Scientific Truth and Scientific Change

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Introduction: What Is the History of Science For?

A historian of science among scientists sometimes feels called upon to justify her very existence. In a society saturated with science and science-based technology, it may seem obvious why the general public needs to learn something about how modern science emerged, how it became intertwined with technology, and under what social and political conditions it flourishes and also under which conditions it withers away. Historically speaking, it's been the exception rather than the rule for cultures to support large-scale scientific inquiry: the short-term costs are evident, and the long-term benefits often seem very remote indeed. It's especially important that citizens of democracies, in which up to 90% of the funding for scientific research is financed by public funds, understand how science developed in the past and how it works in the present in order to make informed decisions about which research deserves support and indeed why sustained support for research is so vital to any modern society, even when resources are scarce and election cycles are short.

But why do the scientists need the history of science? After all, science is focused on the future, on the next new discovery, the next theoretical breakthrough. Scientists may revere the pantheon of great past scientists and even read biographies of the likes of Galileo or Darwin or Einstein, but they rarely cite literature more than five years old in their own publications. What use is the history of science for science right now?

There is a contradiction at the heart of modern science that the history of science can help to resolve. Scientific knowledge is the most reliable knowledge we have, but it is not the eternal, unchanging truth of the philosophers and the theologians. At precisely the moment when a branch of science is advancing by leaps and bounds, it is also leaving behind what we thought we once knew in a cloud of dust. And the scientific past can suddenly once again become urgently relevant. Lines of investigation which have lain fallow for decades may suddenly bear fruit and overturn long-held scientific orthodoxies. Data that had been slumbering in archives for decades can be revived, as happened in the 1990s when astronomers turned to glass photographic plates that had been gathering dust for a hundred years in search of evidence for the existence of dark matter. Or a theory that had delivered wide-ranging explanations and astonishingly precise predictions for centuries can be overturned in the space of a decade, as Einstein's theory of General Relativity overturned Newtonian celestial mechanics in the early twentieth century. Theories may be celebrated with Nobel Prizes; textbooks may turn discoveries into doctrine; historians of science may award laurels to the winners in the race to discover radium or figure out protein structures or predict the existence of black holes. But eventually, all will have to be revised in light of new achievements, discoveries, and predictions. Because science advances, the history of science will not stay written.

The price of scientific progress is impermanence. If there is one lesson to be learned from the history of science, it is that whatever scientific truth is, it is dynamic – more like the flowing river of Heraclitus than the eternal forms of Plato. It is the business of philosophers to sort out conceptual contradictions like that between scientific progress and Platonic ideals of truth. Scientists generally have little time or patience for puzzles that cannot be solved empirically, but occasionally they too must confront this uncomfortable contradiction, especially when called upon to explain to the general public why yesterday's scientific truth is now today's scientific error. The SARS COV-2 pandemic is only the most recent example of scientists thrust into the limelight of media scrutiny and asked about what the virus was, how it spread, and what could be done to mitigate disease and death. Disconcertingly, the scientists' answers to all these questions seemed to change weekly. New observations by clinicians, new experiments in laboratories, new results of clinical trials corrected, contradicted, or simply confused the old answers. Governments counseled citizens to follow the science, but following the science left everyone breathless, including the scientists themselves. At such moments, scientists too are forced to ponder the implications of scientific progress for scientific truth.

Much of my work in the history of science has been an attempt to understand the nature of scientific progress and its deep implications for how we live and how we think in societies that are saturated with science and science-based technology. I believe that the long perspective provided by the history of science can help answer the stark question posed by many people, including scientists, and not just during a global pandemic: can scientific progress co-exist with scientific truth?

Science Taken at Tempo: Allegro, Andante, Largo

"Science" is one of those suitcase words that begs to be unpacked. First of all, it contains a multitude of different disciplines, each with its own subject matter, methods of inquiry, standards of proof, and criteria of success. Even within the same science, there can be significant differences. For example, physicists who study elementary particles can predict their behavior with great precision, but their colleagues who deal with turbulence – for example, the world climate system – face challenges of complexity that boggle even the most elaborate model and the mightiest super computer. Such crucial differences in methods and standards must be kept in mind when public pronouncements about science-in-general are airily declaimed, whether pro or contra. In most contexts, science-in-general is an imaginary beast, like griffins or unicorns.

We're not done unpacking the science suitcase. There are also important distinctions to be made about scientific progress, which can be imagined either as a cathedral being built, brick by brick, over generations, or as a vertiginous ride on a locomotive bound for who-knows-where. Since the Enlightenment in the eighteenth century, scientists have used both metaphors, sometimes in the same sentence. But if we pay closer attention to what exactly ii is that is changing, and how is it changing, we can see that the two metaphors capture different aspects of science. By expanding the timeline of scientific development beyond the present moment, the history of science can help us understand how this is possible.

Science ticks according to three clocks. The fastest of these, running at allegro tempo, times the pace of empirical discoveries. From the first scientific journals of the mid-seventeenth century to the latest issues of *Science* and *Nature*, these novelties from the laboratory, the observatory, and the field succeed one another at breakneck speed. The second clock, progressing at a stately andante, tracks the emergence of significant new theoretical frameworks, which we often abbreviate with the names of those who first formulated them. As more and more scientists work on more and more subjects, this second clock is speeding up, but it cannot rival the breathless tempo of the first. Its innovations are measured in decades and even centuries, not weeks and months. The third clock is the slowest of all, inching forward at a glacial largo: it times the slow accumulation of ways of knowing so fundamental to science that they seem self-evident: practices like experimenting, observing, finding correlations, mining data, simulating with computers. This is the basso continuo of science, which unfolds over centuries and millennia. It is on this scale that the ideals and practices of scientific rationality emerge: what it means to know and how to go about knowing.

At any given moment in time, a given science may be gripped by novelty at any one of these three levels of change. During the SARS-COV-2 pandemic, for example, new empirical results in virology and immunology accelerated from allegro to prestissimo, to the point where even online preprint servers buckled under the volume of submissions. At the andante level, theoretical deliberations about how to sift through all of these results, produced in haste and not all equally reliable, which inferences to draw from them, and how to make them cohere with each other and with what was previously known about corona viruses, is still ongoing and likely to take years, if not decades. And at the slow, largo level, there is the immense challenge of squaring three ways of knowing in the biomedical sciences: one ancient (clinical observation, but this time conducted on a global scale), one about a century old (randomized clinical trials), and one brand new (data-mining in search of suggestive correlations). Attempts to integrate clinical observation and randomized clinical trials have been going on for decades and are still a work-in-progress; work has hardly begun on how to integrate data-mining with the other two.

It is precisely in situations like these that the two narratives of scientific progress collide. The locomotive model fits the breathless allegro of the latest empirical results, each hot-off-the-press, some apparently contradictory, and none digested into a theoretical scheme that can weed out likely artifacts or irrelevances and make sense of what remains. "Hot-off-the-press" is used advisedly: because the allegro tempo of empirical novelty matches the media's own breakneck tempo and the public's urgent desire to know anything and everything about a new disease that has brought life all over the globe to a standstill, this is the level of scientific change that snags attention. Scientists are not entirely innocent partners in this pas-de-deux with journalists: in countries in which most research is funded by the public purse, there are both good motives and bad to want to bask in the media spotlight.

The journalists, for their part, hype their headlines by deleting the error bars and confidence intervals that signal uncertainty in scientific publications. If attention remains fixated at the allegro level, the pall-mall pace of both the latest empirical results (each only a tiny piece of an immense puzzle and perhaps not even pieces of the same puzzle) as well as the short-lived practical measures based on them can be dizzying. Disoriented and desperate, many citizens begin to lose confidence in scientific pronouncements with a shelf-life shorter than that of unrefrigerated milk.

But at the andante level of scientific change, the pieces of the puzzles are being mulled over, matched, and sometimes discarded. This is slow, painstaking work and is unlikely to attract a reporter to the lab. It is also a stumble-blunder process fraught with failure and controversy: one scientist's promising pattern may be another's fata morgana. This is a narrative that unfolds over many years, with innumerable dead ends and blind alleys, and which rarely concludes triumphantly with a Nobel Prize ceremony – a narrative that only a historian of science could love. Yet when the puzzle-solving succeeds – and there is no guarantee that it will – the results are not only more durable than those splashed across the weekly covers of *Science* and *Nature*; they also act as a sieve for the pieces that turn out to belong to another puzzle – often one not even recognized to be a puzzle until decades later. If attention were trained at this level, the overall impression would be one of greater durability, though not of eternal truths. Sooner or later, the bill for empiricism will once again come due. Does the third, largo level of scientific change rescue those eternal truths from the uncertainty inherent in all empirical inquiry? Its results are certainly more cumulative than those at the allegro and andante levels: once acquired, a way of knowing is rarely abandoned, though it may be marginalized by a method of investigation deemed more reliable or efficient or universally applicable, as clinical observation has been increasingly marginalized by randomized clinical trials in medicine, or large-scale statistical surveys have edged out more time-consuming ethnographic fieldwork in some social sciences. Marginalized does not mean replaced. Without clinical observation to spot new syndromes, randomized trials would have nothing to test (as in the case of AIDS, in which doctors first noticed a strange new constellation of symptoms in some of their patients). Without ethnographic fieldwork, statistical surveys could not generate causal hypotheses to explain macroscopic patterns (as in the case of declining rates of teenage pregnancies in several countries). But a way of knowing, however long-lived, is not an eternal truth: it is about how to conduct inquiry, not inquiry's end result. Nor is it a guarantee of the truth of the end result, only that at least some sources of possible errors have been eliminated.

Conclusion: Rethinking Progress and Truth

There is a good-news and a bad-news conclusion to this story. The good news is that there is a plausible version of progress at the allegro, andante, and largo levels of scientific change. We know ever more about many more things; we understand more about their causes and effects (and sometimes how to manipulate both to our advantage); and we are even inventing new ways of knowing. Depending on what level one focuses on, the narrative of progress looks more like the vertiginous version (allegro) or the cumulative one (largo), with andante somewhere in between, just as in music. And just as in music, scrambling the three levels creates cacophony, or worse.

The bad news is that none of the three levels produces certain, immutable truths. Knowledge that is reliable, in the sense of being able to bank on it, and illuminating, in the sense of deepening our understanding, is not necessarily the same thing as Platonic truth. The history of science and technology abounds with examples of knowledge sturdy enough to support workable technologies and insightful enough to connect apparently disparate phenomena – but knowledge eventually displaced, all the same. Just how durable scientific knowledge proves to be is highly variable, determined both by its level (allegro, andante, largo) and historical contingency (for example, cultures willing to encourage and support research are a relative rarity, historically speaking). Progress may bring improvements, but it may also bring trade-offs. For example, machine learning programs applied to Big Data may yield more accurate predictions of some phenomena, but at the price of obscuring their underlying causes. What kind of improvement is valued most – in predictive accuracy, in explanatory depth and breadth, in practical applicability – will define the direction of scientific progress. But whatever the direction and whatever the successes, progress in and of itself cannot secure the immutable truths that have so long been the standard against which all knowledge has been judged, including scientific knowledge.

Does science really need such truths? The ideal of certain, eternal truths originated in philosophy (partly inspired by mathematics) and became entrenched in some versions of theology. This ideal is incompatible with systematic empirical inquiry, both with its intrinsic uncertainty but also with its progressive character. Yet the empirical, progressive knowledge produced by science is even by philosophical accounts the very best knowledge we have. If philosophical and theological ideals of truth can't do it justice, so much the worse for those ideals. The conclusion to draw from the restless impermanence of scientific knowledge is not that progressive knowledge can't be true knowledge but that we need a better way of thinking about truth.