

Schisms Beyond Arithmetick*: how science's past might be its future

"I dream of a new age of curiosity. We have the technical means for it; the desire is there; the things to be known are infinite; the people who can employ themselves at this task exist. Why do we suffer? From too little: from channels that are too narrow, skimpy, quasi-monopolistic, insufficient. There is no point in adopting a protectionist attitude, to prevent "bad" information from invading and suffocating the "good." Rather, we must multiply the paths and the possibilities of coming and goings."

Michael Foucault ¹

"Fake realities will create fake humans. Or, fake humans will generate fake realities and then sell them to other humans, turning them, eventually, into forgeries of themselves. So we wind up with fake humans inventing fake realities and then peddling them to other fake humans."

Philip K. Dick ²

Epistemological crises are thankfully rare in human history, but from the looks of it we appear to be one of those handful of generations fated to suffer through one. In an epistemological crisis all the old traditions and institutions that normally constitute a shared social reality begin to fray and unravel. In these crises, once widely shared distinctions between truth and falsehood, fact and opinion, become politicized and subject to bitter disputes between partisans. Elites lose authority not just over politics but over understanding itself.

Historical analogies are always a matter of oversimplification and a coarse graining that does violence to the complexity of our forebears, but when used judiciously they can still be helpful in terms of getting one's bearings. The question is which of the epistemological crises of the past best fits with our own?

For me, the answer to that question lies neither in the relatively recent past, namely, the epistemological crisis of the late 19th and early 20th centuries that gave us both miracles like quantum mechanics, general relativity, and abstract art, along with the horrors of the world wars.³ Nor does the answer lie in the ancient world, rather the epistemological crisis that best matches our own is the one that gave rise to modern science itself. Then as now, new tools supercharged discoveries and challenged established knowledge while new means of communication eroded the control of experts over the dissemination and interpretation of this knowledge. Then as now, this occurred during a time when traditional authorities and institutions had fallen under a cloud of distrust.

Below I will argue that an updated version of the early modern's response to their crisis of knowledge might provide us with solutions to our own, and that such solutions might even open to a future where democratic hopes once dreamt of but never realized by science might at last be fulfilled. Yet because history is contingent and the product of human choices nothing is guaranteed, everything stands at fork roads leading to radically different futures. A darker 21st century is just as possible, and probably more likely, one in which science is replaced by increasingly sophisticated pseudoscience or where science ceases to be a human endeavor at all. Let me begin with the history.

Past

The caricature that once was the history of modern science has been definitively disproved over the last half century. Modern science in no sense emerged fully formed like a rabbit out of a hat in Europe during the 16th and 17th centuries from the brilliant minds of Galileo, Kepler, Bacon, Newton, and Descartes. The era that preceded the emergence of modern science was not shackled by a religious superstition whose bonds the moderns had at last managed to break. The world before the age of European imperialism and Western international dominance was not scientifically impoverished and in need of "Enlightenment".

Rather than being a complete break from the past or a development without a deep connection to the larger world, the European scientific revolution leveraged both its past and the knowledge of other cultures spanning the globe, along with the practical brilliance of its own craftsmen. This is most obvious in the case of the tools that drove the scientific revolution. Many of the most important ones were first developed by societies far outside of Europe. The compass and printing press were invented in China, algebra and the Arabic number system were imports from the lands of Islam and the Indian subcontinent.

Long existing old-world civilizations weren't the only source of the explosion of knowledge in Europe that began in the 16th century. European conquerors and merchants deliberately set out to mine the world's knowledge and where it suited them obtained this knowledge through force or fraud. They mined the wealth of knowledge fostered over generations by its newly conquered peoples, such as the botanical wisdom of the Aztecs,⁴ along with tapping the genius of Europe's own craftsmen- the mechanical clocks first imagined by monks and perfected by "lowly" instrument makers⁵, the lenses improved over centuries through labor and experimentation.⁶

Even when confined to the realm of ideas, pre-scientific era thinkers were never the angels on the head of a pin counters conjured up by later protestant rationalists. Instead, medieval Scholastics invented a rich natural philosophy with an empirical bent that was built upon the proto-scientific works of Aristotle.⁷

What separates early modern Europe from both its past and other societies contemporary with it was that only there was ever greater knowledge being created and absorbed during a time of institutional breakdown and elite civil war. In that sense a scientific revolution the likes of which had never been seen before certainly did occur.

Contradictions undermined the authority of the ancients passed on to them through the Arabs upon which European knowledge of the natural world had been based. The discovery of the New World, the Copernican system, the first glimpses of the microscopic world, Vesalius' discovery of contradictions in the ancient medical system of Galen via human dissection, all occurred simultaneously with the once universal source of learning in Western Europe undergoing a crisis deeper than any in its history and fracturing under the weight of corruption and upstart challengers empowered by the rise of the printing press.⁸

The church which for centuries had been the seat of learning in Europe lost much of its authority under accusations of corruption and Christianity splintered into warring factions. The textual authority of the past collapsed with the important exception of the Bible, which itself became a source of often violent contention and political dispute. Knowledge had become for the first time not only abundant but also plastic, malleable in the hands of readers who not only turned modern authorities against ancient ones but approached all texts with a new spirit of doubt.⁹

Under these conditions a new source of authority and factual solidity needed to be found, and it was found. What was needed was a way to distinguish the increasingly prolific information enabled by the printing press from true knowledge, a means to distinguish reliable models of the world from sophisticated flights of fancy. What was invented gradually over time, what was truly novel and came to be a defining feature of modern science as opposed to its predecessors, was institutions and methodologies that acted as a sieve turning the flood of information into a constrained but constantly growing body of knowledge confirmed through the accumulation of evidence and the successful response to challengers.

The means to the establishment of these "matters of fact" were invented by the scientific societies that had adopted the methodology of proof created in the sphere of law, and eventually married it to the new mathematics that would become its language of theory and demonstration in contradiction to the warnings of Aristotle that numbers could not fulfill this role.¹⁰ The unspoken assumption of these societies was that the world was comprehensible, its underlying order discoverable given the right methodology to delineate truth from human error and fantasy. In their ideal future, universal education would someday place this true knowledge of the world in the hands of everyone.¹¹

Yet it would take a long time for what we would recognize as scientists to emerge from the ranks of these natural philosophers who began the scientific revolution. The sharp line between science

and magic took time to draw. Even the early modern physicist today seen as a giant, Isaac Newton, was an adherent of arithmancy, alchemy, and an occultist. Rather than being at war with religion, early science was shaped by it and driven by its preoccupations. The road to what we today recognize as science was a long and torturous one.¹²

Present

Fast forward five centuries and we have a science that is the fruit of that revolution. But what is the status of this revolution today? On the surface, at least, science has never been better. There are far more scientists now than there have ever been in human history, and a larger number of scientific publications. Arguably, science has never been so well funded, or afforded as much public respect.

All scientific fields have benefited from the unfolding of Moore's Law. The ability to gather and process data has increased to a degree almost unimaginable even a few decades ago. The internet now facilitates a degree of scientific communication and collaboration that would make the journal publishers and letter writers at the birth of science blush.

Many of these new capacities were on full display with the development of novel vaccines during the Covid-19 pandemic- the first truly global crisis of the internet age. In addition to the creation- almost overnight- and deployment of a novel form of mRNA vaccination for a never-before-seen pathogen, scientists were able to share research globally in *real time* using preprint servers and engage in debates over merits using social media. Yet as the public and institutional response to that crisis made painfully clear, there are a myriad of problems afoot.

As in the early modern period, there has been a notable decline in all forms of authority, including scientific. Vaccines may have been created and deployed in record time for a novel virus, yet a significant portion of the population didn't trust the medical establishment enough to take them. To a degree probably unprecedented science has become politicized with positions on one side of an issue or another driven less by evidence than by political allegiance and ideology.

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The same communication capacities granted scientists by the internet enabled a whole host of pseudo-scientific personalities to emerge as guides for those of the public deeply suspicious, and not wholly without reason, of both the government and pharmaceutical companies.¹⁴ The attitude of public authorities in such a charged atmosphere was often not to communicate rational decision making under what are necessarily conditions of *uncertainty*, but to police dissent.¹⁵

Arguably, the largest moral failure of society during the pandemic was the failure to immediately give developing countries full access to Western mRNA technology largely out of proprietary concerns. ¹⁶That this happened should not come as a great surprise given that societies outside the sphere of the major scientific powers continue to be exploitatively mined for knowledge and labor. Exploitation that today ranges from biopiracy and red markets, ¹⁷ to training machine learning systems and providing the resources necessary for large scale computation. ¹⁸

Still, while the problems of contemporary science can most clearly be seen in the life sciences and were especially on display during the extreme societal pressures experienced during the height of the pandemic they do not end there. For quite some time now the so-called "soft sciences" have found themselves in a replication crisis. ¹⁹ Findings once thought gospel have proven to an unnerving degree to not be replicable upon concerted attempts to do so.

The replication crisis is not a problem in the human sciences alone and is but one aspect of a broader problem with the practice of scientific publication. ²⁰ The internet age has seen the rise of predatory journals ravenous for studies regardless of the quality of their findings or the qualifications of their authors. "Publish or perish!" has become an all-too-common mantra in academia, where researchers are also burdened under the weight of seemingly ever-increasing administrative tasks.

Given the sheer volume of information and the need for extremely narrow specialization, peer review faces the danger of becoming far too superficial. Nor do enough researchers make thorough review after publication by outside experts easy by, for example, including a detailed methods section that includes access to the code used by those who performed the study- an omission perhaps largely driven by proprietary concerns.

Funding, or more importantly the lack of it, decides which of sciences' many interpretative paths are explored, and which are relegated to the status of permanent terra incognita. Nowhere is this clearer perhaps than in physics where existing theories are so successful they seem irreplaceable and yet leave us with massive unanswered questions such as the nature of Dark Matter and Dark energy-phenomena that just so happen to comprise the bulk of the universe. Some have gone so far as to blame this impasse on dogmatism among physicists, a kind of echo of the caricature of medieval scholastics with mathematics playing the role of God. ²¹ Even in an era where there are more scientists than ever and with an enormous number of resources directed towards science, the rate at which paradigm shifts occur appears to be *slowing down* rather than speeding up. ²²

The same tendencies that have helped give rise to a growing public distrust of science- namely the enormous influence that corporate and state interests have over what passes for scientific truth- have eroded the status of pure science. Many of these problems might be traced back to the surrender of nearly every element of contemporary life to market forces- neoliberalism- towards

the end of the 20th century. And such problems are not merely a matter of the distortion of research, the perverse incentives of scientific publications, or the corruption of academia by the drive for profits but have affected the ways in which science communicates its findings to the public, that is, science journalism. Much of this journalism appears to be in the service of advertisers rather than public education its headlines driven by the need for "click-bait" ripe with hyperbole and prone to whatever reflects and feeds the current technological hype-cycle.

One of the few gains from the privatization of research was that, occurring in a post-cold war world, science had entered its first truly global era. That era now appears to be closing as we enter a period of heightened geopolitical and technological completion. Doors and exchanges, especially between the two major powers- China and the US- are closing at the precise time deeper cooperation is needed if we are to tackle global problems, something the pandemic surely showed.²³

Still, not everything is bad, in addition to the positive aspects mentioned earlier, there have been other small steps in the right direction that indicate hopeful future directions for science. We have seen a push for open science with publicly accessible data and a move away from predatory and obscenely expensive journals.²⁴ There has been a renewed focus on screening research for errors and fraud, along with a turn towards reproducibility and the publication of negative outcomes.²⁵ As mentioned, for all its faults, social media has often served as a source of real-time, crowd sourced and expert driven critique of research, though one that is now under threat.²⁶ We have also seen glimpses of something quite new, the large-scale mobilization of citizen scientists and amateur researchers.²⁷

The instruments of discovery we have at our disposal are astounding, none perhaps more so than the recently launched JWST. Above all, scientists now have a new and very powerful tool in the form of machine learning, an effective form of artificial intelligence which provides a brand-new kind of lens allowing us to see not the very big or the very small- as in the early modern world- but the shape of higher-dimensional data. All these positive developments will have to be replicated and leveraged for science to have a future that is both positive and human. To that future and its shadow, I now turn.

Future

As in the early modern epistemological crisis the future of science hinges on how exactly we make our exit from it. The arrival of artificial intelligence will certainly play a large role in that exit. The question is do we use AI as a tool to help solve science's contemporary problems in a way that leaves us in a better, more democratic place than before or will it serve as a weapon in a kind of scientific counter-reformation, or even make the crisis much, much worse?

As far back as 1961, Stanislaw Lem, in his non-fiction work *Summa Technologiae* predicted that scientific discovery would outstrip the limited capacity of human minds evolved in light of completely different concerns to understand it. Once that stage was reached, Lem posited, humanity would need to turn the pursuit of science over to intelligent machines.²⁸

Given the increasingly narrow specialization of science and the growing time required for individuals to learn even a modest amount of the information acquired by their field, the present seems to have borne Lem's predictions out. But our machines aren't quite at the point where they could replace let alone supersede human researchers, so one should ask what AI can do for science today before imaging what farther off futures it opens to for us?

AI could free scientists from many of the tedious tasks that steal time from research- such as grant writing and administration. It could be used by journals to better filter the flood of research they are drowning in, allowing them to identify flawed studies both from the past and present. It could also help scientists better separate competing hypotheses, even pointing experimenters in directions that might tip the balance in favor of one theory over its rival. This freeing of researchers' time might help facilitate contact between scientists in diverse fields in a way only seen in outstanding outliers such as the Santa Fe Institute today. Artificial Intelligence, if used wisely, could mean *more* human scientists not less and with them more opportunities to explore paths not taken.

The AI we possess currently or are close to having could serve as such a positive tool, but it could also be directed to other much less optimistic ends. AI might eventually completely dominate the discovery process putting it into the hands of large corporations and relegating humans to the most uninteresting parts of research. The discoveries of these AI systems may even someday reach a degree of complexity that no human is able to understand them, their pronouncements merely believed like the divinations at the Oracle of Delphi.

AI could also be used as a tool to reassert elite control over knowledge production. We see moves in this direction most clearly today in authoritarian regimes, but it is a global phenomenon whereby elites are attempting to regain monopolies over information flows and exchange. A plausible future would be one in which AI was used to police knowledge as much as create it. This could be under the orders of the state and justified due to national security concerns but could just as well be done in the name of corporations that wish to assert proprietary claims over human knowledge.

One can also imagine a quite plausible future in which AI is less a tool of science than the main source of an even deeper erosion of its legitimacy. We could see yet further collapse of universally accepted facts, the proliferation of fake studies, fake reviewers or completely made-up research that will give the illusion of plausibility absent deep forensic review. In the style of

Umberto Eco's prescient novel *Foucault's Pendulum*, we might witness the creation of whole pseudosciences out of the minds of machines, the proliferation of an AI dreamt up and enabled occult in some strange way bringing us full circle from the alchemy of Newton.²⁹ These are dark thoughts, but I should end like Francis Bacon, one of the first of the new scientists began, with a utopia.

I can imagine a future with a greatly enhanced role for citizen science facilitated by AI, where the knowledge of humanity is mined not as a form of exploitation, but as a means of universal benefit. One merely needs to extend the widespread passion for birding and amateur astrophotography to imagine more coordinated efforts to peer into realms of nature we have yet to fully explore. Such efforts might serve as a school for an enlightened citizenry allowing them to learn through practice that science is never a body of dead facts but an active methodology for understanding the world via constraints on our prejudices.

Perhaps this will counterbalance our moves towards fantasy. Empiricism has eroded under conditions in which many of us are merely tasked with moving information around. Science and engineering, much like art and in distinction to myth, fiction, and virtual or televisual worlds, faces a reality that "talks back" and refuses to ever be completely bent according to our model of it. We are in deep need of relearning this and not just in science but in politics, law, journalism, and the humanities. Such a citizen science need not be restricted to nations alone but could be a globally crowdsourced exploration and witnessing of the extraordinary world we are blessed to inhabit and the state of its health under our pressures.

The dream of modern science when it was created so many centuries ago was not only that the world was comprehensible, but that the mind of an individual was sufficient to obtain this comprehension. We have long exited the place where our individual intellectual capacities are the equal of the knowledge we have so carefully accumulated, so we needed to place our faith in the knowledge production of collectives in which we played no part. Perhaps the machine intelligence we are creating will be the tool that allows us to fulfill that dream of understanding at the very moment it appeared to be lost not just to individuals but for humanity.