce typically depicts induction and abduction as thoughtful procedures extended over time. Basic forms of inductive and abductive procedures can accordingly be schematized.

Induction - Temporal

These 3 small fruits are from that tree.
Those fruits are also red.
These 4 small red fruits are from that tree too.
Those fruits are also sweet.
These 5 small red sweet fruits are from that tree too.
Those fruits are also soft.
Therefore, fruits of that tree are small, red, sweet, and soft.

During the process of temporal induction, one's conception of the conclusion's object, that tree's fruits, is modified. Alterations to the object of the conclusion also occur for temporal abduction.

Abduction - Temporal

These are small and red fruits.
That tree's fruit is small and red.
If these fruits are from that tree, then they are small and red.
These small red fruits are also sweet.
That tree's fruits are also sweet.
Therefore, these fruits are from that tree.

And, as Peirce proposes, abduction and induction in their temporal forms can be combined.

Abduction – Inductively Temporal

These are red fruits.
That tree has red fruit.
If those fruits came from that tree, then they would be red.
These same red fruits are also small.
That tree has small red fruit.
If those fruits came from that tree, then they would be small and red.
These same small red fruits are also sweet.
That tree has small red sweet fruit.
If those fruits came from that tree, then they would be small, red, and sweet.
Therefore, these small red sweet fruits came from that tree.

Inductively temporal abduction ensures that one's conception of that tree's fruits is gradually modified, and the actual origin of those fruits (that tree) is now expected by the reasoner. Furthermore, with each additional observation, confidence in the accuracy of this conclusion reasonably increases. Deduction is not left out of this iterative process. At each stage, the statement of the hypothesis is a deduction in miniature, e.g.: "If those fruits came from that tree, then they would be small and red." Gathering more empirical evidence modifies the conception of the conclusion's object, and it develops the hypothesis. Let us call this "procedural abduction." The dynamic relationship between the growing evidence and the developing hypothesis is the basis for the realism that arises from procedural abduction: it is more and more credible that the hypothesized entity exists. This is discovery, from a reasoning procedure, where no bright line is separating the logic apart from the learning.

In summary so far, the inferential modes of deduction, induction, and abduction can be compared in stages from postulation to confirmation.

Deduction does not seek more premises, deduction cannot change the meaning of terms during reasoning, and deduction cannot discover the existence of anything.

Induction could seek more premises, and repetitive induction can change the meaning of terms during reasoning, but induction does not discover things with novel properties.

Abduction should seek out more premises, abduction must change the meaning of terms during reasoning, and abduction can discover unfamiliar things with novel properties. Furthermore, iterative abduction can raise the level of reasonable confidence in the real existence of those things.

Although Peirce labelled a proposal of a hypothesis as an "abduction" it would be a mistake to isolate scientific creativity in general within abduction alone, apart from deduction and induction. Peirce never made that mistake. Only the combination and integration of the three forms of inference is productively utilized within empirical inquiry.

Procedural Abduction

Peirce offered a few examples of cooperation among forms of inference, but he did not explore mixed inferences further. Many combinations of deduction, induction, and abduction can be formulated, and some of them inform sound scientific methodologies. Twenty-five combinations are delineated in Shook

[26], ranging from the fallacious and pseudo-scientific to the proto-scientific and fully scientific. Four types of reasoning, from simpler to more complex forms, serve to illustrate here how the last type of scientific abduction, “strict abduction,” is able to warrant credible conclusions about postulated entities. Qs, Rs, and Ss are placeholders for any sort of observed phenomena, while A (and its capacities C1, C2, etc. that make a difference to observable evidence) is a placeholder for any postulated entity (e.g. an object, model, energy, force, field, and so on).

Retrodicted Induction

Qs !

Suppose that If A then Qs [now expecting Qs from A’s vague definition]

Rs !

Suppose that If A then Rs [now expecting Rs from A’s vague definition too]

Ss !

Suppose that If A then Ss [now expecting Ss from A’s vague definition too]

...

So, A

Retrodicted Induction superficially looks like an abductive procedure. It is far more suspicious, because A’s definition is designed in advance to ‘explain’ not just some initial Qs but also plenty of other vaguely indicated matters, so that any chosen Rs, Ss, and Ts (etc.) can get ‘explained’ when they show up later. Retrodicted Induction cannot attain the level of scientific theorizing.

Predicted Abduction

If A then Qs [from a vague idea of A, by deduction Qs would be expected from A]

A pattern of Qs gets discovered !

If A then Rs [from a vague idea of A, by deduction Rs would be expected from A]

A pattern of Rs gets discovered !

...

So, A

Predicted abduction also falls short of the level required for fully scientific theorizing. It allows a thinker to remain stubbornly attached to an initial conception of the entity to be discovered.

Predictable Coduction

If A then Qs have features F1 [given A’s definition, by deducing how Qs having F1 are expected]

Qs have F1 !

If A then Rs also have analogous features F2 [after adjusting A’s definition, then deducing how Rs having F2 are expected, while still deducing Qs with F1 too]

Rs have F2 !

...

So, A

Predictable Coduction is more plausible, because A is well-defined rather than vague, and A’s definition is permitted to developed in only incremental ways in response to evidence. Predictable Coduction lacks explanatory plausibility, however, since it actually only “explains” things as they get discovered.

Strict Abduction

Qs !

Suppose (only if A has C1), then Qs

Suppose (only if A has C1-2), then Qs & Rs

Rs !

Suppose (only if A has C1-3), then Qs, Rs & Ss

Ss !

...

So, A(Cn)

At this level of scientific theorizing, where postulation and confirmation are thoroughly intertwined, it is no longer an easy matter to see where logic and learning are divided apart. The conceptual creativity applied to developing the object of the conclusion is not a separate thought process apart from the inferential rationality that eventually warrants acceptance of that entity's existence.

Abductive Scientific Realism

The question of philosophical realism is a metaphysical issue, unlike scientific realism. Even if one grants a measure of scientific realism, affirming that postulated entities with ample scientific confirmation are credibly real (more or less as theories conceive them), philosophy can still ask its skeptical question, "Is it rational to think that science's affirmed entities actually exist?" Science's most confirmed entities may not be actually knowable, if philosophy knows knowledge better than any amount of science. Metaphysical anti-realism can be compatible with modest scientific realism, if only to warn science that its excusable confidence in theoretical entities cannot determine their actual reality or compel a rational mind to take them as truly real. This philosophical anti-realism sets the bar for knowledge higher than any methodological standards followed during scientific inquiry. Philosophical naturalism, by contrast, takes the position that science's highly confirmed entities should enjoy at least as much credibility (and often more) as anything else familiarly known from experience [28].

This chapter's topic is scientific realism, not metaphysical realism/anti-realism, or philosophical naturalism. The motivating question is, "Is it reasonable for scientific realism to be affirmed in the course of empirical inquiries applying sound scientific methodologies?" When the application of procedural abduction in scientific methodologies is considered, then scientific realism is warranted because scientific hypotheses about postulated entities become credibly reasonable.⁷ Standing outside of science, and pondering how to inductively or abductively justify scientific realism, is already philosophically futile and scientifically irrelevant [31]. The best explanation for science's success is science's own work: if science itself does not sufficiently justify the credibility of its confirmed hypotheses in the first place, nothing can. Fortunately, science has no need of any non-scientific or metaphysical assistance. Naturalism's worldview, for example, is plausible only if scientific realism is already reasonable; nothing about the scientific realism due to procedural abduction needs any axiom or premise of naturalism.

⁷ Recent studies linking scientific realism with abductive inquiry include Magnani and Betolotti [29] and Niiniluoto [30].

The credible plausibility to abductive scientific realism lies in the special features of Strict Abduction and higher-order abductive procedures in Shook [26]. Crucial features have to do with the creative postulation and re-conceptions of the entity to be discovered. Loose ideas of entities allow for vague predictions about amorphous evidence, evidence that any number of similarly imprecise postulations could equally well “explain”. The poor reputation of abduction is not due to abductive reasoning itself, but rather to vague and unrevised ideas of postulated causes. Strict abduction deals with a postulated entity A by exercising tight control over modestly modifying the conception of A during the reasoning process.

First, at each stage, the conception of A has only one clear definition and set of capacities. Only the capacities required to account for the phenomena are attributed to A, and whatever the definition of A may be, that definition is only permitted to be compatible with those Cs applied in the procedure.

Second, no other conceptions of A, beyond those Cs proposed to account for Qs, Rs, Ss (and so on) are regarded as relevant. Strict Abduction does not permit the definition of A to range beyond whatever is minimally necessary for it to have its explanatory capacities. That strict control allows successful predictions to more impressively support the postulated hypothesis.

Any responsibility for the vagueness or precision of conception of postulated entities must rest with the human conceivers, not the entities. The fault lies with scientists for failing to better define and refine their hypotheses, thereby permitting undeserved “confirmations” and allowing unscientific theories to proliferate. It is a mistake to depict scientific inquiry as a thought process undertaken by a solitary thinker. Peirce expected a scientific community to conduct and control the scientific enterprises of empirical inquiry and collectively evaluate their results. Scientific communities yield knowable discoveries, not any lone mind.

Scientific Communities

Procedural abduction works best for a community of scientific inquirers who consult together about how realistic a hypothesis can become, while they enlarge the collection of evidence and simultaneously develop their conceptions of postulated entities. These additional features of procedural abduction, exclusively the responsibility of scientific communities, have essential roles:

Third, due to the bounded clarity supplied by the second feature, a community of inquirers can apply A together and everyone can agree upon what the explanation is and what it so far entails.

Fourth, although a community will disagree over what new capacities A should have for increasing its predictive range, both the current definition of A and the presently assigned capacities place compatibility constraints on the sort of new capacities that can be assigned to A.

Fifth, if a new prediction goes badly, the community of inquirers only needs to doubt the new implicated capacity of A, not the rest of the capacities of A, preserving the explanatory power A had already earned.

Sixth, the expansion of A's capacities and its explanatory range can halt and pause whenever the community finds no work for A to do presently, but A can be put to work again in the future when opportunities come for relevant observations.

More complex kinds of procedural abduction than Strict Abduction all share in these six features. Those features prevent a hypothesis from being able to explain far too much, and from trying to explain new phenomena only after they are observable. All the same, a hypothesis explaining too much too easily can be convincingly realistic to the smartest minds, including scientists. Histories of scientific fields are replete with tales about good scientists who stubbornly cling to their poor hypotheses. Humility is perhaps the first virtue of scientific character. (Peirce pointed to scientific analogues of faith, hope, and charity as well; see Shook [32]). Peirce wrote,

The scientific world is like a colony of insects in that the individual strives to produce that which he himself cannot hope to enjoy. One generation collects premises in order that a distant generation may discover what they mean. ([20]. 7.87)

Since scientific knowledge of the real world is created, something in this world accomplishes that knowledge – the community of scientific inquirers, who have a shared history of discovery and a shared future of hypothesis testing, bound together by a commitment in their common purpose of creating knowledge. Peirce explicitly connected the ideal of the scientifically real with the idea of the scientific community.

The real, then, is that which, sooner or later, information and reasoning would finally result in, and which is therefore independent of the vagaries of me and you. Thus, the very origin of the conception of reality shows that this conception essentially involves the notion of a COMMUNITY, without definite limits, and capable of a definite increase of knowledge. ([20] 5.311)

That growth of discovered knowledge is due to abductive procedures applied by scientific inquirers. Procedural abduction, by maximizing the value of evidential information and inferential reasoning, yields discovery in its genuine sense of scientific realism.

Procedural abduction overcomes that long-standing dichotomy between psychological learning and rational logic. Where learning and logic, and discovery and justification, are unified for the inclusive goal of knowledge creation, creativity could not be isolated from reasoning. Each finds its scientific purpose in the other. Creativity is reasonable, and reasoning is creative, where an organization of scientists are growing organized knowledge. Three modes of creativity have come up in this scientific context: novelty, development, and organization.

Novelty – new things one after another after another. However, mere novelties may not be relevant to each other, so development is needed.

Development – enlarging capacities to effectively manage sequenced novelties. However, independent developments are not automatically coordinated with each other, so organization is needed.

Organization – improving integration of the whole through harmonious co-development. However, only committed organizations with a shared history and future can guarantee this co-development, so scientific community is needed.

This chapter asked a fundamental question for philosophy of science: How is knowledge of the world created? It was proposed that what is learnable and what is logical is integrated and unified by the processes of creating knowledge. This would require that discovery and justification are organically unified during the creation of knowledge. Procedural abduction, at the scientific level of Strict Abduction and higher, integrates the learnable (postulations undergoing conceptual development) and the logical (hypotheses undergoing rational scrutiny) quite thoroughly. This is where discovery and justification are functionally fused together within the organized process of procedural abduction by scientific communities.

The four questions posed at the beginning are answered by this pragmatist philosophy of science as follows. (1) Is scientific creativity methodologically related to scientific justification? Answer: scientific creativity is integral to abductive procedures yielding scientific justification. (2) Can a distinction between genuine science and pseudo-science be clearly defined? Answer: genuine science is distinguished by the application of procedural abduction at the level of Strict Abduction or higher. (3) Does scientific knowledge achieve the legitimacy of scientific realism? Answer: procedural abduction legitimates the credibility of highly-confirmed hypotheses and hence justifies scientific realism. (4) How are scientific communities responsible for establishing scientific knowledge? Answer: scientific communities using procedural abduction realize (in both cognitive and constructive senses) scientific knowledge.

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