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Principal Challenges Facing Modern Science: A Review of Systemic Strains on the Research Enterprise

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Abstract

Modern science is more productive, more global, and better instrumented than at any point in its history, yet a growing body of meta-scientific work suggests that the *enterprise* of science its institutions, incentives, and social contract is under serious strain. This review synthesizes evidence on eight interlocking challenges: (1) the reproducibility and replication crisis; (2) the fragility of research software, much of it poorly engineered, unmaintained, and abandoned soon after publication; (3) the industrialization of research fraud and a surge in retractions; (4) perverse incentives embedded in scholarly publishing and evaluation; (5) the double-edged role of generative artificial intelligence; (6) signs that scientific progress, despite exponential output, may be becoming less disruptive; (7) funding precarity and the politicization of research, sharply illustrated by events in the United States in 2025; and (8) the erosion and polarization of public trust. These challenges are not independent; hypercompetition and metric-driven evaluation act as a common upstream driver. The review concludes by surveying reform efforts open science, metascience, and the redesign of incentives and argues that the central task of the coming decade is institutional rather than technical.

Keywords: *metascience; reproducibility; research software; software sustainability; research integrity; scholarly publishing; generative AI; science funding; public trust in science*

1. Introduction

The phrase "challenges of modern science" can be read in two ways. In one sense, it refers to the great unsolved *scientific* problems the origin of consciousness, fusion energy, the nature of dark matter, the cure for neurodegenerative disease, the safe development of advanced AI. In another sense, it refers to challenges to the *institution* of science itself: the way research is funded, conducted, evaluated, published, and trusted. This review concerns the second sense. The argument is that the most pressing problems for contemporary research are not, in the first instance, intellectual but structural, and that the health of the scientific enterprise increasingly depends on metascience the scientific study of science itself.

This focus is deliberate. Intellectual frontiers shift constantly and are field-specific, but the systemic pressures described below cut across disciplines, from cell biology to economics, and increasingly determine whether intellectual frontiers can be reached at all. A flawed incentive structure can corrupt any field; a robust one benefits all of them.

2. The Reproducibility and Replication Crisis

The most widely discussed structural problem is the difficulty of reproducing published findings. A finding that cannot be independently reproduced sits uneasily with the idea that replication is a cornerstone of the scientific method. The modern debate is usually traced to a provocative 2005 essay arguing, on statistical grounds, that a large fraction of published claims are likely false (Ioannidis, 2005), and to a series of large-scale empirical efforts in the 2010s. The most cited of these, the Open Science Collaboration's attempt to replicate 100 studies in psychology, reported that only a minority of effects reproduced at their original magnitude (Open Science Collaboration, 2015). A 2016 survey of more than 1,500 researchers found that a majority had failed to reproduce another scientist's experiment, and many had failed to reproduce their own (Baker, 2016).

The causes are now reasonably well understood and largely behavioral rather than malicious: selective reporting of positive results, flexible analytic choices ("p-hacking" and "researcher degrees of freedom"), small and underpowered samples, incomplete reporting of methods, and the chronic non-publication of null results. Computational fields face an additional layer of fragility undocumented code, broken data links, and software environments that cannot be rebuilt.

Two cautions are warranted. First, "crisis" is contested terminology: critics argue that reproducibility rates vary enormously by field, that some non-replication reflects legitimate effect heterogeneity rather than error, and that the discourse has at times outrun the evidence base. A 2023 inquiry by the UK House of Commons Science, Innovation and Technology Committee and the academic responses to it illustrate the difficulty of even defining "reproducibility" precisely enough to set measurable targets. Second, the reproducibility movement has been notably constructive, generating concrete reforms preregistration, registered reports, open data and materials, and larger multi-lab collaborations that are discussed in Section 11.

3. The Research-Software Problem: Code Quality, Maintenance, and Abandonment

A growing share of scientific results now passes through custom software, yet the quality of that software receives far less scrutiny than the quality of the underlying experiment. Because results are only as trustworthy as the code that produces them, software quality is not a peripheral engineering concern but a direct extension of the reproducibility problem discussed in Section 2.

The first difficulty is training. Surveys summarized by Wilson and colleagues found that scientists spend a large fraction of their working time often a third or more building software, while the overwhelming majority are essentially self-taught and have little exposure to basic practices such as version control, testing, code review, and maintainable design (Wilson et al., 2014; Goble, 2014). The gap is widest for students and early-career researchers who write much of this code, frequently while still acquiring both domain expertise and a firm grasp of the relevant algorithms.

The second difficulty is structural neglect after publication. A great deal of research software is written to support a single paper and is effectively abandoned once that paper appears, because professional credit attaches to the novel result rather than to the unglamorous work of maintenance (Goble, 2014). As programming languages, dependencies, operating systems, and data formats drift, unmaintained tools quietly stop working. The decay is measurable: an empirical analysis of tens of thousands of "omics" software resources found that roughly 28% could no longer be reached through the web addresses given in the papers that introduced them, and that more than a quarter could not be installed at all (Mangul et al., 2019). Link rot, undocumented dependencies, and environments that cannot be rebuilt steadily turn yesterday's published tools into inaccessible artifacts.

The third difficulty is a usability gap. The same large analysis found that only about half of the tools tested were "easy to install," and, tellingly, that papers offering a straightforward installation process accumulated significantly more citations suggesting that usability and scientific uptake rise and fall together (Mangul et al., 2019). The picture is not uniformly bleak: a large 2025 survival analysis of more



than 18,000 projects found that scientific open-source software actually tends to outlive matched non-scientific projects (Malviya-Thakur et al., 2025). Constructive responses include structured training (Software and Data Carpentry), the professionalization of the Research Software Engineer role, software citation and persistent identifiers, containerization, and funder mandates that treat maintenance as part of the research lifecycle.

4. The Industrialization of Fraud: Paper Mills and the Retraction Surge

Distinct from honest irreproducibility is deliberate misconduct: fabrication, falsification, and plagiarism. Self-report meta-analyses have long suggested that roughly 2% of scientists admit to having fabricated or falsified data at least once, with substantially higher rates admitting to questionable research practices (Fanelli, 2009). What has changed in the past decade is the *industrialization* of fraud.

"Paper mills" commercial operations that manufacture fraudulent manuscripts and sell authorships have scaled dramatically. Estimates suggest that hundreds of thousands of paper-mill articles may already have entered the literature over two decades, and recent network analyses describe organized rings that bribe journal editors and route manuscripts to compromised gatekeepers. One 2025 analysis estimated that paper-mill output is doubling roughly every 1.5 years, far faster than the roughly 3.5-year doubling time of retractions meaning detection is losing the race (Richardson et al., 2025).

The retraction record reflects this pressure. More than 10,000 papers were retracted in 2023, a then-record figure, with large tranches attributed to compromised peer review, paper mills, undisclosed AI-generated text, and citation manipulation (Van Noorden, 2023). Because retraction lags fraud by years, recorded retractions almost certainly understate the contamination of the literature, including downstream effects on systematic reviews and clinical evidence synthesis. Crucially, integrity and reproducibility share a root cause: an evaluation system that rewards the *quantity* of positive, publishable output.

5. Perverse Incentives and the Dysfunction of Scholarly Publishing

Many of the problems above are symptoms of a deeper pathology in how science is evaluated and disseminated. The "publish-or-perish" culture, intensified by hypercompetition for shrinking pools of permanent positions, ties professional survival to output metrics that are easy to game (Edwards & Roy, 2017). Surrogate measures such as the journal impact factor, the *h*-index, and raw publication counts illustrate Goodhart's law: once a measure becomes a target, it ceases to be a good measure. Formal models have shown how such incentives can drive a kind of cultural natural selection in which the methods that maximize productivity rather than those that maximize truth proliferate ("the natural selection of bad science"; Smaldino & McElreath, 2016).

The publishing system that mediates these incentives is itself strained. Peer review, the traditional quality-control mechanism, depends on unpaid volunteer labor that is increasingly scarce relative to submission volume, leaving reviewers overstretched and the system vulnerable to manipulation (including fabricated reviewer identities). The economics are contested on two fronts: the subscription model locks much publicly funded research behind paywalls; the open-access model that was meant to remedy this has, in its dominant "author-pays" form, shifted costs onto authors through article-processing charges, raising concerns about affordability for under-resourced researchers and about a financial incentive for "mega-journals" to accept more papers. The proliferation of predatory journals which charge fees while providing little or no genuine peer review exploits exactly this seam.

6. Generative AI: Accelerant and Threat



The rapid diffusion of large language models (LLMs) since late 2022 is reshaping research practice faster than norms can adapt, and it cuts in two directions at once.

On the constructive side, AI is a genuine research accelerant: protein-structure prediction, materials discovery, large-scale literature synthesis, code generation, and hypothesis exploration have all benefited. Used responsibly, LLMs can lower drudgery and widen access for example, by helping non-native English speakers prepare manuscripts.

On the destructive side, the same capabilities lower the cost of producing plausible but unreliable text. Documented risks include AI-fabricated articles difficult to distinguish from genuine research, hallucinated citations, contamination of the literature and of peer review by undisclosed machine-generated content, and the amplification of biases present in training data (van Dis et al., 2023). Detection tools remain unreliable, especially against lightly edited or "humanized" output, and journal disclosure policies are heterogeneous, creating regulatory gaps. There is a real danger that AI will supercharge the paper-mill economy while simultaneously eroding the human judgment that peer review is supposed to supply. The emerging consensus is that LLMs should *assist* rather than *replace* human reviewers and authors, and that transparency through disclosure, provenance tracking, and possibly watermarking is essential.

7. Is Science Slowing Down? Output, Overload, and Disruptiveness

A more contested challenge concerns the *productivity* of science. Scientific output grows exponentially millions of papers per year yet several analyses suggest that breakthroughs are not keeping pace. Economic work has argued that research productivity is falling, in the sense that ever more researchers and resources are required to sustain a constant rate of progress ("are ideas getting harder to find?"; Bloom et al., 2020). A widely discussed bibliometric study reported that papers and patents have become, on average, less "disruptive" over six decades, relying more on a narrowing base of prior work (Park et al., 2023). Related work links the sheer size of fields to the entrenchment of established ideas and the slowed rise of new ones (Chu & Evans, 2021).

These findings should be read with care. The disruptiveness metric (the CD index) has drawn methodological criticism, and at least one reanalysis correcting for measurement and citation-practice changes found no decline and possibly an increase in disruptive patents. The underlying phenomena, however, are plausible regardless of the metric debate: the "burden of knowledge" means researchers must learn more before contributing; information overload makes it harder to find and integrate relevant work; specialization fragments fields; and hypercompetition may push researchers toward safe, incremental projects over risky, potentially transformative ones. Whether science is genuinely slowing or merely growing in ways our metrics measure poorly remains open and is itself an important metascientific question.

8. Funding Precarity and the Politicization of Research

Science is expensive, long-horizon, and dependent on stable public investment conditions that sit awkwardly with short electoral and budget cycles. The chronic challenges are familiar: low and stochastic grant success rates that consume researcher time in proposal writing, a bias toward incremental "safe" proposals, and the precarity of early-career researchers on short contracts.

These chronic strains were overshadowed in 2025 by an acute shock in the United States, historically the world's largest research funder. The administration moved to cut and freeze billions of dollars in grants, terminate thousands of awards, reduce headcount at major agencies, and cap universities' reimbursement of indirect (overhead) costs at 15% a move challenged in court. Proposed fiscal-year budgets sought reductions on the order of 50%+ for the National Science Foundation and large cuts at the National Institutes of Health and NASA's science programs, though Congress rejected the steepest proposals and total agency outlays for FY2025 ended closer to prior-year levels even as the number of new grants fell. Beyond the budget arithmetic, the episode demonstrated how exposed science is to



political volatility, and raised concerns about a "brain drain" of researchers and a relative shift of scientific capacity toward jurisdictions that signaled increased investment. The deeper challenge is structural dependence on a small number of national funders whose priorities can change abruptly.

9. Public Trust, Communication, and the Post-Truth Environment

Science ultimately depends on a social license: public trust underwrites public funding and the uptake of scientific advice. The evidence here is genuinely mixed and should not be flattened into a simple "collapse of trust" narrative. A large 68-country survey published in early 2025 found that public trust in scientists remains, on balance, fairly high worldwide (Cologna et al., 2025), and US polling through 2025–2026 continued to show majorities expressing trust in scientists, who often rank among the more trusted professions.

The clearer signal is *polarization* rather than uniform decline. Trust in science has diverged sharply along political and educational lines, particularly in the United States, where the gap between left- and right-leaning respondents has widened markedly since roughly 2018, accelerated by the COVID-19 pandemic. The communication environment compounds the problem: social media accelerates the spread of misinformation; the legitimate provisionality of science its tendency to update conclusions is easily reframed as failure; and partisan or sensationalized framing pushes audiences to interpret evidence through a tribal lens. Repairing this requires not louder assertion of authority but better communication of uncertainty, transparency about limitations, and engagement that treats the public as a partner rather than a passive recipient.

10. Inequities in the Global Research System

A cross-cutting challenge is the uneven distribution of scientific capacity. Research funding, elite journals, prestigious institutions, and citation flows remain concentrated in a handful of wealthy countries. English functions as a near-universal scientific language, advantaging native speakers and disadvantaging others in writing, reviewing, and visibility. Author-pays open-access charges can price out researchers from lower-income settings, while the same economic pressures that fuel paper mills are most acute where national policies tie career advancement rigidly to publication counts.

The result is a system in which much of the world's talent is underutilized and in which research agendas may neglect the problems of the majority of the global population. Addressing this is both an equity imperative and a matter of scientific efficiency: a broader, fairer base of participation expands the pool of ideas.

11. Responses and Pathways Forward

The encouraging counterpoint to this catalogue is that none of these problems has gone unanswered, and several reform movements are maturing.

Open science has moved from advocacy to infrastructure: preregistration and registered reports (which peer-review the question and method **before** results are known) blunt publication bias and p-hacking; open data and open materials, organized around the FAIR principles findable, accessible, interoperable, reusable (Wilkinson et al., 2016) enable verification and reuse; and preprints accelerate and democratize dissemination. National investments, such as the Netherlands' substantial annual commitment to open science and replication, are beginning to normalize these practices.

Metascience has emerged as a discipline in its own right, studying replication, bias, and incentives empirically and feeding the results back into policy. *Reform of evaluation* is the linchpin: initiatives such as DORA (the San Francisco Declaration on Research Assessment) and the responsible-metrics movement push institutions away from journal-based proxies toward assessing the actual content and integrity of work, and toward rewarding replication, data sharing, and negative results. *Integrity infrastructure* image-forensics and paper-mill-detection tools, post-publication peer review (e.g.,



PubPeer), retraction databases, and cross-publisher alliances such as the COPE/STM "United2Act" effort is being built, even if it currently lags the threat.

No single fix suffices, and some reforms carry their own risks (metrics can be gamed; AI detection can stigmatize legitimate use). The common thread is that durable solutions are *institutional*: they change what behavior the system rewards.

12. Conclusion

The principal challenges facing modern science are, at root, problems of incentives and institutions rather than of intellect or instrumentation. Hypercompetition and metric-driven evaluation propagate downstream into irreproducibility, fraud, and a publishing system under strain; generative AI threatens to accelerate these failures even as it accelerates discovery; questions about slowing disruptiveness suggest the system may be allocating effort poorly; and external shocks to funding and trust expose how dependent science is on a fragile social and political contract.

The reassuring news is that the scientific community has turned its own methods on itself: the rise of metascience, open science, and evaluation reform represents a credible, if incomplete, response. The defining task of the next decade is therefore less to invent new tools than to redesign the institutions and incentives within which the tools are used so that the system selects, reliably, for getting things right.

Data & Code Availability

This article is a narrative review and does not contain original datasets or analysis code. All cited sources are referenced in the bibliography below.

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Ethics

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Competing Interests

The author declares no competing interests.

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