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Title

The art of scientific performance

Authors

Ralf Seppelt[1,2,3,*], Michael Beckmann[1], Tomáš Václavík[1,4], Martin Volk[1,2]

Affiliations

[1] UFZ – Helmholtz Centre for Environmental Research, Leipzig. Department Computational Landscape Ecology, Permoserstraße 15, 04318 Leipzig, Germany

[2] Institute of Geoscience & Geography, Martin-Luther-University Halle-Wittenberg, 06099 Halle (Saale), Germany

[3] iDiv – German Centre for Integrative Biodiversity Research, 04103 Leipzig, Germany

[4] Palacký University Olomouc, Faculty of Science, Department of Ecology and Environmental Sciences, 78371 Olomouc, Czech Republic

[*] Corresponding author: ralf.seppelt@ufz.de

Abstract

Humanity builds upon scientific findings, but the credibility of science might be at risk in a "post-factual" era of advanced information technologies. Here we propose a systemic change for science, to turn away from a growth paradigm and to refocus on quality, characterized by curiosity, surprise, discovery, and societal relevance.

Text

Modern Science: A 350-year-old Success Story

Modern science is characterized by a well-established system of self-control by peers. It has not substantially changed since the first publication in the Philosophical Transactions of the Royal Society of London in 1665. The launch of this first modern outlet for scientific achievements was only one event in a long-lasting success story. Throughout its entire history, humanity has built upon scientific findings. Being able to understand functional principles of the environment made it possible for humankind to know when and where to plant and harvest, how to best fertilize and irrigate, fight pests, trade efficiently, build houses and dams, optimize transport and stay or get healthy. While there are multiple examples of scientific findings that had negative consequences (e.g. industrial emissions, weapons) or are questionable within ethical standards (e.g. genetic modifications), today – more than ever – good science is part of what is needed to solve the most pressing environmental challenges such as coping with climate change, maintaining the functioning of ecosystems, halting biodiversity loss while feeding 10 billion people and improving the well-being for diverse societies. Despite such potential, science has been lately criticized for lacking societal relevance. The most recent proclamations of the "post-factual era" indicate that humanity might be turning away from its most trusted source of knowledge.

We here provide a short history of science and synthesize the various facets of the recent "scientific crisis". From this analysis we infer that systemic changes are needed in academia. We propose several guidelines for everybody working in academia which may help re-evaluate our understanding of the "quality of science" but also amplify academia's role in society.

Causes and consequences: A great acceleration, databases and metrics

The 350yr-old systematic approach of science to self-assess its outputs in the form of peer review is currently undergoing a transformation due to globalization and advances in information technologies. Short research summaries, called papers, have replaced books because of their much faster publication process. Online publications and web-based marketing have resulted in negligible production costs and stimulated a substantial growth in the number of journals. Publishing has changed from a philanthropic idea to a business model that rests on the shoulders of tax-payers, as all three aspects involved in creating a scientific publication (research, paper writing and reviewing) are done largely by tax-funded scientists. All this has led to a "Great Acceleration in Science", Box 1.

At the same time, global publication networks provide new options for collaboration by offering access to almost everything that is published. Open science and open access was kick-started together with pleas for more transparency and openness [1], which has given researchers the opportunity to disseminate scientific knowledge in a global village. Scientific databases have led to the development of indicators, which, allegedly, measure scientific performance. Most prominently the h-index was proposed to measure the productivity and impact of a scientist, while the impact factor is supposed to measure the outreach and impact of a journal [2]. However, a major disconnect evolved between the original purpose and the way researchers and administrators apply such metrics today [2, 3]. Single indicators are used for too many purposes: evaluating individuals in academia, promoting faculty members and deciding on funding schemes. New indicators have been proposed, suggesting that major innovations can occur throughout a scientist's lifetime [4, 5]. However, even new and highly comprehensive indicators cannot resolve the issue, as all metrics refer primarily to some measure of quantity. Goodheart's law in economics – "*Any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes.*" – unequivocally leads to "*the natural selection of bad science*" [6].

The scientific community seems to have decided for a simple growth paradigm on all levels, from institutions and universities down to individual scientists. Scientists, publishers and institutions are measured by the sheer amount of output and citations. Writing many papers and being active on social media is now perceived as being more crucial for career advancement than adhering to quality. For a scientist, time not spent on publications will simply lower performance if measured by a simple output metric of papers and citations. A hundred years after its first use in the modern sense, the phrase "*publish or perish*" has changed to "*impact or perish*" [3]. Sadly, it seems that the original meaning of the old Jesuits' proverb "*publish lest the knowledge should perish with you*" has been forgotten.

Transitioning back from quantity to quality

Science is inherently capable of self-reflection and self-critique. The change that is needed is systemic but achievable: overcome our addiction to quantity, re-learn and trust in quality and minimize our distance to society. However, optimizing the work in an institute might be prone to failure if this is not orchestrated with changes in education, promotion and incentive systems. We suggest a handful of easy-to-adopt guidelines for authors, editors and reviewers, but also science administrators to overcome the erroneous practice of measuring quality with quantity-based indicators, Box 2.

To authors, editors and reviewers: Drastically change assessments of individual performance, starting with your self-perception. Limit yourself to the most exciting, most relevant publication projects with respect to what you want to lead. Creativity and innovations originate from free time, so stop putting too much pressure on yourself. Don't get distracted by too many co-authorships. Aim at highest standards for transparency and reproducibility and make results, data and methods openly accessible, transparent and long-lasting [1]. Correspondingly, editors and publishers should allow the publication of repetitions as well as failed experiments. Studies on the reproducibility of critical findings should be fostered, e.g. [9]. Reviews should be made public together with the paper to guarantee the quality of the review. This should be accompanied by adopting open science principles, fostering open data exchange and finding a fair payment system, which does not exclude research from financially less equipped institutions. Similarly, aim at highest standards for publishing your work: rather than focussing on a journal's impact factor, select publication outlets with the best-suited open access standard, low publication cost, fast, constructive and perhaps open review, Box 2, c.f. Faculty of 1000 (F1000).

Evaluation committees and science administrators need to change their perception: Don't judge applications by the simple number of publications but focus on which are the most exciting and achievable goals. Don't use quantitative indicators in synopses and avoid sorting a list of applications simply by the number of papers, h-indices, or grants acquired. Let members of the committee openly select their own indicators of quality or performance and reserve sufficient time to discuss and agree on a suite of suitable quality indicators. The productivity of applicants should be considered equal if a maximum of about two papers as lead author per year is achieved. More papers mostly indicate good collaboration skills. Finally, a focus on sheer numbers of performance can discriminate against women in science [7]. Clarivate Analytics, Scopus and Google Scholar will continue to be with us but we need to revisit the complex incentive system that science has developed: Use these systems correctly in synthesis reports as well as for measuring performance [4]. If at all, indicator systems such as Eigenfactor® should be used more widely as they are less prone to being used for cheating [5]. After decisions are made, be patient: Creativity can happen at each point in time throughout a scientist's lifetime [4], and research is supported best if money spent provides time for being creative rather than demanding more output.

Reducing distance to society

While the previous recommendations address academia's internal organization, the scientific community also needs to be aware of its role within society. Science will likely continue to be funded by donors and taxpayers, which entails certain agendas but this does not necessarily affect academic freedom. Creativity, innovation and consequently economic growth were and still are the general arguments that support science and research. However, societies do request evidence-based solutions to pressing problems, which range from placed-based environmental management problems to global change. Consequently, scientists must be able to collaborate with stakeholders or be part of a science-policy process and be ready to act as "Honest Brokers" without compromising the quality of scientific findings. In global change research this has led to the implementation of science-policy advisory bodies of the United Nations: The Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Contributing to this trans- and interdisciplinary process of knowledge synthesis and dissemination is demanding even for senior scientists and often poorly supported by academic institutions. Funders and science administrators need to acknowledge that these emerging tasks require additional time and a broad range of competences. In order to get promoted, however, scientists usually develop profiles through specialization rather than evolving into generalists – as scientists did in the times of Humboldt or Newton. This inherent demand to be unique counteracts demands for integrative research that is relevant for society. While research topics of modern science are highly specialized, this should not keep a scientist from aiming at explaining the discoveries and societal relevance of his or her topic to a broader audience. Scientists need to be prepared to explain the significance and merits of their own research to a wider public, to a layman, your grandma, Box 2.

A joint effort: Enabling academia to re-evaluate quality

A plea to foster quality in science opens a can of worms. Quality is multifaceted, an aspect that science managers might not find helpful. There is no such thing as a generic measure of scientific ingenuity, repeated but futile attempts to measure it notwithstanding [4]. Like the protagonist of the 1974 novel "Zen and the Art of Motorcycle Maintenance: An Inquiry into Values" by Robert Pirsig, academia needs to re-evaluate what is understood by the quality of science and acknowledge that the current scientific system hampers the assessment of quality. We need to recognize that our understanding of quality might evolve even throughout one scientist's lifetime. Its constituting elements, however, remain the same: curiosity, surprise, discovery but also societal relevance for problem solving.

The changes needed in our current science system should affect scientists of all career stages, funders, publishers, reviewers and science administrators and must be orchestrated amongst these groups. This joint effort can rely on a simple basic principle: Anybody who works in science does this with a tremendous intrinsic motivation, curiosity and voluntary hard work. But at the end of the day, everybody is confronted with some very basic requirements: to get a grant, get promoted, get tenure, earn one's livelihood and possibly support a family. No matter what the specific next steps are, we need to acknowledge the fact that the system is made up of human beings. To save modern science from being a candidate for the UNESCO list of intangible cultural heritage, we all need to recognize that it is time to stop promoting quantity and instead take our time to assess quality.

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Box 1: "The Great Acceleration in Science" and outstanding examples of bad practices.

In 2015 the top five publishers held 40% of all journals (Fig. 1, 2b), continuously increasing profits (Fig. 2c) and determining licence models: A "Publishers Oligopoly" [14, 15]. This was accompanied by an exponential increase in the number of journals as well as published papers (Fig. 3), exceeding 50 million published papers in 2008 given the extrapolation in [8] (Fig. 3b), while the number of papers read as reported by scholars was linearly increasing only (Fig. 3c), which could simply be due to the reduction of the average paper size.

Given the vast quantity of papers, it can be reasonably expected that not all publications followed the principles of good scientific practice; a non-comprehensive list of examples include:

- Lack off "reproducibility": Only 36% of controlled experiments in psychology were reproducible and confirmed earlier findings [9]. Less prominent was the failure to reproduce findings from a simple Excel sheet analysis which resulted in questioning the foundation of European fiscal "austerity" politics [10].
- Publishing "fake-papers": Sokal-style hoax articles receive positive reviews in credible journals, e.g. [11].
- Fostering "cross citation": Editors promote citations between journals to boost impact factors, e.g. [12].
- Misuse of metrics: The obsession with metrics motivate trickery such as "h-index farming", or even "misconduct" [3].
- Emergence of "Predatory journals": Open-access publishing models are increasingly used to generate money and offer easy publishing without quality assurance, reported on the "black-list" by J. Beall till 2017 [13].

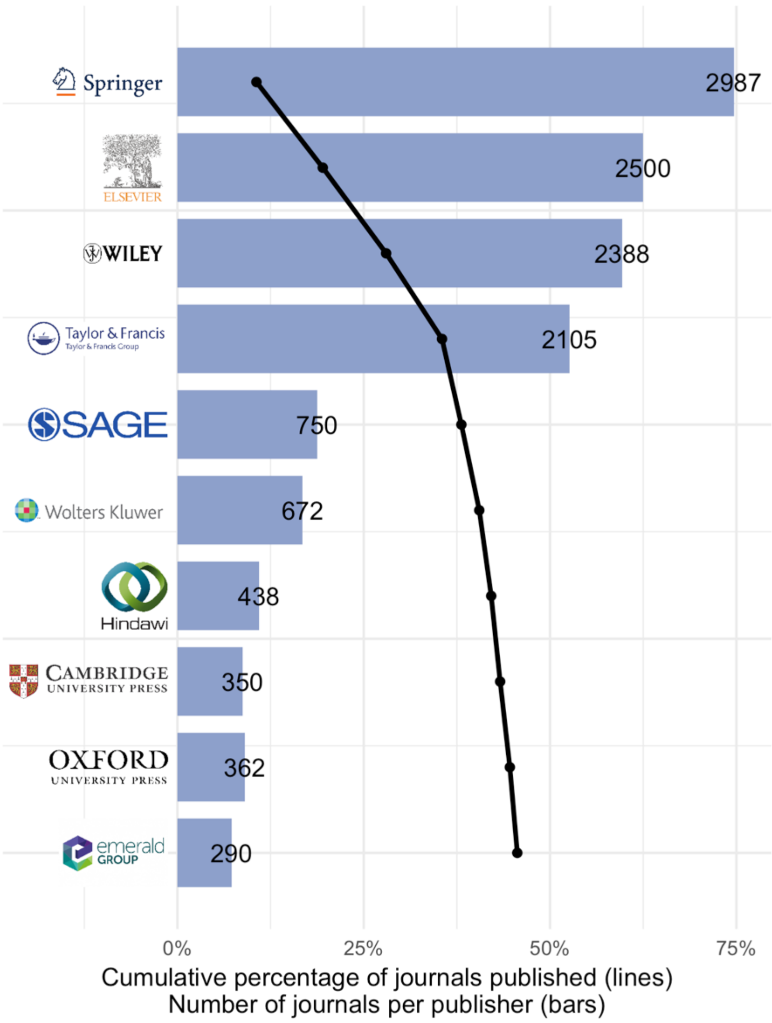

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Fig 1: Numbers of journals published by each of the ten largest publishers and their cumulative percentage of the total number of published journals, data from 2015 [14].

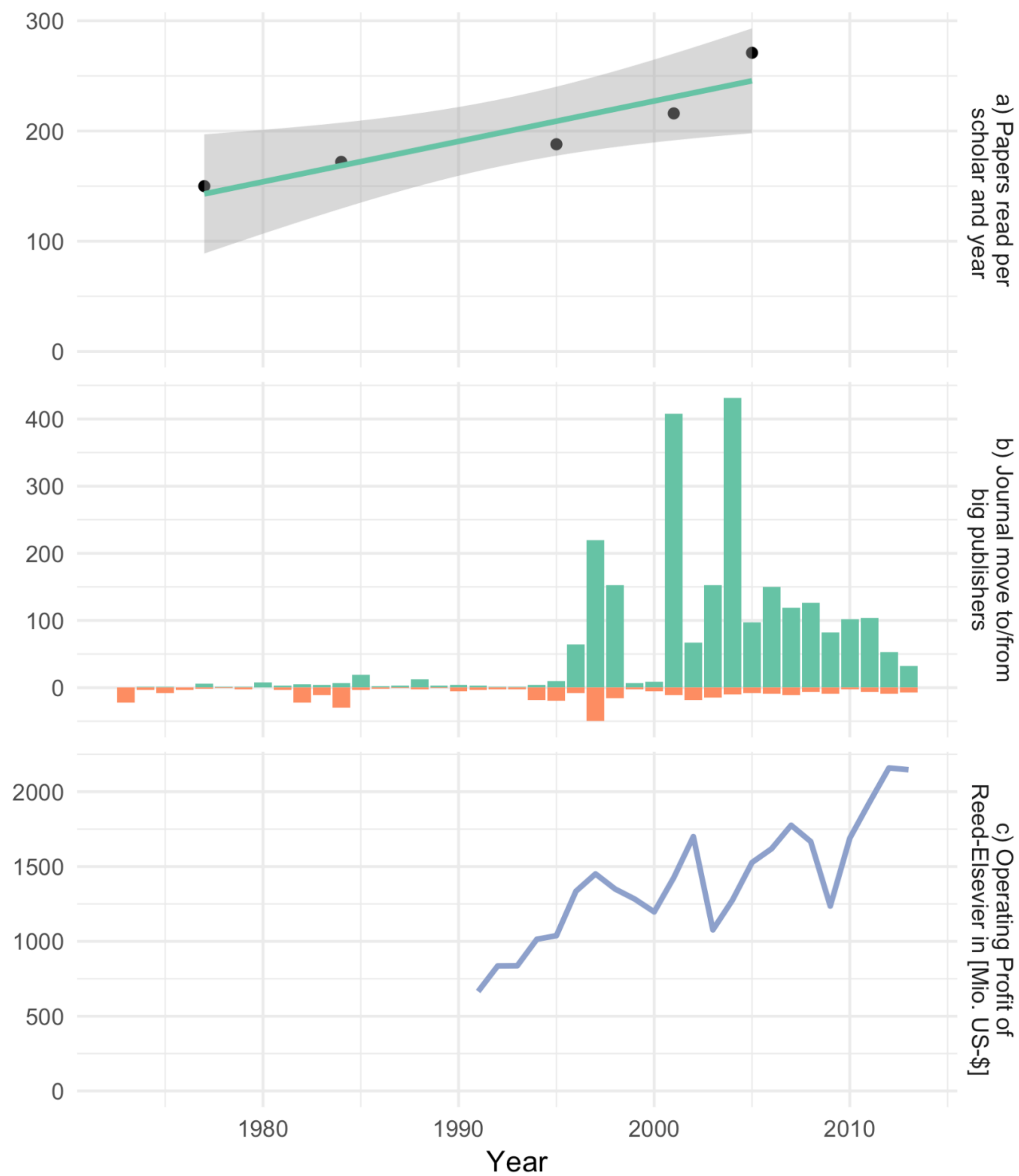
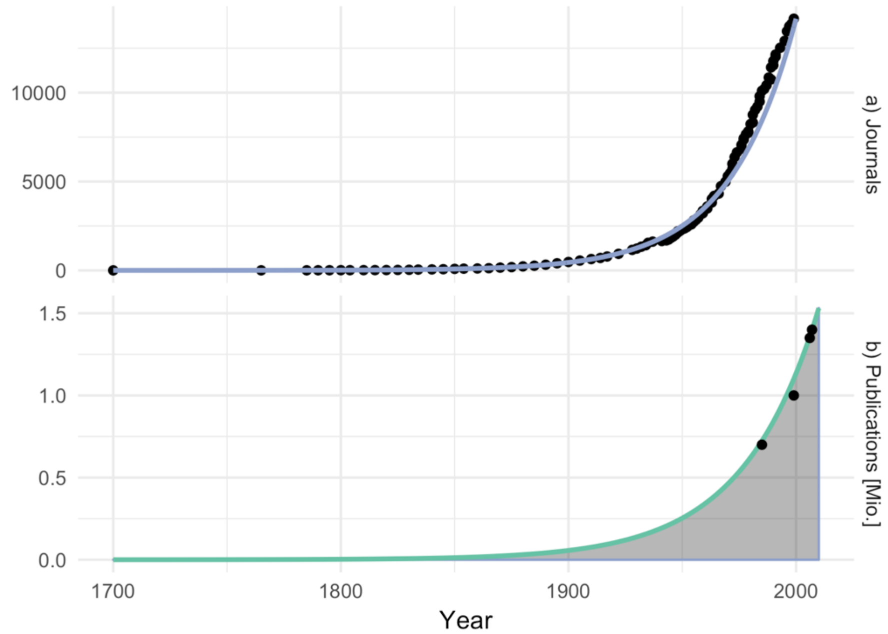


Fig 2: Recent trends of the "Great Acceleration of Science": While the number of published papers increased exponentially (Fig 3), the number of papers read pear years as reported by scholars increased linearly (a). A major portion of journals moved to large publishers (b, green bars), while only a few moved to smaller publishers (orange). This increased publishers profits: operating profit of Reed-Elsevier as example (c), average profit margin of Reed-Elsevier in this period was 20% (range from 13% to 26%), data sources [14, 15].



250 **Fig 3**: Development of peer reviewed journals (a) and extrapolated number of published papers (b) since 1700, estimating approximately 50 Mio. published papers till 2008 (shaded area), data and regression functions from [8, 15].

Box 2: Easy-to-adopt guidelines for authors, reviewers and science administrators to transition back from quantity to quality and support a systemic change in science.

To authors, editors and reviewers

(1) Stop putting too much pressure on you. Creativity originates from free time.
(2) Limit yourself to the two most exciting, most relevant papers with respect to what you lead.
(3) Make materials, data, analysis scripts, and results open access. To avoid confirmation bias, preregister your study and hypotheses before data collection.
(4) Acknowledge reviewers, support quality check of reviews, publish reviews and responses.
(5) Select a journal by the licence and review model of a publisher of journal rather than the impact factor.
(6) Make (your view on) scientific quality an obligatory element in education.
(7) Be prepared to explain discoveries, significance and merits of your research to a wider public.

To evaluation committees and science administrators

(8) Reserve sufficient time to discuss and agree on a suite of suitable indicators that capture quality for the decisions at hand.
(9) Don’t use quantitative indicators in synopses. Let members of evaluation committees openly select appropriate performance indicators.
(10) Don’t award on number of papers or even the impacts factor of the journal they appear in.
(11) Treat candidates as equal if they achieved the doable, see (2).
(12) After decisions are made, be patient: Creativity can happen at each point in time throughout a scientist’s lifetime.
(13) Research is supported best if money invested in research provides free time, rather than requesting to increase output, see (1).