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Abduction in Cognition and Action

Logical Reasoning, Scientific Inquiry, and Social Practice

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Abduction, the Logic of Scientific Creativity, and Scientific Realism

John R. Shook

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?

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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 nineteenth and twentieth 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 *legitimates* scientific realism; and scientific communities using procedural abduction *realize* (in both cognitive and constructive senses) scientific knowledge.

1 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 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

[1] An entryway into the literature could start by consulting Magnani [18], Paavola [19], Barrena and Nubiola [20], Park [21].

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-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.

[2]Prominent philosophers of science who stress the epistemic link between realistic modelling and controlled experimental conditions include Hacking [22], Geire [23], Cartwright [24].

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.

2 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. 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 logicality, 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 nineteenth 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 twentieth 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 not 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 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

[3] See Nickels [25], Snyder [26], Schickore and Steinle [27].

[4] Whewell [28, vol. 2, p. 186].

[5] Popper [29, p. 32].

[6] Popper [29, pp. 7–8].

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 [3] and theories of knowledge [4]. 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"?

3 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 [5]. 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 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.

4 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 logicality, requires inferences about (a) objects not already known to exist and (b) not rigidly preconceived. 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 [6] and not just inferences to “the best explanation” [7]. 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. ([4], 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 [8]. 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” ([4], 5.194).

The creativity inherent to abductive postulation, as Peirce repeatedly explained, allows for a genuine logic of discovery [9]. 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.

5 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 [10]. 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" ([4], 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. ([4], 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. ([4], 5.145)

> Abduction is the process of forming explanatory hypotheses. It is the only logical operation which introduces any new idea. ([4], 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 two premises: "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" ([4] 5.181). However, Peirce treats this "insight" more like an informed guess [11] that arises in various guises *during* inferential reasoning [12]. 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" ([4] 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. ([4] 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. ([4] 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 [13] 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.

6 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. ([4] 5.17)

Peirce occasionally referred to "mixed" reasonings and inferences ([4] 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 motived 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. ([4] 7.218)

Deduction, induction, and abduction have very different inferential characters and results. That is why each needs the others 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. ([4] 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. [14]

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 gets productively utilized within empirical inquiry.

7 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 [13], 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.

8 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 [15].

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 [16]. 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.

The credible plausibility to abductive scientific realism lies in the special features of Strict Abduction and higher-order abductive procedures in Shook [13]. 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. That control is emphasized in the first two special features of Strict Abduction.

> 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

[7] Recent studies linking scientific realism with abductive inquiry include Magnani and Betolotti [30], Niiniluoto [31].

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.

9 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 have disagreements 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 seem convincingly realistic to the smartest minds, including scientists. Histories of scientific fields are replete with tales about good scientists who stubbornly cling to their inadequate hypotheses. Humility is perhaps the prime virtue of scientific character. (Peirce pointed to scientific analogues of faith, hope, and charity as well; see Shook [17]). 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. ([4]. 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. ([4] 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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