The Academic Synopticon

Part Six
Science and Technology

> An adequate philosophy of science should have normative force … Mere descriptions of scientific practice, no matter how general or sensitive to detail, will not do. Without normative force, studies of methodology, however interesting, would translate as a catalogue of fortuitous and mysterious particular accidents, with no method at all.
>
> [W. Wimsatt 2007, 24]

ONE. Science, Observation, and Reason

Scientific Method is used to construct scientific knowledge about nature. Knowledge is increased through careful observation and logical inference. ***Observation, inference, and knowledge are almost always fused together to some degree.*** For example, much of our observation of the world is recognition of the familiar, which is observation informed by knowledge. Also, most of our observations of objects in the world are informed by inference, because the information from our senses in quite superficial by itself. Using vision, we only really see surfaces, shadows, colors, patterns: but we observe objects having depth and volume and texture. Using hearing, the various noise we hear become the sounds of things near and far, like approaching cars or hidden animals. Our ordinary everyday experience of the world is a type of knowledge, which we can characterize as practical reliable knowledge. Although this knowledge of ordinary experience is often mistaken, it works well enough for our daily activities. Examples are gathering vegetables and cooking them for a nutritious meal, or weaving cloth and sewing it to make clothing.

Empiricism and Rationalism

Philosophers who believe that experience is the source and ultimate justification for all knowledge are called empiricists. Some empiricists have looked to experience to provide a higher type of knowledge than practical reliable knowledge, a type of knowledge that is infallible and certain, which will never turn out to be false. But not all empiricists search for certain, perfect knowledge -- we might call those who do undertake this search “extreme empiricists”. There have been few extreme empiricists, since there are serious problems with trying to find reasonable cases of experiences that give perfect knowledge about the world. These problems are so severe that other rival philosophers have concluded that experience by itself cannot be a source of perfect knowledge at all. Indeed, most empiricists do accept that experience needs help from reason to establish knowledge about the world. However, experience (even with help from reason), can never establish perfect knowledge about the world (as will be explained below).

A philosopher searching for perfect knowledge will conclude that experience cannot play any role in perfect knowledge. What other source of perfect knowledge is possible? The alternative to experience is reason, and philosophers who emphasize the large role that reason must have for knowledge are called rationalists. Some rationalists, searching for perfect knowledge, will use only reason to find knowledge, and we might call them “extreme rationalists”. As it turns out (also to be explained below), reason by itself cannot establish any perfect knowledge about the world. That is why there have been few extreme rationalists in the history of philosophy. Most empiricists have decided that experience needs a little help from reason to establish knowledge, and most rationalists have concluded that reason needs a little help from experience to establish knowledge about the world. Debates between these empiricists and rationalists are surveyed by this article about “Rationalism vs. Empiricism”. If both sides assume that perfect knowledge must be the quest, then both sides must fail. Experience and reason can indeed be artificially separated from each other, in the philosophical imagination (again, far from our ordinary experience in which observation, inference, and knowledge are partially fused together). By artificially separating experience from reason, extreme empiricists and extreme rationalists destroy the possibility of knowledge about the world. That is why most philosophers conclude that both experience and reason are needed for knowledge about the world, and the difference between empiricists and rationalists comes down to different estimates about how much experience and reason contributes to knowledge.

In the extreme empiricists' philosophical imagination, experience is "purified" of anything that might admit the possibility of error and illusion, and the empiricists announce the discovery of a realm of "sensations" or "sense data" that can never prove false. Example: "There is a bright point of light." In this example, a person making this judgment is claiming to observe something and describe it so narrowly that she can never be shown to be wrong. If instead she claimed, "There is a star in the sky", this judgment could conceivably turn out to be wrong, because we can imagine how further investigation could show that what this person really experienced was not a star (but instead a planet, or an airplane, etc.). The problem with pure sensations, even when described in infallible ways, is that they cannot help establish knowledge *about the world*. Knowledge consists at least of judgments about the world expressed in propositions of some public language.

If pure sensations are expressed in judgments, they either (1) fail to be about the world, and instead are about some realm of pure experience (just lights and colors and noises and tastes, etc.); or (2) they try to be about the world but begin to suffer from the possibility of error and illusion (e.g. is that really a circle of light, or maybe an ellipse -- and is it red, or reddish-orange? etc.). Furthermore, anything like scientific knowledge about the world would at minimum consist of judgments about the regular behavior of objects and events in the world. Yet pure experience cannot establish these sorts of judgments because of the "Problem of Induction": even though a series of experiences may have common features, and appear to present a pattern, it is impossible to have perfect knowledge that this pattern would continue into the future. Empiricism's quest for perfect knowledge through experience alone can therefore only lead away from knowledge about the world and can never produce anything like scientific knowledge. In the 20th century, scientific anti-realists have generally preferred types of Empiricism (like positivism's view that science can only describe patterns of phenomena).

On the other side, in the extreme rationalists' philosophical imagination, reason must have a method of inference for establishing perfect knowledge. The only method of inference that promises to prevent all possibility of error is deduction. Deduction is a careful relation between premises and a conclusion, designed so that if you know that the premises are all true, you can also know that the conclusion is true. So long as the premises remain true, the conclusion can never turn out to be false, and your knowledge of the conclusion is perfect knowledge. You can read an advanced article about "Classical Logic" here. The difficulty with deduction is that a person's perfect knowledge of conclusions depends on perfect knowledge of the premises. How can a person perfectly know the premises? Well, perhaps other deductive arguments show that each of the premises are knowably true. Ok, but those additional arguments must have their own additional premises, which all need their own deductive arguments to justify why they can be known to be true, and so forth, and so on -- are an infinite number of arguments needed for any knowledge? That seems strange, since no person could hold an infinite number of arguments in their mind, and thus can never be assured that perfect knowledge is achieved.

There are two other alternatives: (1) perhaps some premises can be known to be true without any argument (see "Foundationalist Theories of Epistemic Justification"), or (2) perhaps some special conclusions can serve as premises for other arguments, which in turn prove conclusions that serve as premises justifying those special conclusions, so that only a finite number of arguments are actually needed (see "Coherentist Theories of Epistemic Justification"). Rationalists have usefully developed the foundationalist or coherentist alternatives, and these developments are very important for scientific method and realism, so they will be discussed further in sections below. However, extreme rationalism is a dead-end because pure deductive inference (nor inductive or abductive inference either -- more about these below) cannot establish any perfect knowledge about the world. Reason by itself can form perfectly coherent systems of thought, but there is no way to determine which system must be true, and most are quite compatible with the natural world. In other words, pure reason's truths are either (1) not about the natural world at all, or (2) somehow they are true about all possible worlds. Most rationalists therefore admit that reason needs some information from experience in order to produce knowledge about the actual natural world (thus agreeing with most empiricists that experience needs some assistance from reason).

The endless debates between extreme empiricism and extreme rationalism are inconclusive, because each side can show why the other side must be inadequate. Experience by itself cannot be a path to perfect knowledge about the world, but reason alone cannot establish any knowledge about the world either. Most philosophers turn away from this fruitless debate and take a compromise position that could be called “Rational Empiricism”: knowledge about the world is created by experience and reason working closely together. However, rational empiricism is a philosophical position that admits that perfect knowledge about the world is never possible. There may be types of perfect knowledge, but none of them can be about the actual natural world. Since scientific knowledge is about the natural world, then scientific knowledge cannot ever reach perfect knowledge, and therefore any scientific knowledge is less than certain -- instead, scientific knowledge, even at its best, is always fallible (could be exposed as false in the future) and revisable (could be improved or entirely replaced with better scientific knowledge).

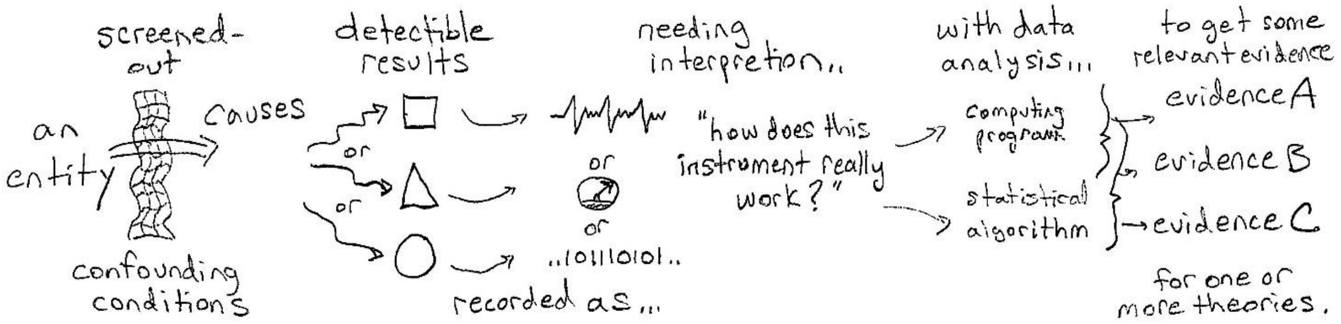
The scientific method itself is not a case of perfect knowledge either -- rather, scientific method is a tool that can be (and has been) modified and improved through regular use and testing. Furthermore, although there is general scientific method that is explained here, each of the sciences uses its own specific version of the scientific method that works best for that science. General features to scientific methodology are given an overview here.

Evidence and Theory

The word ‘evidence’ is quite vague in ordinary language. Scientific evidence has a clearer meaning. First, “evidence” only makes sense after theoretical expectations, and not before. Second, “evidence” only exists because of theory, and nowhere without it. Any perception lacking conceptual anticipation and clarity cannot contribute to data or information, and cannot serve as evidence for anything. People commonly think that the use of scientific instruments permits the collection of “pure” data untainted by prior theoretical ideas. Nothing could be further from the truth. Such ‘data’ would be noise and beneath scientific notice except to weed it out.

Gathering evidence from scientific observation require several layers of anticipatory and participatory theory.

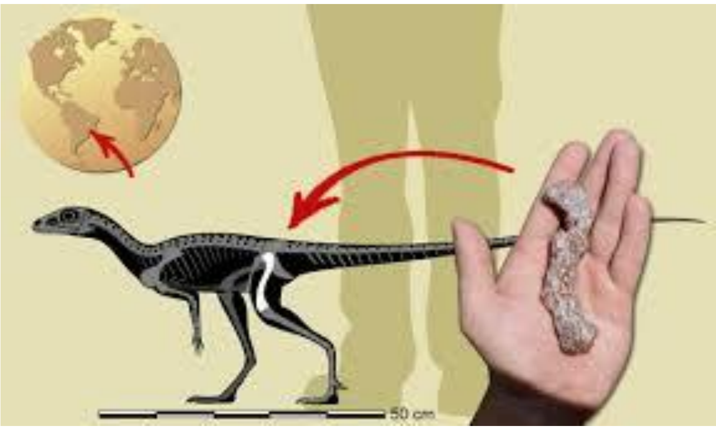
An entity ... causes ... effects on instruments ... needing interpretation ... and analysis ... to be evidence.



Every stage involves pre-theorizing. First, observational efforts have to be directed towards some particular aspect or part of the world around us to be perceived. No one gazes around without a thought in their head and sees specific objects: to observe is to look first for something, even if it turns out to somewhat unexpected. Surprise comes from anticipation, not empty-mindedness. Second, a careful observation, unlike mere perception, is made from a chosen standpoint and set conditions to avoid interference or obscurity due to prevailing conditions. This allows for a controlled experiment. Astronomers wait for a cloudless night to observe the moon; chemists clean all the tubes and beakers first; and so on because of some prior theoretical understanding of confounding conditions. Third, whatever happens under those controlled conditions has to interact with a scientific instrument in some direct manner, and unless there is prior theory about how an object detectibly interacts with the mechanism of an instrument, the experiment is pointless. Fourth, the scientific instrument has to already be calibrated to reliably provide a quantitative stream of recordable data from that detectible interaction, providing outputs already theoretically understood to be useful. Fifth, unless established theory about how that scientific instrument works is already in place, no one would accept that instrument’s output of data to be anything but noise (and most instrumental output is usually noisy error).

Sixth, even good-looking stable data requires further refinement, as many iterations of the same experiment can be algorithmically and programmatically analyzed to reduce instrumental and measurement error as much as possible. Confidence in those refined procedures of data analysis requires even more theoretical understanding. At last, after all that strenuous testing, the scientific community has high confidence in some genuine data results, so it is ready to credit an observation of an entity with the title of “evidence”.

What about supposed evidence that needs no prior theory in place to be discovered? No such theory-free evidence has ever been collected anywhere. Let’s pursue what seems to be a fine case of innocent evidence just waiting to be stumbled over or dug up somewhere. What is a “fossil”? Common sense says that a fossil is the remains of a long-dead animal. Evolution loves fossils, because the theory of evolution would be implausible unless fossils of innumerable long-extinct species could be found and viewed. That makes sense, so let’s specifically ask, when did a “fossil” become “evidence for the theory of evolution? We today simply imagine that someone digs up a weird-looking rock and says, “That’s from a bone that once was part of a dinosaur skeleton from millions of years ago!”



Except no one stumbling across odd-shaped rocks 300 years ago were ever doing this. First, those odd objects are obviously made of rock, not bone. Why are rocks shaped a little like bones, but having weird shapes and sizes unlike any living animal today? No one thought that these collections of odd rocks were evidence of anything, other than the God’s mysterious sense of humor, or God’s desolation of the earth with the Biblical Flood. 300 years ago, no “fossils” for evolution existed anywhere. 200 years ago, the idea that bones from long-dead animals could get naturally petrified (organic material replaced by minerals) underground was accepted, but almost no one could imagine that any of these fossils were millions of years old, because that idea of the vast geological age of the earth was not accepted yet. Besides, Darwin wasn’t born until 1809. There were no “fossils” in evidence for evolution in 1800; they were only a natural curiosity barely fit for museums. Fossils as scientific evidence only came into existence AFTER Darwin formulated his theory of evolution by natural selection, partly to explain why so many fossils from extinct animals could be dug up everywhere. The first person to hold fossil evidence in his own hand was Darwin himself.

Theory creating its Own Evidence

The notion that the best support for a hypothesis comes from evidence that already exists for people already accepting that hypothesis doesn’t sound scientific, or even logical. Logic says, “That’s a fallacy of circular thinking!” If that circle was reasonable, anyone could be reasonable for believing any crazy thing.

In philosophy of science, that close relationship between theory and evidence cannot be denied. Seven major positions on the credibility of a theory can be distinguished. Proponents of each position argue strongly against other positions over whether a theory’s postulated entity should be actually thought to exist. If the “evidence” for a theory is too dependent on the theory and its believers, there should be less reason to think that this theory’s postulated entity is actually real.

I. Exclusionary Realism. The theorized entity X really exists, explaining why it is exclusively necessary to explain something going on in nature. If X didn’t actually exist, the theory would fail for lack of evidence and explanatory power, but that theory's established credibility does guarantee that X is what really exists. Disciplines and fields that take themselves to be "more foundational" in some methodological or ontological sense (eg. psychology, physics) usually foster strong exclusionary realism, along with dualism or reductionism (with aid from philosophy).

II. Inclusionary Realism. The theorized entity X really exists, explaining why it cannot be omitted from good explanations about what is going on in nature. While X probably exists, other conditioning and explanatory entities are involved too, so little about X requires the denial of other participating factors discovered with other theories. Disciplines and fields in close collaboration with neighboring areas tend to foster inclusionary realism.

III. Instrumentalism. The theorized entity X is just a hypothetic model or idealization that convenient allows the theoretical formula(s) and law(s) to work properly, but it doesn't have to really exist at all. The formulas and laws do the real explanatory work, especially when the direct verification of X itself is practically impossible.

IV. Positivism. In some disciplinary subjects and scientific fields, there is no point to postulating hidden entities at all. Real knowledge only consists of what is practically and directly observable: all the specific observations, patterns to collections of observations, and trends discerned in those cumulative patterns. If it can never be actually observed or closely detected, it doesn't matter if its real or not. Hard data, classifiable things, generalizable statistical results, and predictable trends are the beginning and end of knowledge.

V. Social Constructivism. Ordinary people are positivists about intellectual matters (see above) and pragmatists about mundane daily matters. If it works, its real enough. People talk about endless things: beliefs, promises, practices, relationships, rituals, rules, institutions, and all the things that make up organized society. None of these things really exist except where people think and talk about them, but all that talk does influence people's decisions and actions, so there are real social effects to social beliefs. However, none of these social matters could be real without people creating and sustaining them. (If people stopped believing in banking tomorrow, banks would promptly vanish from the planet.)

VI. Academic Constructivism. Intellectuals form expert communities around different kinds of disciplined investigations. In that academic world, investigators form theories about what is "actually" going on within whatever aspect or part of the world around them they are interested in exploring and explaining. A discipline eventually convinces itself that some theoretical entities are credibly real, but these are just fictions taken too seriously by intellectuals. If the sensible boundaries set by positivism are exceeded, then other intellectuals should throw skeptical doubt at those fictions by pointing out that they are only imagined constructions built by faith.

VII. Disciplinary Realism. A discipline becomes methodically convinced that a theory has been so well-confirmed that the postulated entity has to exist (it is part of the ontology) instead of any rival entity (or no entity per positivism) as an alternative explanation. Any academic discipline can reach this highest degree of confidence in its theoretical knowledge, from history and anthropology to psychology and medicine and on to biology and physics. When a disciplinary field asserts in its basic manuals and textbooks that "X is real" and rejects any other discipline's questioning or replacement for X, that entity is well-established with its ontological status. (At least until the next paradigm revolution.)

These seven alternatives form a circle rather than a spectrum. Strong disciplinary realism leads to Exclusionary Realism (I), while weaker disciplinary realism amounts to Inclusionary Realism (II). While constructivism serves as the greatest opposition to realism, instrumentalism seeks compromise while positivism regrets the whole folly.

From these debates, several arguments have congealed to keep philosophy of science invigorated. These arguments are each designed to make realism look implausible. Counter-arguments, if plausible, provide good support for realism. Key arguments include: the Theory Dependency problem, the Paradigm Incommensurability problem, the Underdetermination of Theories problem, and the Pessimistic Induction problem.

Theory Dependency. This argument points out that evidence depends on theory as much as theory depends on evidence. The notion that theory is receiving independent support from evidence cannot be accurate. Since realism

seems credible when evidence independently supports a theory, that realism cannot be so credible. Philosophy can point out that epistemology makes room for a “coherence theory” of truth where all propositions mutually support each other in a maximally consistent web. However, epistemology hasn’t credited coherence with much realistic objectivity. (Although idealism admires coherence, it has its own issues over realism).
Counter-argument for Realism. Properly disciplined areas (such as scientific fields) do not test a hypothesis against evidence only found by assuming that hypothesis. Instead, evidence is collected and assessed by way of different theoretical commitments, so that relevant evidence can then test a different hypothesis not involved with evidence gathering. Multiple theories, for example, make the evidence of fossils relevant to the theory of evolution, from paleontology and anatomy to geology to minerology – but none are biology itself, so biology can assess evolution with evidence that it didn’t create. That “consilience” of multiple disciplines agreeing on the objectivity of evidence lends additional credibility to a theory explaining that evidence. Evidence is never independent from theory in general, but specific evidence can be quite independent from a particular hypothesis to be tested.

Paradigm Incommensurability. On some definitions of “paradigm”, a paradigm compromises not only a discipline’s or field’s dominant theories, but also that area’s core methodologies for acquiring all evidence and inventing and assessing all hypotheses too. In short, there is nothing outside that sort of paradigm which could possibly be relevant to skeptically doubting or denying theories and their entities within the paradigm. For each paradigm, its knowledge seems realistically secure and unchallengeable, but of course every other paradigm takes the same attitude. Nothing but stalemates result from paradigm contests, and not even philosophical epistemology can intercede to rank and pick winners.
Counter-argument for Realism. Disciplines that encourage bloated paradigms that are resistant to challenges from surprising evidence, fresh experiments, or inventive hypotheses will suffer from that paralysis of immovable paradigms. Realism’s credibility would inevitably fade. Disciplines discouraging domineering paradigms compel rival theories to compete against fresh evidence and each other, and disciplines incorporating some scientific methodologies have less vulnerability to paradigm bloat. The principle that prefers fewer theoretical postulates and simpler formulas and laws help to deflate and discard paradigms propped up by ad-hoc postulates only rescuing the paradigm from empirical refutation. Fully scientific fields look for “crucial experiments” capable of discovering independent fresh evidence compatible only with one theory or its rival theory. Lean theories surviving perpetual experimental testing enjoy greater realistic credibility.

Underdetermination of Theories. A sizeable and growing body of evidence can be compatible with not only the currently-credible theory, but any rival theory could be sufficiently clever to be consistent with that same body of evidence too. How would a theory be able to reasonably claim a greater degree of empirical confirmation? Furthermore, for any theory that does make the best fit with evidence today, there are many not-yet-invented theories equally able to explain that same evidence too. The capacity of the imagination has not yet been exhausted, and may never be (not to mention the fertile imaginations of intelligent alien species.) The odds that a single theory, no matter how well confirmed so far, has luckily hit upon the real truth must be very small.
Counter-argument for Realism. No discipline with a modest scientific orientation, and no fully scientific field, allows itself to claim that final theoretical truth is achievable. All disciplined knowledge is partial and fallible, only counting as knowledge because of its superior fit with evidence than rivals. Furthermore, that scientific orientation forbids any inventive theory from inflating with postulates and formulas just to handle any additional evidence that comes along. That inflation just to prevent disconfirmation is itself a disqualification from science, and from any properly disciplined field. Furthermore, good theories are applied to experimentally discover fresh evidence able to put it to serious tests. Again, lean theories that are proposing and surviving risky experimental testing enjoy greater realistic credibility. Realism does not rely on invulnerability or infallibility.

Pessimistic Induction problem. The pessimistic argument has this schematic form:
1. Every theory currently enjoying credibility is put into risk by the arrival of future fresh evidence. Indeed, any theory around today defeated a previous theory that couldn’t explain the evidence as well.
2. No theory – past, present, or future – is aloof and immune from disconfirmation due to an ever-growing body of empirical evidence.
3. Since every theory will eventually be discredited and falsified, no theory could be said to get reality just right, so it could never be reasonable to believe in a theory’s entities realistically.

Altogether, it is unreasonable to think that any theory's entities have to be real, since they will all be proven false, eventually.
Counter-argument for Realism. Each theory getting disconfirmed by evidence gets replaced by a better theory able to explain all the evidence. Unless scientific inquiry simply halts, better theories replace worse theories no matter how much new evidence is accumulated into the future. Indeed, one might propose the "Optimistic Induction" argument: since any theory is fallibly replaceable by a more empirically adequate theory, knowledge is improving along the way, and realistic confidence in theoretical entities should improve in the long run.

These four arguments and their counter-arguments are only sketched here. Many refinements and sub-arguments have proliferated. Understanding those continuing debates requires a closer look into the relationship between scientific evidence and scientific theories. Disciplines distant from scientific methodologies may witness bloated paradigms, invulnerable dogmas, and unrealistic theories. Disciplines closer to scientific methodologies follow a set of principles, principles that emerged from the progress of science itself.

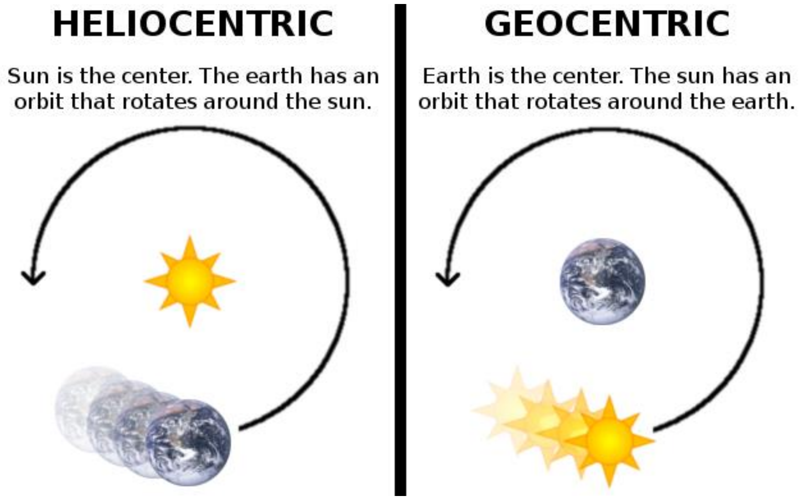
TWO. Theories and their Evidence

The beginnings of the scientific method can be found in medicine, agriculture, technology, and nature. Our story here is nature's story – how does the cosmos work? This question led to astronomy and physics.

A few ancient thinkers speculated that the earth moves while the sun is stationary. The common opinion was the 'geostatic' view that the earth never moves in any way. Why change that view? Everyone had the identical body of evidence accessible just by observing the sun's path.

We now understand the difference between "phenomena" and "theory" in a way that the ancients had to invent for themselves first. To know what is phenomenal, simply observe your surroundings carefully. What is "visual" is what is seen by perception. But there is a second kind of "seeing" only with the mind's own imagination. That is where theory arises: to "see" an ideal model and imagine that this model is the real situation, of which the phenomena is only a part or aspect. It requires theory to imagine how the earth could be moving instead of the sun, allowing the sun to "appear" to move instead of "really" moving. When reality is understood to be more like theory than just what plain observation shows, the journey of science begins.

Rumors of the Egyptians allowing the earth to move cannot be substantiated in their surviving works. The first Greek philosophers such as Anaximander (6th C. BCE) were indebted to Egypt's geometry and architecture. Heraclides of Pontus (4th C. BCE) suggested that the earth is a sphere that rotates so the sun appears to move across the sky during a day. Aristarchus of Samos (310-230BC) completed this model of the cosmos by proposing that the sun isn't moving since the earth goes around the sun during one year. Both the geostatic and geocentric views had to be mistaken. The Sun's motion can be explained by two rotational motions of the Earth: the Earth rotating on its spherical axis, and the Earth rotating around the stationary Sun.



The evidence for the heliocentric and geocentric models consists of what can be observed from the surface of the earth, on the ground looking up and around. Imagine two earths and two suns, and two observers standings on their earthly ground. Person H says, “I see the sun moving across the sky from east to west.” Person G says, “Me too.” Person H says, “The sun’s motion is evidence that my H model is correct.” Person G says, “That same motion of the sun is evidence that my G model is correct.” Person H then says, “We both have all the available evidence, the same evidence, for our own models.” Person G then admits, “I don’t have enough evidence from my position to tell whether my planet goes around its sun or the other way around.” Person H agrees, “Right, I am in that same situation here on my planet too.”

So far, this is a debate between theoretical models that at least satisfies the first scientific expectation.

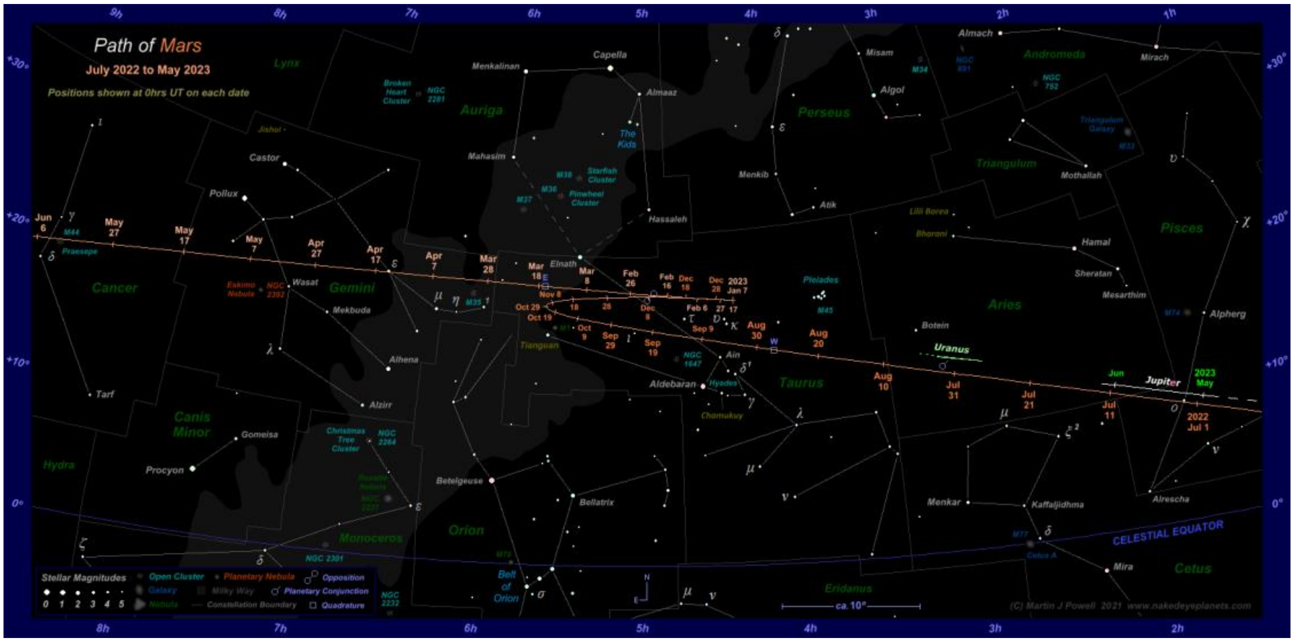
1. A theory should explain all the available evidence.

However, two models can both satisfy Principle 1, which is a situation called “empirical equivalence.” Model H is empirically equivalent with Model G. All the evidence (available so far) is “equally valent” to make either model credible. However, in an equivalence stalemate, neither model can be scientifically accepted. The lesson learned: the goal of a scientific theory is not just to “explain all the evidence.” Theories compatible with current evidence are not thereby “scientific” enough, although they may be proto-scientific. A second lesson has been learned too, about a second expectation of science.

2. A theory should seek additional evidence further supporting its credibility.

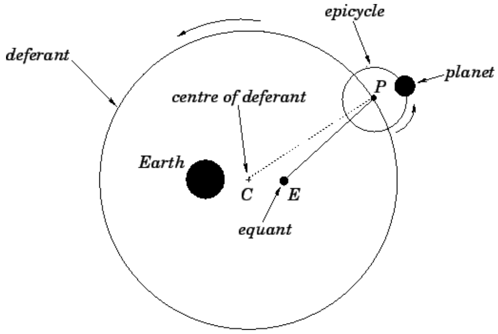
The notion that a theory should somehow stay aloof and uninterested in pursuing more evidence is not a scientific notion. Dogmas prefer that evidence remains static.

The dogma that the sun is the center of the universe carried on. Egypt remained a center of advanced learning. In Alexandria, where its world-famous library was instituted, Claudius Ptolemy (85-165 CE) pondered not just the earth and the sun, but the planets as well. The planets were no longer those “wanderers” because astronomy has tracked the decades-long and centuries-long circuits through the zodiac.



Those circuits became formulaic and mathematical, and the model of the universe had to become more complicated too.

Ptolemy was an excellent mathematician, able to put the planets in circular paths around the Earth at the center. However, to fit the data for a planet's position over time, he had to add complexities: a planet goes around an epicycle whose center itself revolves around the primary center near the Earth.



By the fifteenth century, the Ptolemaic system seemed secure until a mathematician in Poland fitted the planetary motions into a heliocentric model but retained perfectly circular orbits. Copernicus and his book *De revolutionibus orbium coelestium* (On the Revolutions of the Celestial Spheres, 1543) had to retain some epicycles to fit the planetary observations. In fact, the Copernican model (which was simpler) did not fit the data as well as the Ptolemaic system (with its many complexities).

Europe's greatest astronomer, Tycho Brahe, was impressed by Copernicus, but kept the Earth at the center of his "geo-heliocentric" system (c. 1587) so that the rest of planets circled the Sun while the Sun circled the Earth. That system remained just as complex as Ptolemy's, with highly complex mathematics (for that time) required to even approximately fit the planetary observations. By the late 1500s, three different models offered quite complicated geometrical orbits without making a close fit with all the observational data.

No astronomer was satisfied with this scientific situation. Astronomy was getting reduced to abstract mathematics without any improved understanding of how the solar system works. Why do the planets move in the first place? What force could the Earth, or the Sun, have to keep the planets moving around the way that they do? No answers were forthcoming. Dissatisfaction with the Ptolemaic system was only growing, with arguments over pointless mathematical complexities. A third expectation was arising among astronomers:

3. Avoid adding more and more complexities to a theory just to manage the available evidence.

Principle 3 seemed particularly relevant since none of the models was still following Principle 2.

Johannes Kepler then inherited Brahe's observatory and improved his tables of astronomical observations. The Brahe-Kepler astronomical charts and tables were published across Europe. Kepler eventually realized that a planet does not go in a perfect circular orbit around the sun, but follows an elliptical orbit instead. In 1609 Kepler published a book showing how this elliptical-heliocentric model provided for easier calculations and made a far closer fit with all observations while requiring a quite simple model: one elliptical orbit for each planet around the sun, with no 'deferents', 'equants', or 'epicycles'.

The intellectual world was not ready to abandon a theological dogma about the Earth's centrality (seemingly based on the Bible) or the heavenly perfection of the circle. Kepler's theory was the most scientific model yet, because it relied on three additional expectations about scientific theorizing.

4. Continue to accumulate and refine the optimal body of observational evidence and make it publicly accessible.

5. Let all of that additional evidence itself inspire a novel theory, or at least modifications to a current theory.

6. Do not let mythical or metaphysical dogmas interfere with theory invention and revision.

Although an ellipse is geometrically a little more complex than a perfect circle, Kepler's model was overall the simplest one yet: for each planet, one elliptical orbit. The real trouble was with the Catholic Church. In Italy, Galileo was soon convinced by Copernicus and Kepler, and added his own observations about little moons going around Jupiter and the rings about Saturn. Galileo's persuasive musings about the superior credibility of the Kepler model made a vast impact on the course of science in Europe. One core message was this:

7. A theory can be invented and then adjusted where its complexities are called for by the growing body of evidence.

Principles 4, 5, and 7 together recommend "evidence-driven hypothesizing" for scientific theories. The alternatives, rationalist speculation and principled deduction, should be last resorts only at the highest levels of theoretical invention. Kepler abandoned an earlier attempt to fit planetary orbits into a scheme of platonic solids, after seeing how that rationalistic scheme couldn't make a better fit with the observed orbits. We will see more examples as our story of physics proceeds.

Kepler's model of planetary motion had three formulas: (1) a planet's orbit follows an ellipse with the Sun at one focus; (2) a line from the Sun to a planet sweeps out equal areas in equal times; and 3) the square of a planet's orbital period is proportional to the cube of the semi-major axis of its orbit. Kepler added an explanation for planetary motion: each planet maintains its velocity due to its own "inertia": without an external force applied, a moving body keeps moving the way that it does. This explanation is a case of principled deduction: conceiving of a first principle of motion (everything has inertia) permits the deduction of an actual course of movement (a planet maintains its own orbital movement).

The next important scientist in the narrative is Galileo. Galileo adopted the principle of inertia from Kepler, but his experiments with balls rolling along inclined planes suggested that the most natural kind of motion was simply straight motion. His book *Discourses and Mathematical Demonstrations Relating to Two New Sciences* (1638) describes the first controlled and replicable experiment resulting in a quantified formula: a body falls with a constant acceleration, so that D [distance] = kt^2 where k is a measurable constant. Galileo could not suppose why that constant had its particular value, and only later with Newton's theory of gravity did that k become .5g where 'g' represents the force of gravity.

Galileo recognized how Kepler's idea that a planet has its own inertia to move forward matched his own view that a body in motion will continue steadily in that direction until something else affects it. Galileo had already applied Principle 6 to abandon ancient metaphysical dogmas, such as supposing that mathematics cannot be applied to motion, and assuming that heavier objects fall faster than lighter objects. He easily believed that it was time to abandon another dogma about circular motion being more "natural". However, this principle of inertia actually made it harder to explain why a planet's orbit has to be curved. Why haven't the planets sped away from the Sun in straight paths? Kepler's model was accurate, but it required more details about the mechanism: what is the real cause for the observed elliptical orbits around the Sun? The Sun must be playing a key role.

Galileo's inquisition trial and punishment, after defending heliocentrism in his Dialogue Concerning the Two Chief World Systems (1632), did not slow down the work of astronomy. The new frontier was the study of comets. Cassini and then Halley observed comets, following Principle 4, to determine their peculiar trajectories through the solar system. Halley provoked his friend Isaac Newton to apply his mathematical genius. Newton figured that the Sun was essential, but not for its heavenly status. The Sun is helping to cause the planets to orbit around it, due to a "centripetal force" (a force towards the center) pulling the planets inwards to the Sun.

Newton's *Philosophiæ Naturalis Principia Mathematica* (1687) proposed that two forces are responsible for planetary orbits: one force impelling a planet to simply carry forward in continuous motion (straight, as Galileo found), and one force pulling the planet directly towards the Sun. That combination of those two forces, in accord with Principle 5, results in either a circular path or an elliptical path for planets. (Some interstellar comets follow a hyperbolic orbit because the Sun's gravity is not strong enough to capture them.)

What is the nature of that centripetal force towards the Sun? Newton applied Principle 6 to abandon the dogma that the celestial realm must follow different rules than material objects of the earthly realm. Newton's theory proposed that a newly discovered force, the force of gravity, always pulls two objects towards each other, with the greater mass proportionally moving less than the smaller mass. Following Principle 7, his calculations proved that the vast mass of the Sun keeps each planet in an elliptical orbit, an orbit that closely matched the observed orbits of all the planets and moons yet observed.

If Newton's achievements had halted there, his status as a great scientists was guaranteed. But Newton pushed further, provoked by scientific doubts about this "universal force of gravity". Although Newton had completed the Galilean revolution by discovering why objects would naturally move, his force of gravity still seemed too rationalistic or mythical. Two key problems left gravity in a mysterious condition: (1) inserting a principled deduction about an invisible force looked suspiciously too convenient, (2) this force of gravity is a case of instantaneous action at a distance which seemed more occult than scientific. Balancing against these concerns were these scientific considerations. Newton's theory was evidence-driven, proposing a force necessary to account for the elliptical paths of all orbiting bodies from the largest planets to the smallest moons. Newton's theory explained the paths of comets too, which no other model had tried to account for, without adding any more forces or laws. This simplicity was convincing. Given only two forces (inertia and gravity), Newton's exactly derived Kepler's formulas for planetary routes.

The majestic achievement of Newton's theory of gravity, and his model of the solar system, inspired additional principles for science.

8. A theory should postulate a force only when necessary to yield empirical formulas verifiable from observations.

9. A theory's postulated force should permit its empirical formulas to apply to any similar observable phenomena.

Principles 8 and 9 were satisfied by Newton's model. Gravity – while itself universal, unobservable, and a little 'unnatural' – yielded the already-known empirical formulas for moving bodies here on Earth as well as planets moving through space. Those formulas were able to apply to any other body in the solar system such as moons, asteroids, comets, and so on.

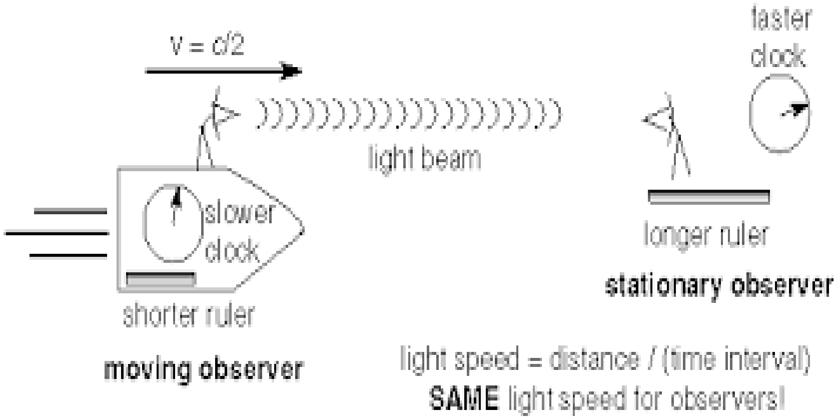
Other frontiers in physics were advancing during the 1600s and 1700s, such as the discovery of air pressure and explanations for thermodynamic phenomena. Scientists were postulating more invisible things and forces, such as the "empty vacuum" and "atoms". Confidence in their credible reality was earned by theories respecting principles 1-9.

The branches of physics were all incorporated and elaborated through that Newtonian worldview. Only two areas of natural phenomena were resisting that paradigm of theoretical explanation: the realm of the very small and the very fast. Investigating the parts of atoms was not leading to formulas fitting into Newtonian mechanics – hence the invention of quantum mechanics. Investigating motions of things moving at high speeds, such as the fast orbit of Mercury around the sun and even the speed of light itself, were not fitting into the Newtonian paradigm either. Albert Einstein (1879–1955) revolutionized physical theory for both realms. Here, we will survey only his new theory of relativity for high-speed physics.

Einstein was struck by the way that the constant speed of light permitted observers to make reliable and repeatable observations of the motions of objects moving around in nature. However, there is no immovable center to the universe anymore, and any observer is moving relative to some other observer. Usually, this makes no difference when both observers are near each other (in the same laboratory, for example). However, physics seeks generalizable and universal laws of nature, not just local conveniences. What would it be like for someone to make observations while moving at the speed of light, for example?

Whatever that observer could measure must be consistent with that constant speed of light and the fundamental laws of nature, neither of which could be changing just because the observer is moving. Natural light and natural laws are not just universal but also *absolute*: they are invariant under all conditions everywhere, forever. Precisely because

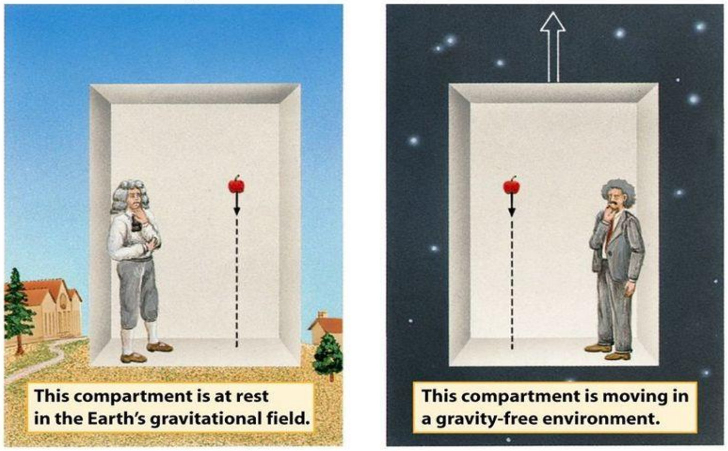
Einstein could assume two absolutes, how observers actually make their measurements in terms of clock time and spatial distance had to be relative.



Galileo and Newton had made a different rationalist assumption, that space and time themselves were absolute and invariant no matter where any observer was traveling. Einstein realized that there could be no way to empirically confirm that assumption, so in line with Principle 6, he abandoned it. In fact, all empirical confirmations had to assume the opposite: it was actually space and time that changed for observers depending on their motions. So long as those variations of distance and duration were taken into formulaic account, then all scientists anywhere in the universe could agree about observationally confirming the same basic natural laws.

Einstein theory of special relativity followed, but the force of gravity was not yet taken into account. He realized that “inertia” and “gravity” could not be two different forces, since they were empirically equivalent anywhere in the universe (to be avoided with Principle 1) and fewer forces are preferable (in line with Principle 8).

Equivalence principle



(a) **The apple hits the floor of the compartment because the Earth’s gravity accelerates the apple downward.**

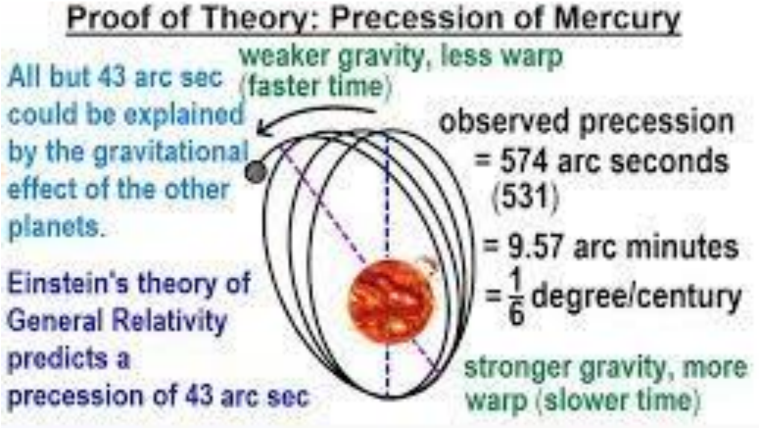
(b) **The apple hits the floor of the compartment because the compartment accelerates upward.**

The point of this thought experiment is not to see the phenomena where both Newton on the surface and Einstein in space could both be right. Both of them are “in a closed box” unable to tell whether they are on a planet’s surface or out in space. But the apple moves in the exact same way for both observers! This illustration makes the same point as that illustration of two observers, one on a stationary planet and one on a moving planet. Newton likes to think that he is on Earth observing gravity, and Einstein likes to think that he is out in space. Person N says, “I think that I have enough evidence to know that the apple is moving downwards at $D=kt^2$ due to the force of gravity.” Person E says, “I think that I have enough evidence to know that the apple is moving downwards at D=kt2 due to the force of inertia.” Person N then admits, “I don’t have enough evidence from my position to tell whether my box is near a planet or out in space.” Person H agrees, “Right, I am in that same situation here in my box too.” What they can agree on is the way that neither of them have a good reason to keep assuming that they are observing two difference forces at work on those apples. Where one single force can replace two while still yielding the same empirical formula, the scientific option is to proceed with a single force.

Combining special relativity with the inertia=gravity principle yields Einstein’s theory of general relativity: everywhere in the universe, mass is simply “what curves space-time around it” and mass is no longer “what generates an instantaneous force of gravity on other masses.” Einstein eliminated both inertia and gravity as separate forces, and the motion of bodies simply follows the curvature of spacetime in accord with the conservation of energy and momentum (two additional natural absolutes retained from Newton’s laws).

That theory of the curvature of space-time followed some principles but violated others. Space-time curvature is completely unobservable in itself, it introduces a highly counter-intuitive complexity into physics, and its formulaic laws are tremendously more complex than any Newtonian laws. Einstein realized that the credibility of his theory of general relativity had to depend on satisfying Principles 8 and 9.

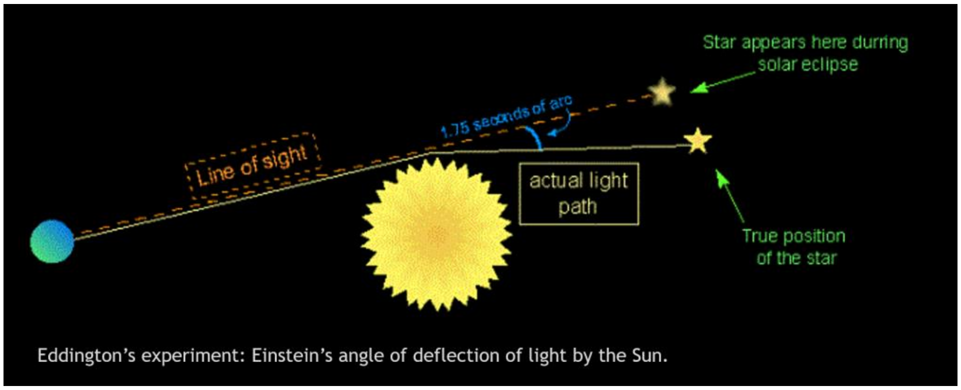
First, Einstein’s theory eliminated that occult and unnecessary “action as a distance” of gravity, in according with principle 8. The curvature of space-time shifts as massive bodies move, but at speeds less than the speed of light. Second, Einstein pointed out that his theory explains a long-standing problem with the observed orbit of Mercury. Mercury never was where Newton’s laws said it would be, so Einstein’s theory had the advantage over Newton’s according to Principle 9. Even after subtracting the tiny influences of other planets, astronomers observed the precession of the perihelion of Mercury: its orbit kept shifting a little bit on every journey around the Sun.



These two features of Einstein’s theory was somewhat persuasive, but it was easy to also point out that his theory really tells us nothing new about nature: occult forces had been ejected from natural science centuries ago, and the odd orbit of Mercury had been known for many decades already. That only means that Newton was wrong, not that Einstein had to be the only right answer. Could Einstein’s theory be used to predict any new formulas and new evidence where previous theories had failed?

Einstein needed another “natural experiment” like Mercury’s odd orbit, where nature simply provides unusual conditions waiting for scientific observation so that new evidence can be accumulated. Mercury’s orbit was detectably odd because it is a planet that moves fast close to the Sun, where the curvature of spacetime is greater. What else moves fast near the Sun? The fastest thing in motion is light itself, and light from distant stars is always going past the Sun on the way to Earth for our observation. How could observers on Earth measure the curved path of light coming from a star that goes near the Sun first before reaching the Earth to be seen? Stars are seen at night; the Sun is too bright to see stars positioned close to its bright disk. The only exception is what happens during a total eclipse of the Sun, where the stars comes out while Earth is in the shadow caused by the Moon.

Einstein proposed that a photograph of the eclipsed Sun with stars nearby should show how stars close to that disk should not be positioned where Newton's laws said they should be. According to Newton, no spacetime curvature, no shift in any star's position. According to Einstein, due to spacetime curvature, a star should be shifted in position when it appears close to the Sun.



Eddington's experiment: Einstein's angle of deflection of light by the Sun.

In 1919 astronomer Arthur Eddington took photographs that verified how stars near the Sun's disk appeared closer to the Sun than they should be if light always goes straight. Furthermore, the amount of deflection matched the precise predictions made by the formulas of Einstein's theory. Not only was it impossible for Newton to be right when the stars were in the 'wrong' place, only Einstein's theory made that novel and precise prediction about where those stars should appear in the 'right' place.

Eclipse Shows Space Is Limited; Greatest Discovery in History

LONDON, Nov. 9.—The results of the observations of the total eclipse of the sun last May, which have just been worked out, appear to establish the limitation of space. This, if true, is the most portentous scientific discovery in the history of the world.

Sir Joseph Thompson, one of the world's most famous scientists and educators, today pronounced the conclusions of the Royal Society and the Royal Astronomical Society "the greatest discovery in connection with gravitation since Sih Isaac Newton enunciated the principle, and one of the greatest achievements in the history of human thought."

Apparently the results of the calculations based on the observations prove that the rays of the stars are deflected in their passage past the sun in consequence of the sun's gravitation. This, authorities say, tends to prove the truth of the Einstein theory, which is somewhat obscure even to scientists, but includes the idea of limitation of the space of the universe.

Straight Lines Meet.

Dr. Andrew Crommelin, of the Royal Observatory at Greenwich, said today:

"The consequence of the discovery would be that space would no longer be looked upon as extending indefinitely in all directions and that if in-

SIR OLIVER LODGE CALLS DISCOVERY GREAT TRIUMPH

By SIR OLIVER LODGE.
(Famous British Scientist.)

The eclipse result is a great triumph for Einstein. The quantitative agreement is too close to allow much room for doubt and from every point of view the whole thing is of intense interest.

I was rash enough to express hope for a result equal to half Einstein's value, but the double-valued result can be assimilated and specified in various ways, one of which is the ponderability of light, coupled with the definite effect of motion on the Newtonian constant of gravitation effect, which behavior of Mercury and other planets it has already rendered probable; while another is the more vague suggestion that one of the two etherical constants

That scientific showdown between Newton and Einstein added one more principle about good science.

10. A theory should precisely formulate how to make new experimental observations that rival theories cannot predict as well.

Principles 1-10 set the gold standard for what counts as a genuine scientific theory worthy of higher credibility than rivals.

The paradigm shift from the Newtonian worldview to the Einsteinian worldview brought about major changes for philosophy of science. What counts as scientific knowledge, and scientific objectivity?

Newtonian Absolutes	Newtonian Objectivity	Einsteinian Objectivity
A law of physics is invariant and universally valid everywhere.	Objective scientific knowledge discovers physical laws.	A law of physics (including light) is invariant and universally valid everywhere.
Space and Time are universally invariant and mathematically Euclidean.	Nature is theoretically knowable as if from a standpoint outside of the universe (a God's eye point-of-view).	Space-time is flexible and non-Euclidean, from every standpoint inside the universe.
Light provides an instantaneous medium of information.	Observing a real thing is mostly passive, not affecting that thing or what it is doing.	Observation is dynamic and interactive, altering what is observed in the process.
A scientist knowing nature has the same knowledge as God the Creator.	Any careful observer would be able to make the same measurements from observing nature the same way under the same conditions.	Size, motion, and time depend on the observer's position, so special formulas adjust for that relativity to arrive at the same empirical results.

THREE. Scientific Observation

We can now ask this question: what is the relationship between the knowledge of ordinary everyday experience and scientific knowledge? Is scientific knowledge a quite different sort of knowledge from ordinary reliable knowledge? This introduction to scientific method takes the position that scientific knowledge is also a kind of reliable practical knowledge, but vastly improved: the reliability and practicality of scientific knowledge is far greater than that of ordinary everyday knowledge. Also, the scientific method depends on ordinary experience, but often must improve that experience for its own purposes to become scientific observation.

A person makes a scientific observation by *properly* using an approved instrument (one that has the confidence of the scientific community) for focus and/or measurement to carefully experience a thing or event that is *public* (could be observed by others too), and the person makes a record of the observation using a description that is *precise* (the thing or event is described in a more formal way than ordinary language, using special concepts and categories to increase discrimination and accuracy).

The best kinds of scientific observations are designed to be both precise and public: these observations are described using concepts and categories specially designed and used by a scientific community of people, all trained for making good observations. Example: Measuring the movement of a planet across the sky from night to night across two years' time. The astronomy community designed a system of concepts and categories (right ascension and declination) for describing the exact position of any object in the sky. Using this system, any trained and careful observer will be able to accurately record the position of a sky object.

When a community of scientists all use the same system for observation, and are well-trained to perform observations using this system, the community has established the possibility of *scientific objectivity*: scientific knowledge about natural objects and events within experience. This scientific objectivity, which provides reliable and practical information about objects and events, is the starting-point of scientific method and makes science possible. The scientific method uses experience to produce knowledge, but not just any sort of experience: only scientific observation counts. Of course, scientific observation is still fallible and revisable, since scientists make errors and misjudgments even when sincerely trying to do their best. The best kind of scientific observation is highly objective by being repeatable and durable: lots of scientists have been able to make the same observation (or almost the same, within a reasonable amount of error) over long periods of time.

Observation, inference, and knowledge are always fused together to some degree. This is true for ordinary experience, and it is true for scientific observation. Astronomer Tycho Brahe observed and recorded the positions of the planet Mars during the late 1500s using the best instruments before the invention of the telescope, his over-sized triangular sextant and his Great Equatorial Armillary.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Brahe’s observations enjoyed a high level of scientific objectivity because of their precision and replicability. Only an instrument already approved by a scientific community, which agrees on how that instrument is correctly used, can be used to make scientific observations. After the telescope was added to an astronomer’s instruments, the same expectations applied.

A scientist’s own senses can qualify as scientific instruments. For example, a scientist’s own eyes can be adequate instruments for making scientific observations. Unless Brahe’s eyes were adequate instruments for using his instruments properly, his observations would not have been accepted as scientific by the community of scientists. The trained eyes of a botanist are used to make scientific observations about the structures of flowers. The trained ears of a ornithologist are used to make scientific observations of bird calls, as another example.

Scientific observations are observations about natural objects that really exist. How do scientists know that their observations are truly of things that really exist? Rational Empiricism would say that a valid observation is an experience aided by inference and knowledge. A scientist must have an experience of an object that includes its “identifying qualities”. The scientist already knows what qualities a certain thing must have, which identify it. In the observation of a thing, the scientist looks for its identifying qualities, and when those identifying qualities are observed, the scientist infers that it is indeed that particular thing which is observed. This inference could be mistaken (maybe other things also have that quality), so a scientific observation remains fallible, like any knowledge. Scientists reduce the possibility of mistaken identifications by having rigorous tests for several qualities that uniquely identify particular things.

Science makes a useful distinction between a thing’s qualities that depend on their being observed (“perspectival” qualities), and a thing’s properties that exist regardless of whether they are being observed (“independent” qualities). Perspectival qualities only exist when organisms are perceiving them: colors, sounds, tastes, textures, etc. Independent qualities exist even when they are not being perceived, although we naturally detect them using perception: shapes, mass, size, etc.

Also, science makes a useful distinction between those perspectival qualities which can be observed by the unaided senses (“directly observed” qualities), and those which can only be observed through mechanical instruments (“instrumentally observed” qualities).

Finally, some independent qualities are detected only by inference from other instrumentally observed qualities.

Five kinds of qualities are therefore discriminated by science, according to the method of their identification:

(1) the directly observed perspectival quality (DOPQ). Examples of using a DOPQ: a chemist identifying a mineral by its color, a ornithologist identifying a bird by its song, and a geologist identifying a rock by its texture.

(2) the instrumentally observed perspectival quality (IOPQ). Examples of using a IOPQ: an astronomer identifying a red giant star by its flickering color through a telescope, and submarine sonar operator identifying a surface vessel by its amplified propeller noise.

(3) the directly observed independent quality (DOIQ). Examples of using a DOIQ: a paleontologist identifying a fossil bone by its shape, and an oceanographer identifying a tide by the water height.

(4) the instrumentally observed independent quality (IOIQ). Examples of using a IOIQ: an official of the bureau of weights and measures using a standard gallon container to identify a full gallon of gasoline from a station pump, and an engineer using calipers to measure the size of a machine part.

(5) the instrumentally detected independent quality (IDIQ). Examples of using a IDIQ: a physicist identifying a metal by calculating its density from its measured volume and weight, and a geologist identifying an iron ore by measuring its magnetic attraction.

In actual scientific practice, identifications often use a combination of two or more of these means. There is one kind of natural entity which must receive additional scrutiny: that entity which, due to the scientific conception of that entity, can *only* be identified by one or more IDIQs, and thus cannot be identified by any direct or instrumental observation. Examples of such non-observable entities are black holes, the force of gravity, and the curvature of space-time. Evidence for such entities will only consist of the detection of their effects on scientific instruments.

Summary

1. Observation, inference, and knowledge are almost always fused together to some degree.

2. Scientific observation requires a combination of experience and inference, and a person can make a scientific observation only after training and approval by a scientific community.

3. There are five important kinds of qualities that can be scientifically observed.

FOUR. Logical Inference and the Scientific Method

> Dr. Watson joined Sherlock Holmes on an overnight campout in a empty field.
> Waking up Watson in the middle of the night, Holmes exclaimed, “See the sky! What do you think?”
> Watson quickly said, “I deduce a cloudless night, to see so many stars.”
> Holmes sighed. “Too obvious, Watson. What else do you think?”
> Watson tried again, “I can infer that there must be endless more stars, many with their own planets, and maybe other kinds of life too.”
> “No, Watson. Someone has stolen our tent!”

There are three types of logical inference: deduction, induction, and abduction. Dr. Watson first made a deduction from the evident to the obvious, with just a little thought. Then Dr. Watson offered an induction from a pattern to a larger trend. Interesting, but impractical. They are both looking up at the same evidence, but Holmes has his mind trained on abduction: the evidence wouldn’t even exist unless an unseen agent had been at work.

Deduction: If the two premises are both true, then the conclusion must necessarily be true. Conversely, if the conclusion is false, then one or both of the premises must also be false. Deduction is the only method of inference that is capable of proving that a proposition is true. You can consult this article on “Deductive Reasoning” and another on “Logical Consequence”.

All the beans from this bag are white. These beans are from this bag. Therefore, These beans are white.	A fault line causes earthquakes. There is a fault line near Boise. Therefore, An earthquake occurs near Boise.	A force exerted by the sun will keep its planets in orbit. The sun exerts a force of gravity on its orbiting planets. Therefore, Planets are in orbit around the sun.

Induction: The two premises describe the qualities of a sample from a larger group, which suggests a pattern. The conclusion states that the pattern will continue. If the two premises are both true, then the conclusion has some (perhaps small) probability of being true (somewhere between 0% and 100% probability). The degree of probability depends on the size of the sample, the size of the larger group, and the method used to select the sample. You can consult this article on “Statistics” and another on “Induction”. Induction can never prove that a proposition is true. That is because it is always conceivable that a pattern will change or stop at some point in the future: this is the “Problem of Induction”. Although induction cannot lead to truth, it remains very useful so long as it is done carefully to avoid “Faulty Generalization”.

These beans are from this bag. These beans are white. Therefore, All the beans from this bag are white.	There is a fault line near Boise. An earthquake occurs near Boise. Therefore, A fault line causes earthquakes.	The sun exerts a force of gravity on its orbiting planets. Planets are in orbit around the sun. Therefore, A force exerted by the sun will keep its planets in orbit.

Abduction: The two premises state what is known now about a situation. The conclusion is a hypothesis about how that observed situation came to be that way -- a hypothesis that tries to explain the current situation in terms of some other hidden situation that hasn’t been observed. An abductive inference has this form:

If P, then Q.
Q.
Therefore, P.

Because abductive inference has this logical form, this inference commits the logical fallacy of “Affirming the Consequent” and it is always invalid. No abductive inference ever gives sufficient reason to believe that its conclusion is true. Because there are always potentially conceivable alternatives for why Q is true (for example, maybe it is also true that If R, then Q -- so maybe R is true instead), there is never good reason to believe that P is true just because Q is true. You can read this article on “Abductive Reasoning”.

All the beans from this bag are white. These beans are white. Therefore, These beans are from this bag.	A fault line causes earthquakes. An earthquake occurs near Boise. Therefore, There is a fault line near Boise.	A force exerted by the sun will keep its planets in orbit. Planets are in orbit around the sun. Therefore, The sun exerts a force of gravity on its orbiting planets.

Understanding abduction is essential to the scientific method. Abduction is science’s only way of suggesting novel explanations for the observable events and things in nature. Deductions do not give explanations: their conclusions only restate, in a re-arranged way, what is already stated by the premises. Inductions do not give explanations: their conclusions only make predictions about the future.

Abductions do give explanations: their conclusions are statements about things or events that have not yet been observed, or will never be observed, which are responsible for the facts stated in the premises. In the first example about the beans, the two premises state what is known now: all the beans from this bag are white, and these beans are white. What might explain where these white beans came from? Well, they might have come from that bag, where all the beans are white too. If these beans really did come from that bag (an event that was not observed by the person making the abductive inference), that would explain where the beans came from. In the second example about the sun and gravity, the two premises state what is known now: a force exerted by the sun will keep its planets in orbit, and planets are in orbit around the sun. What might explain why these planets go in orbit around the sun? Well, the first premise states that if there was a force exerted by the sun then the sun will keep its planets in orbit. What force could be exerted by the sun? Well, a force of gravity, if it really existed (but it has not been observed), would explain how the sun could exert a force on its planets. If there really was a force of gravity exerted by the sun, that would explain how the sun keeps its planet in orbit.

A scientific explanation in general has the following abductive form: These facts are known to be the case now; if some presently hidden thing really exists or did exist, then the known facts would have to be true; therefore, some presently hidden thing really exists or did exist.

There are four basic types of hidden things or events (hereafter collectively called “entities”) that play roles in explanations by science. Let us call them Type I entities, Type II entities, Type III entities, and Type IV entities.

Type I. An entity which could be observed directly, and identified by its DOPQ or DOIQ. Example: Did these white beans come from that bag? -- Well, the explanation is “hidden” in the past. Perhaps someone observed where those beans came from. When a Type I entity is hypothesized by an abduction, that hypothesis can still be proven to be true by actually directly observing it.

Type II. An entity which could be observed instrumentally, and identified by its IOPQ or IOIQ. Example: Did a fault line cause that earthquake? -- Well, the explanation is “hidden” under the ground. Perhaps someone can instrumentally observe the fault line using seismology equipment. When a Type II entity is hypothesized by an abduction, that hypothesis can still be proven to be true by actually instrumentally observing it.

Type III. An entity which could be observed by some new instrument not yet invented, and identified by its IOIQ. Example: Did the very early universe have a certain structure? -- Well, we now have no instrument that can make any good observations of the very early universe. Perhaps someone will invent a far more powerful telescope. After the invention of the needed instrument, the Type III entity changes to a Type II entity. When a Type III entity is hypothesized by an abduction, that hypothesis can never be proven to be true, until the needed new instrument is invented.

Type IV. An entity which could not be observed by any instrument because it can *only* be identified by one or more IDIQs, and thus cannot be identified by any direct or instrumental observation. Examples of such non-observable entities are black holes, the force of gravity, and the curvature of space-time. Observed evidence for such entities must always consist of the detection of their effects on scientific instruments. Sometimes science advances through both a theoretical and instrumental advancement, so a Type IV entity can be converted into a Type III or Type II entity. For example, until the 20th century, science had to classify atoms as Type IV entities, but now large atoms can be instrumentally observed. When a Type IV entity is hypothesized by an abduction, that hypothesis can never be proven to be true, and it is never reasonable to believe with 100% certainty that this entity really exists.

The Scientific Method has three stages and six steps. In the first stage, the "observation stage", there are two steps which describe how science begins with scientific observation and then uses induction to formulate a law of nature. In the second stage, the "hypothesis stage", there are two steps which describe how science uses abduction to postulate one or more hypothetical entities (from among the four Types I-IV) to explain what has been observed in stage one. In the third stage, the "testing stage", there are two steps which describe how science uses deduction to test the hypothesis from stage two against more scientific observations and against rival hypotheses.

Stage One: Observation

Step One: *Phenomena*. Using established scientific knowledge, new scientific observations of a pattern of events are recorded.

Step Two: *Natural Law*. Using induction, this pattern of events is believed to continue into the future, and this pattern can usually be expressed as a law of nature (sometimes as an equation, for example).

Stage Two: Hypothesis

Step Three: *Explanation*. Using abduction, a hidden entity of Type I, II, III, or IV is postulated as the explanation for the law of nature found in step two.

Step Four: *Prediction*. For a Type I or Type II entity: its predicted existence can be tested by direct or instrumental observation, so long as its characteristic IOPQ or IOIQ identifiers have been agreed upon.

For a Type III or Type IV entity: using deduction the actual existence of this hidden entity implies that it must be responsible for other unexpected patterns of events also, besides those observed in step two and other patterns already recognized by science. These other unexpected patterns are the hypothesis's predictions. To be optimally useful, a prediction should be very unexpected (ideally, forbidden by a rival hypothesis); very specific (vague predictions are suspicious because they are too easily confirmed); and not very difficult to test by experiment in the next stage.

Stage Three: Testing

Step Five: *Experiment*.

For a Type I or Type II entity: its predicted existence can be tested by scientific observation, so the needed observations are attempted.

For a Type III or Type IV entity: using established scientific knowledge and deduction, experiments are designed and conducted to find out whether any of the predicted patterns of events from step four can be scientifically observed.

Step Six: *Verification, Confirmation, or Falsification*.

For a Type I or Type II entity: if its existence is looked for and successfully verified by scientific observation, then the hypothesis is verified as true (although there may be additional entities that are also contributing causes to the patterns of events). If its existence cannot be established, then science can return to step three to try again.

For a Type III or Type IV entity: if a predicted pattern of events is scientifically observed in an experiment, then this positive result is a "confirmation" for the hypothesis. A confirmation makes it reasonable for belief in the postulated hidden entity to marginally increase. If a series of predicted patterns are all confirmed, and none are disconfirmed, belief in the postulated hidden entity can become substantial, but should never reach 100% certainty. If a predicted pattern of events is looked for and found to not exist, then this negative result is a "disconfirmation" for the hypothesis. Unless a disconfirmation can be explained by human error (in the prediction, or in the experiment design, or in the observation), this disconfirmation makes it reasonable for belief in the postulated hidden entity to marginally decrease.

Under certain circumstances (where a prediction is carefully deduced, the experiment is well designed, and no scientific knowledge involved in step five can be reasonably faulted instead of the hypothesis) a disconfirmation makes it reasonable for scientists to conclude that the hypothesis is proven false and the entity does not exist. The inference to such a negative conclusion has a valid deductive form, superficially similar to that of abduction, which is called "modus tollens":

If P, then Q.
But Q is false.
Therefore, P is false.

Let P be the hypothesis "this hidden entity exists" and Q be a prediction deduced from this entity's existence. If this prediction is discovered to be false by an experiment, then Q is false and therefore P must also be false: that hidden entity does not exist. This "falsification" will force science to return to step three to either modify the hypothesis or to entirely abandon the hypothesis for some other alternative hypothesis. You can read more about scientific experiment in "Experiment in Physics".

Summary

1. Science uses abduction to postulate hidden entities responsible for observable natural regularities.

2. Only hypotheses about Type I or Type II entities can be verified. Hypotheses about Type III or Type IV entities can only be highly confirmed, at best.

3. Under certain circumstances, it is reasonable to judge a hypothesis false after an experimental test.

FIVE. Scientific Hypotheses, Theories, Paradigms, and Worldviews

We have already defined the genuine scientific observation. A genuine scientific hypothesis is a hypothesis that is designed to explain a natural pattern already scientifically observed, and is testable by the scientific method, outlined above. The statement of the natural pattern discovered in stage one is not a hypothesis, although clumsy use of words sometimes results in labeling a scientific law as a hypothesis. The discovery of a natural pattern is not an explanation -- it is what needs an explanation. It is possible to "explain" a single event by holding a natural pattern responsible (the leaf fell off the tree because trees lose their leaves in the fall). However, a pattern of events cannot really explain why one event in that pattern did happen. While much of science is focused on discovering and describing natural patterns, a field of study does not become a scientific field until it proposes and tests hypothetical explanations for natural patterns.

A hypothesis is scientific when it is treated by investigators as scientific: when it is developed and tested using the scientific method. For example, the Greek philosopher Democritus promoted the idea that all natural things were made of tiny invisible atoms that cannot themselves be divided. But the arguments which Democritus and fellow atomists gave for this idea only had deductive forms and appealed to allegedly "necessarily true" premises, and they did not experimentally test their idea. The atomic theory did not become scientific until the late 1800s.

There are many ways that people can prevent their hypothesis from being genuinely scientific. For example:

(1) Offering an explanation for phenomena that have not been scientifically observed;

(2) Postulating an entity that has no clearly defined identifying qualities;

(3) Postulating an entity that would not be responsible for any unexpected natural patterns;

(4) Postulating an entity so contradictory against established scientific knowledge that experimental testing is impossible;

(5) Refusing to deduce predictions from the supposed existence of the postulated entity;

(6) Ensuring that any predictions are either vague, difficult to experimentally test, or unsurprising;

(7) Ignoring any prediction that turns out to be false;

(8) Modifying the hypothesis just enough to be able to afterwards "predict" a bad experimental result.

A "theory" consists of several hypotheses that are interrelated and support each other in order to provide a fuller explanation of a range of phenomena in some field (chemistry or astronomy or psychology or archaeology, etc.). For example, the theory of natural selection in biology consists of a large number of hypotheses about organisms and how they interact with their environment. **A theory is scientific so long as all of its hypotheses are scientific.** It should be noted that items of knowledge from logic or mathematics are used in a theory, but they are not hypotheses, since they are not postulates about hidden entities. However, logical or mathematical principles may be modified or replaced within a theory, if the theory's development requires these changes. For example, a theory may be able to explain some new natural patterns only if it uses a different mathematical or logical system. In this sense, mathematical and logical principles could be considered as "testable" against scientific evidence, because a theory's ability to explain the evidence can occasionally require modifying these principles. But there is no way to directly test any logical or mathematical principle against evidence -- by themselves, apart from all hypotheses, these principles make no claims about nature and they are compatible with any natural events.

We can also ask whether a scientific theory can ever lose its status as scientific. Some philosophers, including Karl Popper, have argued that a scientific theory must continually be used to generate new predictions and be tested. But this is not a reasonable standard, since most of the established body of scientific knowledge no longer receives serious experimental testing. One serious event can cause a once scientific theory to lose its status: A pattern of nature is discovered which the theory ought to be able to explain, but the scientific community ignores this need and does no inquiry into whether the theory really can explain it. A theory which ignores new patterns of nature will likely be replaced eventually, because a rival scientific theory will emerge which does succeed in explaining the new patterns and gain credibility quickly with these successes.

A "paradigm" consists of several theories that are interrelated and support each other in order to provide the fullest explanation of the widest range of phenomena in some field. For example, biology's current paradigm is evolution, which incorporates theories about natural selection, reproduction by genetic inheritance, DNA mutation by random errors, and other theories about living organisms. **A paradigm is scientific so long as all of its theories are scientific.** Each scientific field is typically dominated by one paradigm for a time, when a large majority of scientists in that field accept only this paradigm. Occasionally, a field may have multiple scientific paradigms competing for dominant status, and at other times a field might have no scientific paradigm that is accepted by even a significant minority of scientists.

The only requirement that a theory must meet to be scientific is the requirement that the theory's hypotheses are all designed to explain scientifically observed natural patterns and they are testable by the scientific method. However, there are some additional criteria which enhance the scientific value of a theory or paradigm. These additional criteria are often labeled as the "pragmatic criteria." The most important criteria are:

1. Logical Coherence. There should be a very high degree of logical coherence among a theory's established hypotheses, and among a paradigm's established theories. If there are logical contradictions between established principles of scientific knowledge, then those contradictions should be eliminated. All other things being equal, a scientific theory with no internal logical contradictions is a better scientific theory. Some scientific revolutions occur because scientists notice such contradictions and resolve them by dramatically changing previously established principles of knowledge. For example, Einstein developed portions of his theory of relativity by noticing that the constant speed of light (required by electrodynamics) is incompatible with the principle of additive velocities (required by classical mechanics): light must have the same speed for all observers no matter how an observer is moving, so much of classical mechanics must be false. You can visit a website about science and "Thought Experiments".

2. Predictive Power. There should be a very large amount of predictions made by a theory or paradigm. There are two benefits to this "predictive power": first, more predictive power means a better chance of becoming highly confirmed (or proven false); and second, a theory that successfully explains a much wider range of natural phenomena will be much more reasonably persuasive than a theory that can explain only a small range of phenomena. You can visit a website about science and "Predictive Power".

3. Physical Unification. There should be very wide range of phenomena unified by a theory or paradigm. For a while, a science may treat one natural pattern very differently than another pattern, but then a new theory arrives which shows how these two patterns are really the same pattern. For example, Newton's theories of motion unified the motions of heavenly objects with the motions of earthly objects, treating their patterns as all obeying the same basic laws of motion. Another example is how James Clerk Maxwell's theory of electrodynamics showed how visible light is the same sort of radiation of photons as all other forms of radiation. Most of modern physics heavily depends on this persuasive power of physical unification. You can visit a website about science and "Unification".

4. Ontological Simplicity. There should be a very small number of entities postulated by a theory or paradigm that are required to explain a wide range of phenomena. If two theories can both explain the same phenomena, yet one theory postulates far fewer entities, that theory appears to be more believable than the other. The value of simplicity is probably rooted in ordinary practical common sense: the simpler explanation is more believable, will probably suffer from fewer internal contradictions, and will be easier to prove false. The more complex theory appears too ad-hoc and too well-designed -- arousing the suspicion that the theory was really designed to prevent its falsification. Also, rationality itself seeks unity behind diversity (e.g. "everything is made of atoms" or "there is ultimately only one natural force causing everything"). You can visit a website about science and "Simplicity".

Summary

1. There are many ways for a “pseudoscience” to fail to be a science by ignoring various steps of the scientific method.

2. Hypotheses are grouped together into theories, and theories are grouped together into paradigms.

3. There are some important pragmatic criteria for enhancing the scientific value of theories and paradigms.

SIX. Scientific Realism and Anti-realism, Part One

Unlike positivism, which holds that science should only attempt to know nature's patterns, scientific realism holds that science should also try to know, and partially succeeds in knowing, about hidden entities behind these patterns. Scientific realism is the view that the entities postulated by highly confirmed scientific hypotheses really do exist, and have the properties more or less as described by these hypotheses. You can read more about "Scientific Realism".

Scientific realism is always tempered by fallibilism, the reminder that scientific knowledge is imperfect and could be modified by future science. But this proclamation that science is fallible and revisable can inspire scientific anti-realism.

Objection One by the Scientific Anti-realist

The scientific anti-realist can argue as follows: If science is always fallible, then there never is a reason to believe that it discovers truths. Unless it discovers truths, science cannot reasonably claim that the things that its theories try to describe actually do exist. So we should not think that the things that science talks about really do exist. This argument is called the "Pessimistic Induction": all past scientific theories have been shown to be false, so all present and future theories will likely be false as well.

What is at stake here? If this argument cannot be refuted, its victory leads to complete skepticism about science and refutes philosophical naturalism.

Reply by scientific realism: The scientific realist should reply that perfect knowledge of truths about things is hardly required for reasonably believing that they exist. After all, we have practical reliable knowledge about matters like refining iron from ore, and it is quite reasonable to believe that iron exists. Science is just the extension of practical reliable knowledge.

This reply to the first objection by scientific anti-realism is the best place to begin explaining why scientific realism is reasonable. There are several good reasons for accepting scientific realism. Joined together, they provide the justification for scientific realism and hence for philosophical naturalism as well.

1. It is common sense to believe in hidden causes for observable patterns. Ordinary common sense consists of reliable practical knowledge about not just the easily observable patterns of nature but also about many of the things responsible for those patterns. We are very good at investigating the hidden causes of events in order to reveal them: what caused the window to break, what caused the loud noise outside, what caused the dog to bark, etc. Ordinary intelligence assumes hidden causes for observable events and applies methods of investigation to reveal these causes by bringing them into our experience. We are naturally curious about what causes interesting events, and we are especially interested about the causes of patterns of events. Human intelligence is very good at detecting and focusing on natural patterns, and we can explain a single event by noticing that this event should be expected since it is part of a pattern. But intelligence usually goes farther, not stopping at patterns, and seeks the hidden causes of patterns. What animals keep causing those patterns of tracks? Which tree produces those consistently tasty nuts? Which clouds always cause the worst rainstorms? The search for hidden causes of patterns requires the application of abductive inference.

2. Intelligence frequently discovers the hidden causes of natural patterns. Intelligence discovers hidden causes so frequently that the human brain is now highly evolved with fairly efficient curiosity and inquiry techniques that children instinctively use for survival and play, and adults refine these techniques into science. The abductive belief in hidden causes is so useful for practical reliable knowledge that intelligence cannot function without such instinctive practical belief. This practical belief in hidden causes explains why science also requires the application of abductive inference and why we provisionally accept the conclusions of confirmed abductive inferences. Making a hypothesis about a hidden cause is an intelligent effort to understand nature, and it is intelligent to provisionally accept the existence of a hidden cause that is postulated by a confirmed hypothesis. Science is merely the extension of investigative methods of ordinary intelligence, and scientific realism is therefore demanded by intelligence.

The limitation of this argument for scientific realism is that ordinary intelligence deals with the practical, everyday world of directly observable objects. We know what it is like to verify beliefs in hidden causes, since we frequently reveal these causes in direct experience after investigation. Some sciences only deal with directly observable objects --

their hypotheses and theories only postulate Type I entities -- but most sciences also postulate causes that are not directly observable: the Type II, III, and IV entities. Should we also be realists about instrumentally observable entities, and about non-observable entities too? Some scientific anti-realists say no.

Objection Two by the Scientific Anti-realist

The scientific anti-realist can argue as follows: Sciences about observable natural patterns and responsible entities that could be directly observed are legitimate sciences, but scientific realism should stop there. We should only be realists about what can be positively verified in our direct experience. The sciences should not try to describe Type II, III, or IV entities, and we should not think that such things really do exist.

What is at stake here? If this argument cannot be refuted, its victory leads to the type of extreme empiricism called scientific positivism or constructive empiricism: only natural observable patterns and the directly observable entities causing those patterns really exist. This scientific positivism is a kind of philosophical naturalism, but a very limited kind.

Reply: The scientific realist should reply that even if empiricism's demand for observable proof is taken so seriously, it is possible to reasonably believe in at least some Type II and Type III entities. First, instrumentally observable entities can be trusted if the instruments can be trusted, and we can reasonably trust many scientific instruments by methods of direct observation alone. Second, if it is reasonable to believe in many Type II entities, it may be reasonable to believe in Type III entities, since scientific progress frequently converts unobservable entities into instrumentally observable entities, increasing our confidence in postulating Type III entities.

This reply to objection two has two stages: First, defending instrumentally observable entities; and second, defending unobservable entities that potentially could become instrumentally observable entities.

First, why should we trust telescopes and microscopes? We come to trust them in the same way we trust our senses: by comparing the information we get from them as we use them under different conditions. We can learn that we have good eyesight by checking whether we can perceive things from farther away as well as we can when we perceive them nearer to us. We can learn whether a pair of glasses improves our eyesight, and we trust a reliable pair of glasses to show us real objects in front of us (should we think that putting on glasses suddenly presents us with a completely false version of reality?) Similarly, we can learn that a telescope accurately depicts a distant tree by comparing that observation with own perception of that tree using our eyes up close. Might the telescope change the way it works when we turn from looking at distant trees to looking at the distant moon to see craters? Skeptics about Galileo's observations of moon craters, sunspots, and moons of Jupiter suggested that a telescope might not work properly when aimed upwards. But direct inspection of the telescope and its parts shows that a well-constructed telescope does not change its functioning if it is pointed upwards into the sky. Some anti-realists have argued that trusting an instrument necessarily requires acceptance of a complete theory about why the instrument works, but such a theory would require postulating non-observables in the first place, begging the question in favor of scientific realism. The reply by the scientific realist is that it is valuable, but not necessary, to have a theory about an instrument's functioning. Summing up, we should be scientific realists about instrumentally observable entities because:

3. An instrument such as a telescope or a microscope can be tested and trusted by ordinary methods, already described above, that only involve direct observation. Of course, this reply only is relevant to instruments like telescopes and microscopes that detect very distant or very small objects, however (along with other instruments that amplify the senses, such as microphones for making sounds louder). This reply does not apply to other kinds of scientific instruments that detect things like electrical current or air pressure or chemical acidity. More arguments, explained below, will describe how scientific realism deals with these kinds of instruments.

Second, why should we postulate unobservable entities even though there currently is no way to even instrumentally observe them? Our experience with inventing and using sense-amplifying instruments demonstrates that nature consists of things much smaller and much larger and much farther away than our human senses can detect. And since the power of our instruments has grown over time, revealing more and more of nature to us, it is reasonable to believe that much of nature has not yet been observed, directly or instrumentally. Why shouldn't science be permitted to make hypotheses about possible entities in that yet-to-be-observed part of nature? Furthermore, many scientific hypotheses about Type III entities, confirmed by experiment, have later been observed by scientific instruments invented after the original hypothesis. Examples: Atoms were proposed before they could be observed by the scanning tunneling microscope; genes were proposed as the transmitters of biological information before DNA was observed by microscope; planets around other stars were proposed before they were observed by more powerful telescopes. Since many Type III entities proposed by confirmed hypotheses have later been verified by improved instruments, it is reasonable for science to propose hypotheses about Type III entities and believe that these entities exist when these hypotheses are highly confirmed by experiment. Recall the “Pessimistic Induction” from Objection One by the Scientific Anti-realist? The scientific realist can in turn propose the “Optimistic Induction”:

4. Since many successful hypotheses about Type III entities have later been verified, it is reasonable to conclude that many more hypotheses proposed in the future about Type III entities will also someday be verified by more powerful instruments. Of course, we cannot yet know which current hypotheses about Type III entities will be verified in the future, but at least it is reasonable for science to try to postulate them now. As for Type IV entities, this Optimistic Induction argument does not help. There are no cases where confirmed Type IV entities have later been verified by improved instruments. This lack of cases is not surprising. By definition, we do not have any conception of what it could possibly be like to instrumentally observe Type IV entities (what would seeing gravity, or a black hole, be like?). So we would not try to invent instruments to observe them -- how could we confirm that we succeeded in observing them without any conception of what to look for?

The scientific realist does want to defend the reasonableness of postulating Type IV entities, but that requires a separate defense against scientific anti-realism, to be explored in the succeeding modules.

Summary

1. The abductive belief in hidden causes is necessary for practical reliable knowledge.

2. Science, as a kind of reliable practical knowledge, requires abductive inference and our provisional acceptance of the conclusions of confirmed abductive inferences.

3. We should provisionally accept the existence of confirmed hypotheses about Type I, Type II, and Type III entities.

SEVEN. Scientific Realism and Anti-realism, Part Two

The scientific anti-realist has more arguments against Type III and IV entities.

Objection Three by the Scientific Anti-realist

The scientific anti-realist can argue as follows: Sciences may postulate and confirm hypotheses about Type I and Type II entities, but scientific realism should stop there. Consider how abduction works: we can never prove a hypothesis true using abduction, since there are potentially many more hypotheses, not yet thought by anyone, which could explain the same predicted patterns equally well. In fact, for any highly confirmed hypothesis H about a Type III or Type IV entity, there are so many potential hypotheses with the same empirical adequacy (able to explain the same natural patterns) that the marginal increase in belief gained by H should be zero or very close to zero -- there is no sufficient reason to believe in that entity's existence. Even if the sciences should be permitted to postulate such entities (maybe to increase logical coherence or predictive power), we should not think that the Type III or Type IV entities postulated by science really do exist.

What is at stake here? If this argument cannot be refuted, its victory leads to the type of rational empiricism called instrumentalism: only natural observable patterns and the directly or indirectly observable entities causing those patterns really exist. Instrumentalism is a kind of philosophical naturalism, but a very limited kind.

Reply: The scientific realist should reply that even though there are many potential hypotheses with the same empirical adequacy as any well-confirmed hypothesis, the real scientific value of a hypothesis, and hence its long-term credibility, lies in its pragmatic value: how well it meets the additional criteria of logical coherence, predictive power, physical unification, and ontological simplicity.

Scientific anti-realists are impressed by the fact that many (perhaps an infinite number) potential hypotheses can explain any particular set of natural patterns. They try to conclude that the probability of any one of the hypotheses being accurate must be very close to zero.

Pierre Duhem (1861-1916), the French philosopher and scientist, was this type of scientific anti-realist. He argued that some sciences, such as chemistry and physics, can never reasonably claim to have proven that their hypotheses are true. Only direct or instrumental observation can prove the existence of hypothesized entities, under the best of experimental conditions, but chemistry and physics try to describe entities that cannot be observed (what we have here been calling Type III or Type IV entities). Duhem realized that hypotheses about Type III and IV entities can never be proven true, since there are always other possible hypotheses that could explain the same observed natural patterns. We have already explained why the nature of abductive inference prevents proving that its conclusions are true. Since there are always many potential hypothetical explanations for the same observable phenomena of nature, scientific hypotheses are "underdetermined" by the currently available evidence. Duhem's underdetermination argument is simply the philosophical point that no hypothesis about a Type III or Type IV entity (the "unobservables") can be proven true. Duhem went farther than this point about abductive logic, however. Duhem claimed that since the available evidence cannot determine which scientific hypothesis about unobservables is correct, no scientific hypothesis about unobservables should ever be believed. In other words, even a highly confirmed scientific hypothesis cannot be reasonably believed at all. Science cannot ever get us even close to the truth. In recent philosophy of science, van Fraassen has revived and extended these arguments against scientific realism in order to support his own "constructive empiricism". Some of his writings, and writings about his philosophy, are online here: http://www.princeton.edu/~fraassen/

The scientific realist replies to this argument by pointing out that empirical adequacy by itself does not produce much real credibility. For any given hypothesis, it is suspiciously too easy to artificially generate a rival hypothesis that can explain exactly what the given hypothesis can already explain. But can the artificial hypothesis cohere with the larger theory of which it must be a part? Can it make any more unexpected predictions? Does it offer any physical unifications, or only disunifications? Does it only increase ontological simplicity? There are far fewer rival hypotheses that can be artificially generated which meet these severe criteria -- and scientists continually try to create them and test them too.

5. Hypotheses about unobservables that continually increase their empirical adequacy and cohere well with larger theories and paradigms, while revealing a simpler reality behind the phenomena, deserve greater credibility. If the scientific anti-realist tries to continue to argue that even the possibility of a few alternative hypotheses which meet this much higher standard should restrain how much credibility any of them receive, this is not a new argument, but only repeats the unoriginal observation that abduction cannot ever prove any hypothesis. But we still can reasonably have some degree of belief in the most successful hypothesis available now.

What is our alternative to provisionally accepting the best hypotheses we have now? Consider what the scientific anti-realist is claiming -- if we really shouldn't think that any hypothesis about unobservables is believable at all, then we are denying that there is any underlying cause for natural patterns. Without underlying causes, it is a sheer miracle of chance that natural patterns persist and a complete mystery of luck that many hypotheses successfully anticipate more natural patterns. The scientific realist can offer a further argument at this stage:

6. If the entities described by highly confirmed hypotheses really exist, that would explain why science's best hypotheses are so empirically adequate. And science's best hypotheses are very empirically adequate. Therefore, the entities described by highly confirmed hypotheses really do exist. This argument for scientific realism has the form of an abductive inference: If P, then Q -- and Q is true -- so P is also true. Of course, this "meta-abductive" argument, also called the "no miracles argument," cannot prove its conclusion. There may be other possible explanations for why science can produce hypotheses that have high empirical adequacy. The scientific anti-realist does have an alternative explanation for the existence of highly confirmed hypotheses.

Objection Four by the Scientific Anti-realist

The scientific anti-realist can argue as follows: It is reasonable to believe that there are hidden portions of nature where unobservable causes for natural patterns do exist. But we should not believe that any highly confirmed hypothesis approximately describes these unobservable causes. For Type III and Type IV entities, their only properties relevant to the empirical success of hypotheses about them are those properties which require these entities to obey certain natural laws. After all, it is only the natural laws that are used for formulating predictions For example, it doesn't matter what an electron is really like so long as its behavior always obeys certain laws. In fact, the entity that really does exist, if it isn't an electron, only has to obey those same laws, since it really has been the laws themselves that enjoy high confirmation. But it possible to imagine many alternative sorts of entities quite different from the electron that still obey the same laws that electrons are supposed to. Therefore, while unobservables exist, and science is reasonable to postulate unobservable entities, we should not think that the Type III or Type IV entities postulated by highly confirmed hypotheses really do exist.

What is at stake here? If this argument cannot be refuted, its victory leads to the type of rational empiricism called pragmatism: only natural observable patterns, the directly or indirectly observable entities causing those patterns, and hidden unknowable causes really exist. Pragmatic realism is a kind of philosophical naturalism, and it is a candidate for being the most reasonable type of philosophical naturalism.

Reply: The scientific realist should reply that even though it is possible to imagine alternative entities for playing the role of an electron, the hypothesis about the electron's existence only describes electrons in terms of the laws they all must exactly obey. The only properties that science attributes to electrons are the properties of obeying those particular laws. In other words, an electron simply is whatever entity obeys all of the electron laws. Any alternative imagined entity that still obeys the same laws is an electron too! Therefore, there are really no alternative hypotheses about alternatives to electrons -- there can only be rival hypotheses about genuinely different entities that obey somewhat different laws, and those have to be tested just like any hypothesis. It is reasonable to believe in the existence of unobservable entities postulated by highly confirmed theories.

In order to refute objection four by the pragmatic realist, the scientific realist here tries to claim that a hypothesis's conception of a postulated unobservable entity consists only of the laws that entity must always obey. But this claim has a steep price. If correct, this claim implies that all of the real work done by a hypothesis to make predictions is actually done by the natural laws postulated. The unobservable entity itself has no role to play in scientific method. Of course, whatever unobservable entities really exist do supply causes for natural patterns, and that is a crucial role. But only the natural laws -- those numerous equations -- proposed by hypotheses are actually used for formulating predictions about natural patterns. These natural laws are what are really being tested in the experimental method, and according to pragmatic realism, highly confirmed natural laws deserve credibility -- nature really does display habitual regularities as (approximately) described by scientific laws.

But is scientific realism the better choice over pragmatic realism? The pragmatic realist approves the existence of verified Type I and II entities, grants the existence of unobservable entities responsible for natural patterns, and agrees that science should propose and test hypotheses about unobservables. Scientific realism additionally claims that it is reasonable to believe that highly confirmed hypotheses fairly accurately describe unobservable entities. But what descriptions are given by such hypotheses? The only descriptions that matter are descriptions of the natural laws these entities obey, and the pragmatic realist already encourages belief in those highly confirmed natural laws. So what remains of any real difference between pragmatic realism and a reasonable scientific realism? Perhaps none.

Consider the role of "mutation" in the Darwinian theory of evolution by natural selection. Billions of years of life's evolution -- millions of of generations from the first life form. So many species, so many mutations, have happened in the distant past. Fossils leave observable traces of organic structure, but no "mutation" can be seen. A new structure here, a new anatomical function there -- but the cause of the genetic variation stays hidden. Do you think that genetic mutation, and whatever causes it, must be a Type III or Type IV entity? Then next consider whether biological evolution can truly explain the causes of genetic mutation -- is that even biology's responsibility? Which other sciences must be consulted to figure out causes of genetic mutation? Finally, since biology appears to require outside help to fully explain species evolution, what would be the argument against theology's suggestion that God is sometimes the cause of these long-ago mysterious mutations?

Summary

1. The most credible hypotheses about unobservables are ones that continually increase their empirical adequacy and cohere well with larger theories and paradigms, while revealing a simpler reality behind the phenomena.

2. Even scientific realists should be impressed by the underdetermination argument, which emphasizes caution when using abduction.

3. The real work done by theories when they become more empirically adequate is done by the postulated natural laws, and not by science's conceptions of Type III and Type IV entities.

EIGHT. Scientific Worldviews

The **“demarcation problem”** is the philosophical problem of justifying a reasonable standard to judge whether an explanation (a hypothesis, or a theory or a paradigm too) is a scientific explanation, or not scientific at all (such as pseudoscience or religion or mythology, etc.). There is an easy way to seemingly solve the demarcation problem: justify an account of scientific method (such as the six-step method described in module 3) and then declare that only hypotheses that are testable by this scientific method qualify as scientific. Sounds easy -- but the most difficult part is precisely justifying an account of scientific method.

Philosophers and scientists have been trying since Aristotle to accomplish this. **A philosophical account of scientific method must explain (1) how hypotheses that survive trial by this method are more likely to be true, and also (2) how hypotheses that do not survive trial by this method are more likely to be false.** The first task is the philosophical problem of explaining why highly confirmed scientific hypotheses have a better chance of accurately describing real entities. We have covered this task in modules five and six. The philosophy of science that survived this task is “pragmatic realism.”

The second task is the philosophical problem of explaining why disconfirmed scientific hypotheses probably fail to describe real entities. Unless the scientific method can at least help scientists to judge which hypotheses are false, science cannot be any help deciding what reality is like.

Pierre Duhem (1861-1916), the French philosopher and scientist, argued that hypotheses about Type III or Type IV entities -- the “unobservables” -- can never be proven false. His argument started from the fact that no hypothesis can really be tested by itself, apart from the larger theory of which it is a part. Duhem, and other philosophers since, are concerned with the worry that a hypothesis cannot really be tested and hence never proven false (or never shown to be probably true either). It is true that a hypothesis cannot be properly tested without also using some other items of established scientific knowledge, as mentioned in step five, “experiment”. For example, an experiment to test for whether water exists on Mars depends on already established knowledge about how to detect water using scientific instruments: the signs that water will give from a distance, the effects of those signs on an instrument, how the instrument works, etc. When an experiment is designed, the logical form of the experimental inference is deductive. In the following table, the deduction on the left illustrates the reasoning when a prediction is experimentally confirmed, while the deduction on the right illustrates the reasoning when a prediction is experimentally disconfirmed.

1. Scientific knowledge item A. 2. Scientific knowledge item B. 3. Scientific knowledge item C. 4. New hypothesis. 5. If 1-4 are all true, then pattern P should be scientifically observed by an experiment. 6. Pattern P is scientifically observed in the experiment. Therefore, 7. The new hypothesis has a confirmation.	1. Scientific knowledge item A. 2. Scientific knowledge item B. 3. Scientific knowledge item C. 4. New hypothesis. 5. If 1-4 are all true, then pattern P should be scientifically observed by an experiment. 6. Pattern P is not scientifically observed in the experiment. Therefore, 7. 1-4 cannot be all true and the new hypothesis has a disconfirmation.

In the second example of a disconfirmation, the premises 1-4 cannot all be true. At least one of them must be false, assuming no experimental error. But which one? Remember, all scientific knowledge is fallible. Just because the purpose of the experiment is to try to test the new hypothesis, this does not mean that only the hypothesis can be shown to be wrong. Any premise, any knowledge, used in the design and execution of the experiment can be held responsible for being false. Reasoning only says that at least one, and perhaps more than one, of the four premises in this inference must be false. Reason and logic cannot identify which is false.

Of course, if scientists decide to trust the other premises rather than the new hypothesis, a disconfirmation makes it reasonable for scientists to conclude that the hypothesis is proven false and the entity does not exist. But this reasonable conclusion depends on the scientist's decision to trust prior knowledge. It is also possible for scientists to protect the new hypothesis by deciding that one of the other premises must be false instead.
Karl Popper's philosophy of falsificationism demanded that scientists must always discard the new hypothesis, but neither logic nor actual scientific practice requires this drastic approach. Scientific method must permit scientists to make judgments about which parts of theories should be changed. Because any single hypothesis needs assistance from other parts of a larger theory in order to be tested [what is now called the "Duhem-Quine thesis"], only entire theories really confront experimental evidence. Theories will gradually change over time as scientists selectively judge which parts require modification or replacement in order to continue to make successful predictions.

In earlier modules, we have already seen how hypotheses are linked together to form theories. In the 20th century, philosophers also began to emphasize how theories are linked together into paradigms. The best example is evolutionary theory. In order to justify the biological theory that natural selection is responsible for gradual species modification and elimination, evolutionary scientists appealed to non-biological theories. For example, 20th century geology confirmed that the age of the earth is at least 4 billion years and that there has been dramatic change to earth's surface and environments over that time. Another excellent example is 20th century physics, in which theories about subatomic particles were confirmed by sophisticated experiments only if physicists could already assume the validity of other theories about how their highly technical instruments worked, which in turn required confidence in many more theories of physics.

The classic example is the "bubble chamber", which is supposed to show the particles created by collisions: the distinctive trails of bubbles left in the wake of these particles, according to theory, reveals the nature of these particles (especially the duration of their existence and their susceptibility to magnetic fields). Of course, a physicist could use the "evidence" of bubble chamber tracks to confirm a theory about particle collisions only if she already assumed the validity of other theories about these particles and their behavior in bubble chambers. This is the situation described by Duhem, and later emphasized by Kuhn: Many theories of physics are together used in the search for confirmations for one new physical theory. Therefore, the problem of disconfirmation already discussed above for a particular hypothesis is analogously repeated at the higher level for a particular theory:

1. Theory of physics A. 2. Theory of physics B. 3. Theory of physics C. 4. New theory. 5. If 1-4 are all true, then pattern P should be scientifically observed by an experiment. 6. Pattern P is scientifically observed in the experiment. Therefore, 7. The new theory has a confirmation.	1. Theory of physics A. 2. Theory of physics B. 3. Theory of physics C. 4. New theory. 5. If 1-4 are all true, then pattern P should be scientifically observed by an experiment. 6. Pattern P is not scientifically observed in the experiment. Therefore, 7. 1-4 cannot be all true and the new theory has a disconfirmation.

In the second box above, the conclusion states that the new theory has a disconfirmation. But does it really? That depends on the judgment of the scientists. It is possible for scientists to refuse to accept a disconfirmation and instead try to place the blame for the predictive failure upon theory A, B, or C. If any of these other theories are modified instead, the disconfirmation could be made to go away and become a confirmation instead. Following Kuhn, let us call a group of theories in a field of science, which heavily depend on each for mutual support, a “paradigm”. [The philosopher Lakatos instead talks about “scientific research programs”, which is a similar notion.] The philosophical problem presented here can be stated like this: how is it possible for a paradigm to proven false by experiment, if its component theories are continually used to protect each other against disconfirmations? This is not merely a hypothetical problem. Historians of science have easily exposed how paradigms gradually change over time as its component theories are modified in order to keep up with new evidence. You can read a webpage about “Scientific Progress”.

Popper supplemented his theory of falsificationism with the idea of the “crucial experiment”, in which theory A can defeat theory B by receiving a confirmation from the very same experimental outcome that causes theory B to suffer a disconfirmation. In his writings, he relies on the example of confirmation of Einstein’s theory of relativity, which correctly predicted (unlike the Newtonian theory) that the sun would bend light from distant stars. For Popper, this single crucial experiment justified the complete replacement of Newton with Einstein. However, Popper’s notion of a crucial experiment between two theories presupposes that both competing theories accept the validity of other theories about how to accurately observe the shifting of the position of stars which is (allegedly) caused by the hypothesized bending of starlight by the sun. In other words, both the Einsteinian and Newtonian theories agreed on some other physical theories about the crucial experiment, so that the Newtonian theory was logically forced to admit disconfirmation (and, according to Popper, admit complete falsification as well). It is very important to realize how the Einsteinian and Newtonian theories were not entirely distinct paradigms -- they actually shared much theoretical ground, and hence they competed on the same experimental “playing field”. While not very frequent, the history of the sciences has witnessed some of these dramatic theoretical changes, during which a paradigm is suddenly replaced by a new paradigm -- in what is called a scientific revolution -- as philosopher and historian of science Thomas Kuhn has described.
But what about a quite different situation, when two distinct paradigms are competing in a single field of science? In this situation, there seems to be little possibility for a “crucial experiment” or any serious competing experiment at all. Consider the following problem:

1. Theory of physics A from paradigm X.	1. Theory of physics E from paradigm Y.
2. Theory of physics B from paradigm X.	2. Theory of physics F from paradigm Y.
3. Theory of physics C from paradigm X .	3. Theory of physics G from paradigm Y.
4. New theory D (and if D is correct, theory H can’t be correct too).	4. New theory H (and if H is correct, theory D can’t be correct too).
5. If 1-4 are all true, then pattern P should be scientifically observed by an experiment.	5. If 1-4 are all true, then pattern Q should be scientifically observed by an experiment.
6. Pattern P is scientifically observed in the experiment.	6. Pattern Q is scientifically observed in the experiment.
7. If 1-3 are all true, then pattern Q cannot be scientifically observed, so theory H cannot compete with theory D.	7. If 1-3 are all true, then pattern P cannot be scientifically observed, so theory D cannot compete with theory H.
Therefore, 8. The new theory D has a confirmation.	Therefore, 8. The new theory H has a confirmation.

In this situation, the scientists who accept paradigm X (hereafter lets call them ‘X scientists’) refuse to believe that scientists who accept paradigm Y (hereafter, ‘Y scientists’) have any legitimate way of getting confirmations for their preferred theories. And vice-versa: Y scientists do not believe that X scientists can legitimately get confirmations for their preferred theories. Here’s an example in the philosophical literature: consider the X scientists who accept a paradigm of Western medicine (eg., tiny living organisms cause diseases) and the Y scientists who instead accept a paradigm of Eastern medicine (eg., imbalances of internal energies cause disease). And let us suppose that both parties are really scientists -- they are using the same scientific methodology. X scientists will not be impressed by alleged “experiments” that “confirm” any relationship between meditational yoga and restored health, and Y scientists will not be impressed by alleged “experiments” that “confirm” any relationship between antibacterial medicines and restored health. In this hypothetical scenario (not far from the real situation, actually!), these paradigms do not share enough theoretical ground to permit the possibility of a crucial experiment. They cannot be compared against each other by any simple measure of experimental evidence, because each paradigm rejects the existence of experimental evidence supporting the other side’s paradigm.

Kuhn describes this philosophical problem as “incommensurability”: if a paradigm encompasses all theories that it uses to create any evidence relevant to its confirmation (let us call this bloated paradigm a “totalitarian paradigm”), then it cannot be measured against any other paradigm. If a field of science happens to have multiple totalitarian paradigms rivaling each other, this field will not make much scientific progress (and optimistic scientific realism will yield to pessimistic scientific antirealism and instrumentalism). Which fields of science currently suffer from this sort of situation? Psychology has seen a variety of totalitarian paradigms during the past 120 years, although behaviorism has lately dominated. Economics can hardly be called a science because of the way that various totalitarian paradigms (incorporating moral and political views as well) only talk past each other. In the natural sciences, quantum physics has occasionally seen the realist and antirealist camps sharply disagree over the interpretation of experimental evidence regarding the particle or wave nature of light (the proposed compromise, that natural things really are both particles and waves, is only the pessimistic peace offering of antirealism).

Because scientists can protect some hypotheses by modifying or discarding others, and they can protect some theories by modifying or discarding others, some philosophers have claimed that experiments do not really determine the validity of a new hypothesis. If this claim has merit, then this problem with experimentation causes more doubt whether either scientific evidence or reason really decides which hypotheses or theories should be believed. If the empirical evidence does not control which hypotheses should be believed, what really makes scientific theories any different from other kinds of theories that some people want to believe in, such as religions or superstitions or pseudosciences such as astrology?

Recall what is at stake here: **A philosophical account of scientific method must explain (1) how hypotheses that survive trial by this method are more likely to be true, and also (2) how hypotheses that do not survive trial by this method are more likely to be false.**

We have tried to formulate a philosophical account of scientific method that explains how this method rationally decides what hypotheses deserve belief, and which don’t. But what happens if this account fails to deliver on its promises? What if a thorough analysis of scientific method, as scientists actually operate, reveals that scientists can protect hypotheses and theories? Then we are in a situation where philosophy and reason cannot deliver an account of how science works (maybe instead philosophy and reason only can describe some ideal utopia where science should rationally work, but that would not be our actual world of real people). So where can we go to learn how science actually works in the real world? Who can discover why some theories and paradigms are accepted and promoted by science?

In the 1970s and 1980s, social scientists undertook this effort to explain how science REALLY works. Much of this effort goes under the label of “Sociology of Science” of “Sociology of Scientific Knowledge”. See this website on “Social Dimensions of Scientific Knowledge”. Sociology is a discipline which, among other things, attempts to understand the activities of social groups in terms of the power relationships existing between people. In its crudest form, sociology of science would explain that scientists believe paradigms because professing such beliefs bring the rewards of social and material status. Nature and truth are almost entirely eliminated from such explanations -- what nature is doing has little to do with the theories scientists promote, and there is no way to tell what the “truth” is anyways.

Inspired by this sociological perspective on science, other philosophers and social scientists have investigated science’s hidden assumptions, looking for premises in scientific reasoning that do not have an origin in science itself, but must have some other origin (for example, an origin in background cultural biases and prejudices). For example, the Aristotelian assumption that reproduction involves the union of a passive formless egg from a woman and an active essence-carrying sperm from a man (giving men all the credit for making human babies) was capable of retarding knowledge of reproduction until into the 20th century. Feminist sociologists and philosophers have successfully exposed a wide variety of gendered assumptions having no basis in empirical evidence. Interestingly, these cultural critiques of science depend on being able to distinguish bad prejudiced science from good unprejudiced science, and hence they still assume that some science can be conducted on the basis of evidence and reason alone. These feminist critiques still have respect for scientific method, therefore, and only demand scientific reform, not replacement.

However, some philosophers demand replacement. Some have proposed that the scientific method itself must be evaluated as a component part of current scientific paradigms. After all, only by assuming its validity can scientists use scientific method to achieve confirmations of its theories. This is a totalitarian view of paradigms taken to its logically ultimate extent. By viewing scientific method itself as just another component theory of modern scientific paradigms, we can begin to wonder whether scientific paradigms must be deeply incommensurable with any rival paradigm that uses a very different system of justification for its own theoretical conclusions. The alleged “psuedosciences” might really just be rival totalitarian paradigms, after all.

The best example of this philosophical problem is the Catholic church’s view (from Thomas Aquinas) that revelations from God are a different but no less valid method of learning truths than the rational/scientific method of empirical inquiry into nature. Religious revelation and empirical science can be viewed as two totalitarian paradigms that nevertheless must reach a philosophical compromise by each agreeing that neither by itself provides a complete and final understanding of all reality.

By taking this philosophical problem of justifying scientific knowledge very seriously, modern Western science begins to look like any other cultural belief system, sustained over generations by mere persuasion or coercion, and not pure reason or absolute truth. If this sociological view of science is correct, then there is no reasonable demarcation between science and any other belief system, and hence scientific “knowledge” should not be permitted to have any greater authority than any other belief system like magic or myth. This view, which is a kind of “Relativism”, was championed by the 20th century philosopher Paul Feyerabend. Feyerabend was not a skeptic, since he believed that plenty of fallible practical knowledge is available to people -- so much knowledge, in fact, from so many cultural sources, that it is impossible to find some objective supreme methodological standard to judge which sort of cultural knowledge is superior to any other.

Summary

1. Philosophy of science has many difficulties with explaining why disconfirmed scientific hypotheses probably fail to describe real entities.

2. Scientific hypotheses and theories can be protected from disconfirmation by complex paradigms that control what counts as legitimate scientific experiment.

3. Totalitarian paradigms cannot be rationally measured against each other through empirical experiment, making it impossible to prove any theory false if it is well protected by its paradigm.

4. Philosophy of science might be unable to explain how actual science relies on evidence and reason alone.

5. If philosophy cannot show how science is only based on evidence and reason, some other discipline such as sociology or economics or gender studies can offer alternative explanations of how scientists actually promote theories.

6. It is important to distinguish socio-cultural criticisms of science that demand reform (these criticisms still assume that science can try to respect reason and evidence) from socio-cultural accounts of science that portray science as just another cultural institution that has no more claim to “truth” (whatever that is) than any other.

NINE. Science and TechnoScience

Primary Disciplines	Main Areas	More subdisciplines, fields
PHILOSOPHY Debates what is fundamentally real, truly knowable, and most valuable.	Cosmology Ethics	Metaphysics, Epistemology, Logic Axiology, Aesthetics
HISTORY Narrates the course of events and consequences of human deeds.	World History Local History	Ancient History, National History Journalism, Biography
SOCIAL THEORY Observes how social relations, practices, and organizations operate.	Anthropology Psychology	Archaeology, Geography, Linguistics Communications, Media, Education
THEOLOGY Discerns the essential commitments that contribute to the religious path.	Systematic Theology Practical Theology	Ecumenical Theology Hermeneutical Theology
POLITICAL THEORY Examines structures of ruling power and standards for legitimate authority.	Comparative Politics Government	International Relations Public Policy, Law, Jurisprudence
ECONOMICS Formulates how exchange systems make and distribute goods and wealth.	Macro Economics Micro Economics	Monetary Policy, Public Finance Industrial Organization, Management
SCIENCE Confirms hypothetical explanations through strict experimental methods.	Natural Sciences	Astronomy, Physics, Chemistry Geology, Earth Sciences
	Life Sciences	Medicine, Physiology, Biology Ecology, Botany, Zoology, Paleontology

Disciplinary perspective on Science	**Key questions about science**
Philosophy of Science	
Science offers a revisable worldview called "naturalism" assembled from knowledge gained by scientific fields about natural causes, forces, and laws.	Are science's theories more accurate about reality than alternative views? Are there different kinds and grades of scientific truth for facts and theories? Are scientific methods the best ways of reasoning for discovering truths? Are rivals to science's knowledge unreasonable for challenging science? What are the moral rules to follow during scientific research? Which sorts of scientific inquiry are too unethical to even attempt?
History of Science	
What counts as "science" and what gets credited as "good theory" has been changing continually since the earliest sciences began three thousand years ago.	Why do sciences invent their methodologies while establishing their theories? Why does each field control what may count as a hypothesis worth testing? Why does each field decide what may count as relevant evidence to gather? Why do some theories get widely accepted, while others are overlooked? Why do some scientists get famous and influential, while others are ignored?
Sociology of Science	
Communities of scientists operate to decide how "valid" science is done and who is able to confirm "true" theories, within wider social/cultural conditions.	How does a scientific field dictate who can be a scientist doing real science? How does a field reward certain scientists for supporting that field's theories? How does a field attain social prestige for providing valuable knowledge? Does science mainly disrupt custom and culture, or does it lead social progress? Which social conditions can foster science, and which can suppress science?

Theology on Science

Science represents a non-religious rival that grows humanity's powers, yet leaves the cosmos without purpose, the world without design, and life without meaning.

Are some religions more compatible with science than other religions?
Can religion accommodate scientific theories; should religion try to adjust?
Could science contribute to understanding God, & humanity's access to God?
Can scientific reasoning discern God's reality and divine activity in the world?
Might science eventually replace all myths about cosmic and human origins?

Politics of Science

Scientific organizations seek government recognition and support to grow their funding and increase their influence over public policy, law, and other social sectors.

How can fields acquire greater public support and government funding?
How do scientific associations lobby for science-based policies and laws?
Where must science compete with purely political motives and agendas?
How can government best support scientific research and development?
How should government regulate scientific research and innovation?

Economics of Science

Scientific developments come from timely investments with high risk/reward factors, while adopted innovations can accelerate or disrupt industries and market sectors.

How do fields obtain funding from non-profit and private capital sources?
How do research funders wisely choose rewarding research proposals?
How does research spin-off into profitable patents and business ventures?
How do innovations disrupt market sectors and create new markets?
How can market forces efficiently distribute monetization and risk in research?

DISCIPLINARY ALLIANCES	**How to think about Science**
A. Philosophy + Theology = **Metaphysics vs. Science**	However ultimate reality may be religiously or philosophical conceived, science will never comprehend it, because the sciences are limited to investigating only what can be observed, measured, quantified, and formulated. Science must assume, and can never discover for itself, that the universe has a cause and why nature has regularities.
B. Philosophy + Social Theory = **Culture vs. Science**	Scientific discoveries and new theories often claim to "falsify" or discredit traditional and customary views about humanity, society, and the self. However, no scientific "truth" could possibly refute common sense ideas about humanity's rationality, self-consciousness, free will, responsibility, moral worth, social equality, and other ideals.
C. History + Sociology = **Social History of Science**	A scientific field stays cohesive because most of its practitioners subscribe to its dominant paradigm that dictates methodology, hypotheses, and evidence. Only under rare crisis conditions, as a paradigm collapses from excessive counter-evidence, would a rival theoretical framework have an opportunity to become the replacement paradigm.
D. Political Theory + Economics = **Political Economy of Science**	Scientific programs are powerful and profitable enterprises that compete for political and economic attention and funding. Because science is a major force in business and civic life, it must be simultaneously fostered and carefully regulated, so that scientific innovation is able to consistently improve human lives and advance the public good.
E. Philosophy + Science = **Humanistic Naturalism**	Religion is invalidated by science and gods are myths, since nature always existed and nothing created it. Religions are human inventions for social company and emotional comfort. Human life has its own purpose and meaning, science and technology will always improve humanity's welfare, and ethics determines what is truly right and just.

Technology, Engineering, and Technoscience

Neither technology or engineering are Disciplines, since they developed separately as phases of **Techne**, practically the oldest capacity (along with language) of our Homo line from H. Habilis to H. Erectus to H. Heidelbergensis and then H. Sapiens. All of the Disciplines are able to investigate and try to comprehend technology and engineering, in their own distinct methodological ways. Here, a sketch of the History of Technology towards Technoscience is presented.

Technos is essential to our nature as a Hominid species. It is not just tool use, which is done by other species. Technos covers these capacities:

Using tools to modifying things in the environment
Modifying tools to work better for tasks
Teaching the young to make good tools
Modifying tools for more and more specialized uses
Making tools specialized for the making and modification of other tools
Teaching techniques for the proper use of specialized tools
Cooperating in the making of complex tools having specialized parts
Cooperating in the application of complex tools to group tasks
Teaching techniques so that many people can use tools alone or in groups

Homo Erectus had many of these capacities; Homo Sapiens had all of them by the time our species emerged around 250kya. Humans advanced the crafting of stone, bone, and wood tools to the point where a wide variety of implements were capably used. The most useful implements for most any craft or task, such as the blade, the axe, and the needle, were the basic tools for efficiently transferring force (essentially, forms of the Wedge) during the Stone Age. During the Neolithic Revolution down to the earliest civilizations (10kya to 4kya), all of the basic mechanical implements and some basic instruments were invented, permitting a wide variety of technological achievements.

The Implement: A tool with no parts or a few parts that is crafted to transfer the user's application of force.

Mechanical Implements and Parts

The simplest kinds of mechanical implements for *efficiently* transferring force by contact are:

Inclined plane, Wedge, Screw

Bow, Bow+Arrow, Bow Drill

Lever, Wheel (w/axel), Pully

Gear, Gear+Belt, Crank

The Wedge is a movable and scalable inclined plane; the Screw is just a cylindrical wedge. A Wheel is a leveraging disk secured by a centered contact of two inclined planes (the wheel hole and the axel rod). A Pully is the combination of wheels and rope. A Gear is the incision of wedges around a wheel's disk. A Crank consists of jointed attached levers. Combinations of simple mechanical implements to make a "device" sends technology in the direction of mechanism. For example, a mechanical drill is a hardened screw for boring into solids; and a propeller is a wheel with wedged cutouts turned on a belted axel.

Two fundamental kinds of technology relying on mechanical implements had emerged by 4kya: Static Technology and Dynamic Technology.

Static Technology:	A. Structures (transfer energy w/o motion)	B. Conveniences (transform energy w/o motion)
Dynamic Technology:	C. Instrument (device for observation w/metrics)	D. Mechanism (device transferring power w/ moving parts)

Instruments

Simple instruments are implements designed for quantifiable ratios and metrics (sizes, distances, areas, directions, angles, weights, time durations, space dimensions, etc.) that do not require mechanism. Prominent examples are the mirror (convex for enlargement), the measuring rod, the ruler, the gnomon (carpenter's square), the drawing divider and compasses, calipers, the balance, the plumb line (for architecture), the groma and dioptra (for land surveying), the sundial, water clepsydra, and sand hourglass (for chronometry), the magnet, the compass (for orientation), the quadrant and sextant (for astrometry), and the telescope.

More complex instruments were also known in the ancient and medieval world, employing mechanisms based on wheels, gearing, screws, linkages, weights, and the like. Examples include the odometer for land distances, the wind vane, and the wind wheel.

The arrival of physics, chemistry, and electricity required mechanical instrumentation during the 18th and 19th centuries. The microscope, the scale, the mechanical air-pump, the calorimeter, and the electrometer are early examples. These mechanical inventions in turn allowed the invention of advanced scientific instruments. For example, the air-pump permitted the creation of vacuums inside tubes containing a liquid (such as mercury), which then led to the invention of the barometer (for air pressure) and the thermometer (for temperature and heat). The electrometer led on to the voltmeter, the ampmeter, the oscilloscope, and so on. With the combination of electronics, instruments developed into sensors.

These scientific instruments in turn permitted science to arrive at theoretical principles about energy, force, power, and work, demonstrated through careful measured experimentation. During the Scientific Revolution, the natural sciences became forever dependent on mechanized instrumentation and machines for conducting controlled experiments.

Machines and Engineering

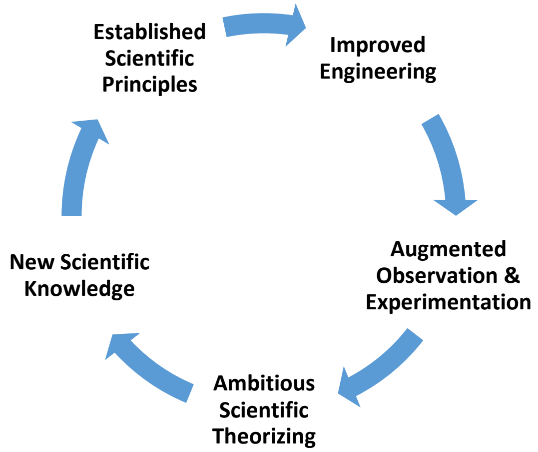
Dynamic Technology led towards the Machine:

Mechanism	Device able to transfer power through its connected moving parts for predictable effects.
Transformer	Device designed to transform energy into a more practical form, and to transfer that power.
Engine	Device for releasing stored energy (fuel) by controlling a reaction (e.g. chemical) for mechanical power.
Motor	Engine integrated within a mechanism for transferring its power to other mechanical parts.
Mechanical Device	Device with internal motor designed to perform stationary tasks with precision (e.g. a clock).
Machine	Mechanism powered by an external transformer or engine designed to execute mobility tasks.
Automated Machine	Machine powered by an internal integrated motor and onboard fuel supply.
Industrial Machine	Automated machine situated within an industrial operation for production (e.g. in a factory).
Automobile Machine	Automated machine designed for its own mobility on land, in water, in air, in space (e.g. a car, a train).
Robotic Machine	Automated machine partially controlled by onboard computerization for flexibility in task activities.
Autonomous Robot	Robotic machine largely or fully controlled by integrated AI computing for independent activities. Autonomous AI robots designed for independent activity include self-driving cars, drones, and androids.

Engineering is the application of scientific principles to improve the design, construction, and functioning of static and dynamic technology and machinery.

Engineering *for* science improves the precision and reliability of science's equipment, instruments, sensors, and mechanized operations.

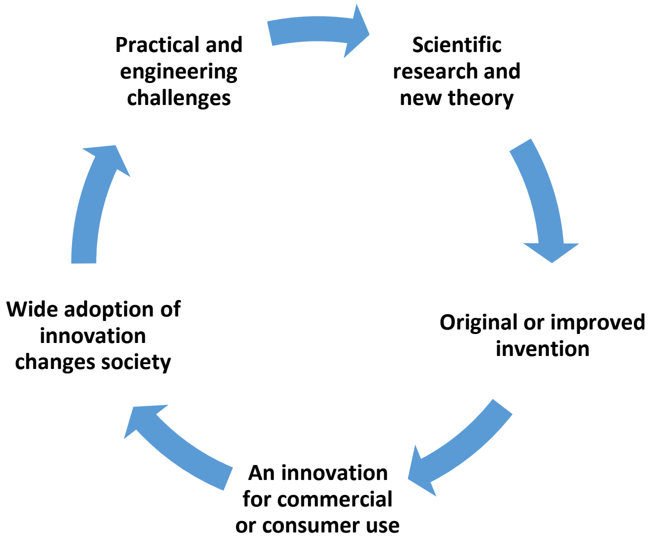
Technoscience is the integration of engineering into the observation and experimentation phases of scientific research and innovation.



Science, Invention, Innovation

Is science operating separately from other social institutions, customs, and social forces? One answer is Yes: "scientific method focuses on objectivity and truth by applying its own resources and methodologies." The contrary answer is No: "Scientific agendas, and resources come from wider society and its values."

Is science pure and abstract, operating separately technology and engineering? One answer is Yes: "scientific research seeks nature's energies, forces, and laws regardless of any practical application. The contrary answer is No: "scientific research relies heavily on technological apparatus and instruments and gets inspiration from engineering challenges."



Three Kinds of Techno-Science Advances

Theoretical advance: a novel hypothesis become overwhelmingly confirmed through experimental testing, and joins a scientific field's established theories.

Invention: an original technology that is more than a variation on a prior invention, permitting a fresh extension of human capability and a new solution to some practical problem. An invention usually follows from a novel theoretical advance, directly or indirectly. An invention is often a physical thing, but it can be some sort of process, perhaps of synthesis, refinement, assembly, and so on.

Innovation: a variation of an existing invention, or combination of inventions together, for a practical item or process, such as a device, equipment, structure, instrument, and so on.

The Scientific Revolution

Aristotle vs Plato.

Aristotle: (a) everything has a natural purpose, and
(b) mind is part of nature.

Plato: (c) nothing natural has a purpose unless bestowed by an ideal Form,
& (d) there is a perfect order behind surface phenomena.

During Christianity's domination over the West,
Plato + Aristotle = Theology. The supernatural Mind (God) gives order to nature, and nature cannot create order on its own.

Nature's energies obey strict and complete laws of nature that ensure that all events are lawful without exception.

Mechanistic Philosophy of Science (17th-18th century)
1. Everything is made of matter, and all matter is powerless by itself. Matter does something due to controlling laws of nature that govern all events to occur precisely as they do.
2. The laws of nature are NOT made by nature, just like human minds (dualism).

After removing a supernatural God creator, Mechanistic Philosophy becomes Materialism.

Materialism:
3. Science is in the business of discovering natural laws, but it will never explain how fundamental laws came to be.
4. Minds are just brains, or they are illusions.
5. There is no value or purpose to nature. The universe, overall, is meaningless (nihilism) and unable to give meaning to living creatures.

After the Chemical Revolution (19th century), Chemistry became more mechanistic, while biology has resisted reduction to complete mechanism. In Chemical (analytic) explanation, the parts are more real than wholes, and what wholes are doing is explained by what the parts are doing. In Biological (holistic) explanation, the wholes (organs / organisms) are most real than their parts, and what parts are doing is explained by what the whole organ or organism is doing.

TEN. **Abduction and Scientific Realism Part 1**

<u>Abduction, Complex Inferences, and Emergent Heuristics of Scientific Inquiry</u> (previously published)

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 – "Interative 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 Interative 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 – "Interative 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 interative 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 Responsibles 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 Conduction 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 Conduction 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 manifestions: 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 Responsibles
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 Responsibles
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 mythos. 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 acquires 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. It 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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ELEVEN. **Abduction and Scientific Realism Part 2**

Abduction, the Logic of Scientific Creativity, and Scientific Realism (previously published)

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

Types of Scientific Creativity

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

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-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

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[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].

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. 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 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:

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

[4] Whewell [13], vol. 2, p. 186.

[5] Popper [14], p. 32.

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 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 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.

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[6] Popper [14], pp. 7-8.

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 logicality, 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, not performing 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. ([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.

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.

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

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 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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