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The art of validating science: four centuries of peer review

El arte de validar la ciencia: cuatro siglos de la revisión por pares

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Denis de Sallo, the first editor of the world's first scientific journal, *Journal des Sçavans*, wrote the following warning in the inaugural issue, published on January 5, 1665, in Paris: *"Our aim is to report the ideas of others without guaranteeing them"*[1]. This statement remains relevant in today's scientific journals, as we have spent nearly four centuries *trying* to ensure the quality of published information-an endeavor first formalized by Henry Oldenburg, the founding editor of *Philosophical Transactions* and widely regarded as the father of peer review [2]. Oldenburg embodied all the qualities of a good editor: he published 136 issues of the emerging journal while also experiencing the unintended consequences of his invention. One of the most famous episodes was his conflict with Isaac Newton, who was so uncomfortable with the peer review process that he never published a single research article in the journal, choosing instead to communicate his ideas and findings through books [3].

Since its inception, the publication of scientific articles has required editors to make three key decisions: to reject manuscripts of low quality, to accept those that are sound and consistent with the methods and results of the time, or to seek the opinion of an expert when a manuscript presents an innovative or potentially controversial idea that challenges the scientific status quo. The peer reviewer thus plays a key, albeit limited, role: assisting the editor in deciding whether a manuscript should be published and, if deemed worthy of publication, providing observations that add value to an already completed piece of work.

That expert also had to fulfill another essential requirement: being responsible with the document sent for review, as no additional copies existed. This early problem marked the beginning of several limitations that technological advances later helped to overcome. The most significant changes in the peer review process have been linked to inventions that facilitated its implementation. Blind peer review, adopted by the *British Medical Journal* in 1893 [4], became possible thanks to the invention of the typewriter and carbon paper; its widespread adoption by most journals depended on the introduction of the photocopier by Xerox, while the use of external reviewers only became feasible with the advent of the internet and email, which allowed the process to become faster and more global. In this new millennium, editorial content management systems have improved editorial efficiency, but have also increased the pressure on peer reviewers. Now, we await the contributions that artificial intelligence might bring to the intellectual work of peer review (Figure 1) [5].

Paradoxically, the same technology that enabled peer review has also increased the demand for it, and to this day, the need for reviewers exceeds the available supply. The consequences remain similar to those at the dawn of scientific journals: delays in publication timelines, outcomes that do not meet expectations, and concerns about fairness. Complaints about peer review have changed little since the early 20th century: *"Reviewers are overworked. The problem of bias is unsolvable. The arbitration system has failed and become an obstacle to scientific progress. Traditional peer review*

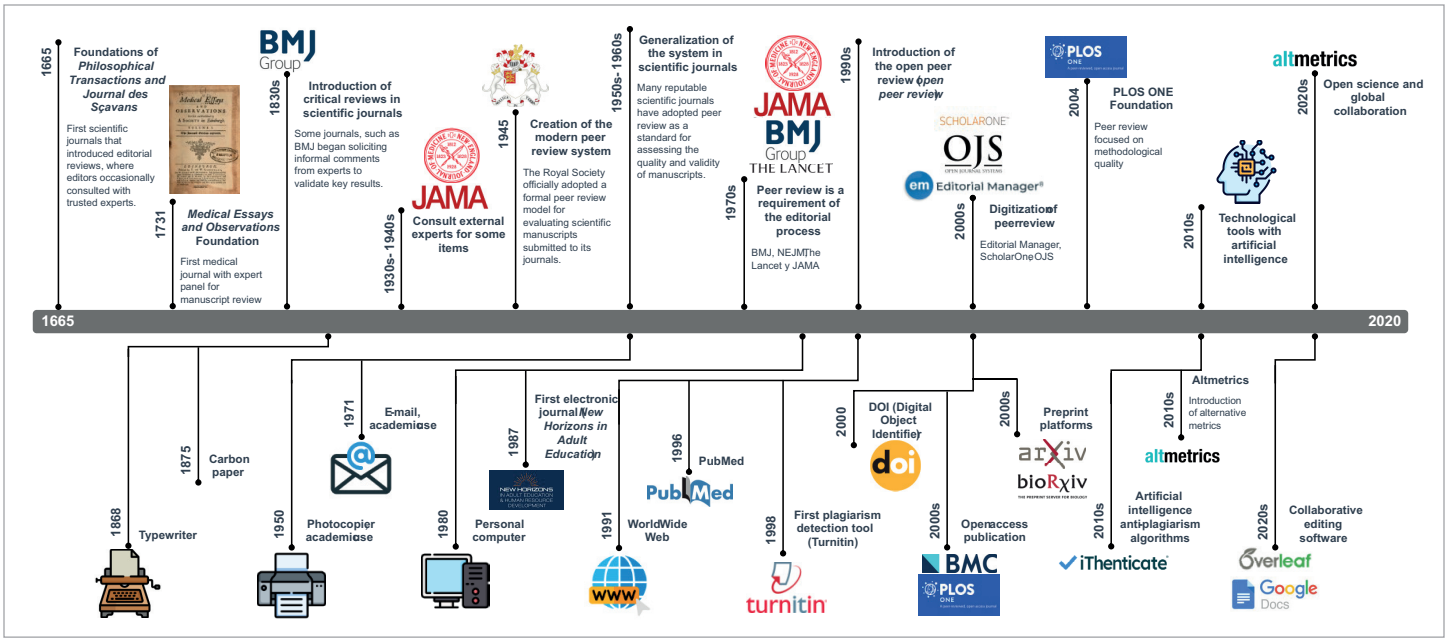

Figure 1. Evolution of Peer Review and Editorial Technologies in Scientific Journals (1665–2020s)

is an outdated method that may have once benefited science but is now obsolete"[6]. These concerns mirror those of *BMJ* editor Richard Smith (1991-2004) in the 21st century: *"(Peer review) ... is slow, expensive, poor at detecting errors, largely a lottery, prone to bias and abuse, unable to protect against fraud, and anti-innovative as it tends to reject truly original research"*[7].

Despite such harsh criticisms, the system has not disappeared-partly because a large majority of academics still trust the process, and because there is no well-supported alternative that effectively replaces peer review. Nonetheless, alternative models have been proposed, including open review, post-publication review, and the publication of peer reviewers' comments alongside the article [5].

At present, the most promising initiatives are those that seek not to solve the problems of peer review, but to better understand them. Peer review is a construct of the editorial process; however, the intellectual process it entails, as well as the expectations placed upon it, vary significantly between reviewers. The direction that the editor wishes to give to the identity of the journal also plays a role.

Recently, Waltman and colleagues proposed a classification of "schools of thought" on peer review in scientific publishing, with the aim of understanding the various approaches and tensions that shape evaluation practices (Table 1) [8]. This framework is particularly useful for editors, as it helps define clearer guidelines for authors and reviewers aligned with each journal's editorial objectives. A notable example is *PLOS ONE*, which has declared its focus on prioritizing data quality and reproducibility over scientific novelty. This stance offers a clearer approach to the "rules of the game" for both authors and readers of the journal [9,10].

There may be a distorted expectation about peer review, as the very name of the process suggests a thorough examination-one capable of verifying data and references to prevent the publication of erroneous information that could harm both science and society. However, if the process were truly infallible, we would not be facing a concerning rise in the number of scientific article retractions [11]. Even worse, many low-quality studies that have negatively impacted the credibility of science and public health have not been retracted. A shameful example is Study 329 [12,13].

In response to these issues, technological advances in artificial intelligence have been developed to assist peer reviewers [14]. The use of plagiarism detection software has become

Table1. Schools of thought on peer review in scientific publishing [8]

School of Thought	Main Focus	Key Objectives	Proposed Improvements
Quality and Reproducibility	Ensuring the accuracy and replicability of scientific results.	Improve methodological quality and transparency in data presentation.	Implement rigorous standards, promote study preregistration, and encourage publication of data and protocols.
Democracy and Transparency	Fostering openness and participation in the peer review process.	Increase transparency in evaluations and broaden the diversity of voices in peer review.	Publish review reports, reveal reviewer identities, and allow public comments.
Equity and Inclusion	Addressing bias and promoting diversity in peer review.	Ensure equitable representation and remove barriers for underrepresented groups.	Enforce inclusive policies, train reviewers in unconscious bias, and monitor diversity in review processes.
Efficiency and Incentives	Optimizing the review process to make it faster and more rewarding.	Reduce delays in publication and provide incentives for reviewers.	Use technological tools to streamline review, offer formal recognition, and introduce reviewer rewards.

an editorial standard, and tools for detecting improper use of AI in manuscripts and image manipulation are rapidly advancing. Additionally, algorithms are being implemented to screen for correct statistical analysis and to review data in tables. Medical journals have a further advantage: they have developed reporting guidelines to improve the replicability and reproducibility of research, compiled in the EQUATOR Network portal [15]. These guidelines can be integrated with AI systems to verify editorial requirements and generate recommendations on the structure and content of manuscripts.

Nevertheless, peer reviewers will remain the main intellectual asset of scientific publishing. There is a longstanding debt to them: their dedication, the anonymity of their work, and the fact that it is unpaid stand in stark contrast to the costs that authors or readers must bear to access journals. Twenty years ago, the professionalization of editorial work was promoted; today, it is essential to establish formal training schools for peer reviewers and to dignify this role, which sustains journals and science as we understand its validation.

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