What Is the Value of Peer Review – Some Sociotechnical Considerations

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ABSTRACT

Scientific and technical knowledge of the world grows through individual processes of speculation, making and documenting knowledge claims, the social processes of circulating and testing them, and the cyclic iteration of these processes to incrementally build on what is already known. Formal publication of claims in journals has been critical to circulating and critiquing new knowledge claims.

Editorial peer review supposedly justifies the costs of the publishing activities surrounding it. Yet publishing costs, largely paid by libraries, have become unsustainable. Also, the costs discourage many from publishing and limit access of others to what is published.

Today's editorial peer review results from the exponential growth and specialization of the sciences in the second half of the 20th Century, but offers little genuine epistemic value. It may actually thwart the advancement of innovative and revolutionary research.

Following Popperian evolutionary epistemology, we consider the social and epistemological dynamics of editorial peer review. We also note that that the ever increasing sophistication of digital technologies extending our cognitive capacities provides a pathway to very substantially reduce the cost of publishing whilst at the same time increasing the transparency and value of genuine peer review.

Keywords: Organization Theory, Karl Popper, Evolutionary Epistemology, Internet Technology, Publishing

INTRODUCTION: WHAT FORMAL PUBLISHING IS SUPPOSED TO ACHIEVE

In the last two decades, as electronic formats and media have increasingly replaced paper, the processes for formalizing knowledge have been undergoing the greatest socio-technological revolution since the invention of the printing press and the scientific journal [14] [17] [33] [78] [12]. This revolution is fundamentally changing the publishing process itself in ways that we cannot yet foresee [11] [46]. We believe that these changes will especially impact editorial peer review.

The first formal scientific journals, the Journal des Sçavans and the Proceedings of the Royal Society (London) were established in 1665 [17]. According to Fjällbrant, publishing in such formal journals offered a number of advantages to authors and the scientific community:

1. information can be spread to a widely scattered group of readers;
2. detailed information, such as descriptions of methods, tables, diagrams, results etc can easily be given;
3. printed documents contain information which can be critically examined and verified;
4. the documents can easily be referred to as and when required;
5. published documents provide a means for establishing "priority" of academic work, and thereby contribute to establishing academic merit for the author(s) [17].

Many scientists recognize the need to have their work "evaluated and validated" by their peers before incorporating it into the body of scientific knowledge as a foundation for further knowledge building. Through most of the history of scientific publishing, such evaluation was primarily considered to be a post-publication process. Because until comparatively recently few journals preserved archives of their editorial processes, the historical development of the process is murky. Much of what is known of the history was surveyed in the First International Congress on Editorial Peer Review in Biomedical Publication held in 1989 [65]. Most of what we have to say here about present processes was already apparent from that conference.

Peer review was first implemented in 1752 by the Royal Society of Edinburgh [51] [66] who used a select group of members to make recommendations to the editor about the quality of submitted articles. However, peer review remained sporadic through the mid 20th Century [6] [66] [7]. Most editors knew their fields, and had to work hard to find enough even barely publishable papers to fill their journals [6]. What editorial support was provided to authors via editorial boards or peers apparently was focused on finding articles and improving the quality of expression and presentation. At least through the Second World War, if a scientist had a story to tell it was comparatively easy to find a publisher who would help present the manuscript. According to the editors and publishers of early journals [51] [6] [66], the act of publishing did not imply that the claims to knowledge as published carried any stamp of approval that they were certified "safe to use" for application or for building further knowledge.

After the War, the number of increasingly narrowly specialized scientists began to grow exponentially; while the number of research journals numbers grew more slowly than the numbers papers submitted and scientists writing them. Editors also became more specialized, and les able to cover all disciplines their journals covered. Peer review was increasingly used by editors to help choose the "best" papers and reject the worst, and thus improve the quality of the product in an increasingly competitive publishing environment. Competition by journals for best papers provided readers with a way to prioritize their reading to the "best" journals [7]. In turn, academic and research administrators considering scientists for promotion or grants, but who lacked qualifications to assess the authors' work directly, increasingly determined authors' "worthiness" by the number of papers published.

Consequently, rather than focusing primarily on research and originality, authors faced increasing pressure to maximize the number of papers published. As more people submitted ever more papers, rejection rates rose to where a popular journal might have to review 10 papers for every one accepted. The journal Science now rejects around 92% of original research papers submitted [71], and other top journals probably have similar rejection rates [54]. Besides contributing to the journals' publishing costs, the long cycle of write – submit – review – reject/revise – resubmit… takes months or years between completing a paper and its appearance in the formal literature. Thus, many authors focus on writing short, "safe", and readily acceptable papers; and less on genuinely original research that crosses boundaries and establishes new paradigms [52] [53]. Most journals are narrowly specialized, as are most reviewers. This creates more difficulties for publishing genuinely innovative, cross disciplinary or paradigm shifting work.

In our own personal experiences with submissions, the dynamics of the existing review process makes it difficult to find acceptance for new ideas [26] [30] [35] [32]. For example, it took 37 years to for an appropriate journal to recognize and ask Hall to publish a retrospective review on the impact of his unpublished PhD work [27] [28] [34].

Because so much effort is expended on peer review, it has become deified as the gold standard for science, with the dangerous assumption by many that if an article is published in a peer-reviewed journal the content must be true [47].

The vicious socio-economic cycle involving the ever increasing costs to libraries for journal subscriptions noted in 1990 [65] continues to get worse. Editorial peer review became an increasingly important component of ranking and validating submitted papers prior to publication. For journals – especially those conglomerated by commercial publishers – the burdens of reviewing ever increasing proportion of papers that have to be rejected increases costs, and thus subscription prices. By 2000, subscription prices were already dire for research libraries [59] [74] [49] [50]. Today costs are financially untenable even for the largest and most powerful research universities, as exemplified by the recent standoff between Nature Publishing Group (NPG) and the University of California. The University is threatening to cancel many of its subscriptions and to advise its scientists to boycott NPG publications. [72] [58] [15].

Also, as indicated by high profile scandals (which happened even in the era before 1990 [47] [8] [22] [18]), editorial peer review does not detect fraud, error, or plagiarism prompted by pressures on researchers to publish maximally or perish [42] [76] [41] [67] [4]. Consequently, despite the common belief that editorial peer review certifies published claims to knowledge as safe to use, in some cases it spectacularly fails to do this. Nor is the process necessarily fair to those who depend on the publishing and ranking of their papers for academic and professional advancement [54] [1].

Finally, to publish in this paper-based framework, authors often have no option but to surrender copyright on their intellectual work to the publishers, who then effectively control who is allowed to read the work, when, where and at what cost. For example, Hall chose to self-publish an important early paper [30] when the conference publisher required formal permission even for him to reuse his own graphics in his further work. However, if publishers are to stay in business, they have no option but to treat the works in their publications as merchantable commodities. This limits access to that work only to those who can afford sometimes astronomical subscription costs or who have access to holdings and subscriptions of major research libraries not available to academics, professionals and students not associated with premier institutions.

Other than helping editors select content and improve its presentation, does editorial peer review ensure that published knowledge claims are reliable and "safe to use" as a foundation for building further knowledge? We think Bornmann et al's meta-analysis says it all:

> We conducted a quantitative content analysis of 46 research studies that examined editors' and referees' criteria for the assessment of manuscripts and their grounds for accepting or rejecting manuscripts. The total of 572 criteria and reasons from the 46 studies could be assigned to nine main areas… None of the criteria or reasons that were assigned to the nine main areas refers to or is related to possible falsification or fabrication of data. [4]: p. 415.

However, despite all these problems, researchers and their employers are still wedded to the idea of the peer-reviewed journal. Is there any value in this cumbersome, costly, time consuming and fallible process?

THE EPISTEMOLOGY OF KNOWLEDGE CREATION

Following Karl Popper's evolutionary epistemology [60] [60] [62], as informed by Thomas Kuhn's ideas on social aspects of the growth of scientific knowledge [52] [53], scientific knowledge is built over time through fallible cyclical processes beginning with speculation based on shared knowledge, and progressing through trial, error-elimination, sharing and publishing of results, followed by subsequent rounds of further speculation based on shared knowledge. Understanding how this works in today's world of the academies and professions in an increasingly socio-technical environment is crucial to minimizing problems revolving around our use of publications to support knowledge growth.

We begin by considering what scientific knowledge is and what it is not from a Popperian point of view. Scientists and others may claim to know something scientifically. However, no matter how many tests a claim has survived; it can never be equated to truth (where truth is the complete correctness of a claim about the real world) [60] [61]. Popper argued that although the truth of a belief statement could never be proven, at least universal statements could be deductively falsified by the failure to observe predicted phenomena. However, Duhem, Quine and others argued that falsifications could always be explained away by auxiliary hypotheses as argued by [13] [64] and other papers collected in [39]. In his later work [62], Popper accepted that hypotheses could also never be certainly falsified, but something about the conduct of science still contributes more to the growth of knowledge than do fantasy and belief.

To clarify his thinking about the evolution and growth of knowledge, Popper [62] introduced an ontology of three worlds, as extended by [30] [31] [32] [78]:

- *World 1* (W1 - *physical events and processes*) is dynamic physical reality and everything in it, including physiology.
- *World 2* (W2 – *cognition* and *living knowledge*) is the domain of embodied behavior of agents, mental states and psychological processes within minds, dispositional and tacit knowledge. W2 encompasses active processes and subjective results of cognition. Cognition produces knowledge embodied in living things as, "dispositional" or "situational" knowledge (propensities to act in certain ways in response to particular situations). By extension, W2 includes the embodiment of all kinds of cybernetically self-defined and self-regulated dynamic processes. In other words, W2 contains the semantic significance or meaning of cognitive processes and their results in living systems, while the physical dynamics of the matter remain in W1.
- *World* 3 ("W3" - *objectively persistent products of knowledge*) is the domain of persistently codified knowledge, where encoded content can exist objectively, independent from a knowing entity. Popper defined W3 to include knowledge in the objective sense, which includes

"the world of the logical contents of books, libraries, computer memories, and suchlike" ([62]: p. 74) and "our theories, conjectures, guesses (and, if we like, the logical content of our genetic code)" ([62]: p. 73), while the physical structure of the codified content remains always in W1. W2 mediates between W1 and W3.

Knowledge evolves and grows as claims in W2 are shared via social expression and codification in W3, and strenuously tested against W1. Claims that survive such intersubjective testing are clearly better than those that fail.

Popper [62] summarized his ideas in what he called his "tetradic schema", or more boldly, his "evolutionary theory of knowledge" as detailed in Figure 1) Popper developed his evolutionary epistemology primarily in the context of human cognition. We argue [30] [31] [35] [32] that knowledge is formulated and applied by living systems across several hierarchical levels of organization [55] [69] [70] including living cells, organisms including people, and social and economic organizations [57] [37].

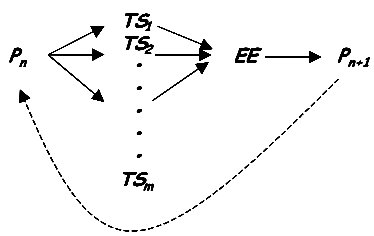

Figure 1. (after [62]: pp. 243). P_n is a problem situation the living entity faces in the world, TS_m represent a range of tentative solutions (or theories in self-conscious, articulate individuals) the entity may embody or propose in W2 to solve the problem. ***EE*** represents a process of "natural" selection imposed by W1 on the entity applying the tentative solution, or a process of criticism and error elimination in W2 that selectively removes those solutions that don't work in practice. P_{n+1} represents the now changed problem situation remaining after P_n is solved. As the entity iterates and reiterates the process, it constructs an increasingly accurate representation of external reality.

The knowledge management literature provides many different versions of learning cycles that involve the formulation of ideas, applying them, and attempting to learn from the results to improve knowledge (e.g., SECI [56]; "knowledge life cycle" [16]; double-loop learning [3], etc.). We prefer the terminology associated with John Boyd's OODA loop process [5]. Not only does this have a very robust derivation from the world of military affairs (e.g., [24] [24], but it is the direct practical application of Popper's evolutionary epistemology to building knowledge about real world situations [30] [31] [32] [36] [78]. The OODA loop involves iterated processes of **O**bservation (i.e., collecting sense impressions of the world), **O**rientation (sense-making, relating observations to prior knowledge, generating tentative solutions, logic testing, planning, etc. [24]), **D**eciding (selecting a tentative solution), **A**cting (applying the selected solution/plan to the real world). The next iteration repeats, beginning with observations of the world – including effects of the action.

SOCIAL CONSTRUCTION OF FORMAL KNOWLEDGE

The production and formalization of scientific knowledge involves social (and increasingly technological) processes at four distinctive levels of dynamic organization (Figure 2), as described in more detail in [78]. From an epistemological point of view these are knowledge building epicycles, respectively termed creation, collaboration, publication and assimilation.

Creation. The first cycle involves the cognitive processes of a single scientist ("**I**"), who (1) **O**bserves the world; **O**rients to it in order to make sense of observations in view of (a) his/her knowledge of society's "**B**ody **o**f **F**ormal **K**nowledge", (b) operative paradigm and (c) local group's prior experience of the world; (2) builds **T**entative **T**heories; and then (3) tests them against the real world to **E**liminate **E**rrors, thereby beginning the next cycle with refined ideas. This process may take place tacitly (W2), or it may involve (4) writing down (W3) ideas, observations, theories and tentative conclusions [78].

Collaboration. The second (epi-)cycle, that may encompass several instances of the first, begins where the individual investigator may articulate and share ideas among a close group of collaborators, ("**WE**"), who **O**bserve intersubjectively to one another and further work to eliminate errors (W2). The result of the individual (and optional collaborative work) is to produce a draft paper codifying the individual or joint knowledge claim.

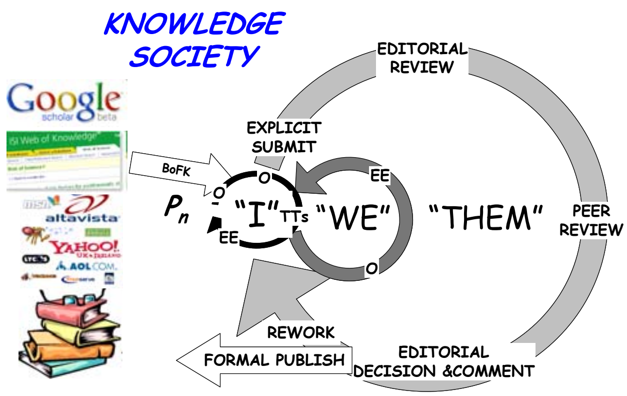

Figure 2 (modified from [78]). Epicyclic construction of scientific knowledge. This involves four distinct levels of organization. "I" – the individual innovator or scientist. "WE" – a group of collaborators working together on a research project or paper. "THEM" – the scholars and journals of a discipline or paradigm within which the project is embedded. "KNOWLEDGE SOCIETY" – the global community of scholars concerned to advance the scientific knowledge of the world and who consume the published and (hopefully) certified products of scientific collaboration.

Publication. In the world of editorial peer review, the third epicycle that may include additional cycles of re-submission begins when an explicit (W3) knowledge claim is submitted to a journal – where most journals today are publication outlets for particular research disciplines generally relating to specific paradigms. As detailed in several papers included in the 1990 symposium [65] and elsewhere, (1) the editor (or editorial staff) reviews the paper. It may be rejected at this point as inappropriate or (2) be forwarded to selected disciplinary peers for review and comment (drawing on their disciplinary knowledge) about relevance of contribution, writing/ presentation, design/conception, method/statistics, discussion of results, reference to the literature and documentation, theory, author's reputation/institutional affiliation, and ethics [4]. (3) Based on reviewer comments and the editor's own decisions, the article is either returned to the author as rejected (with reasons), or with requests or requirements for revision. *Because this review cycle focuses on "quality" and "marketability" from the publisher's and paradigmatic points of view, the editorial peer review actually contributes little epistemic value to the content.* In fact, as has been noted above, because most reviewers will be scholars within a particular discipline, the process may impede or prevent publication of revolutionary or unifying cross-disciplinary ideas not understood by busy reviewers whose own established beliefs may also be threatened by new ideas. Yet, it is these disruptive or paradigm changing works that potentially offer the greatest epistemic value to the knowledge society.

Assimilation. The fourth epicycle is that which involves the Community of Knowledge as a whole and uses the body of formal knowledge (BoFK) to guide real-world activities and to serve as the foundation for further advances in knowledge. Encouraged by the publishers, many readers assume that the peer review process of formal publication somehow or other certifies the formally published claims to knowledge as being "safe to use". However, as documented above, this assumption is *un*safe. Only when other scientists in the community actually assimilate and begin to apply published knowledge in their own investigations of the real world are published knowledge claims genuinely tested. Some published claims are unrepeatable, some are specifically contradicted by further testing, and (unfortunately) some are even shown to be fraudulent.

SOCIOTECHNICAL CONSIDERATIONS

Based on material cited here, the existing paper-based paradigm of the peer-reviewed scientific journal is approaching the end of its life as the dominant source of formal knowledge for the scientific community. This is already demonstrated by the physics community where the Internet-based arXive.org [19] has published more than 650,000 articles since it was established in Aug, 1991, and now adds some 6000 articles per month [2] with more than 40,000,000 downloads in 2004 [20].

> The arXiv is entirely scientist driven: articles are deposited by researchers when they choose (either before, simultaneous with, or after peer review), and the articles are immediately available to researchers throughout the world. As a pure dissemination system, it operates at a factor of 100–1000 times lower in cost than a conventionally peer-reviewed system [20]: p. 9606.

Publishing to arXive is not totally unconstrained. Screening mechanisms are provided to ensure that submissions meet minimum standards for legibility, organization and author credibility. Some authors are content to publish their work to arXiv and forgo the formal publishing route – depending on citations among the community to rate the paper's importance; but even most articles posted prior to journal submission are still accepted and published in formal journals.

Assuming that most journals will disappear as scientists becomes more used to the capabilities of the Internet technology, what is this technology and what does it offer scientific publishing?

The Internet: This is accessible from almost anywhere to almost anywhere, but may be limited by authoritarian regimes. In the developed world, access costs "next to nothing" even to the private individual, and internet access is often bundled with personal communication services.

Body of Formal Knowledge (BoFK): Most current formal knowledge is already indexed and discoverable in seconds via Web tools such as Google Scholar (http://scholar.google.com - free to the Web) or Web of Knowledge ([75] – that requires library subscription). Freely available articles are retrievable in seconds via Google. With an appropriate library subscription, many more articles can also be accessed in seconds via a fusion of Google Scholar and library subscriptions from various subscription-based journal repository servers. Personal experience (as illustrated in the bibliography of this paper) suggests 30-50 percent of relevant articles are already available free-to-the-Web in some form.

Electronic authoring: Authors can easily access free or commodity technology such as MS Office's tools, Open Office or the free, HTML-based Google Docs [38].

Document Repositories: It is not easy to determine how much document storage capacity is available in public, private and academic repositories. The last moderately authoritative study we have found is [43], but the capacity appears to be growing while the cost per given storage volume decreases. Basically capacity is not an issue, but some concerns need to be addressed: guarantee of continued support or alternatives for existing repositories, redundancy against failures and possible societal upheavals, and ensuring bandwidth of access (an issue in less developed areas of the world.

Publishing and indexing: Without concerns for the kind of quality control and aggregation services provided by journals, "publishing" can be virtually free and instant. Anyone can upload documents to academic repositories or personal web sites in seconds. Google indexes academic sites almost daily, and as soon as the document is indexed it can be retrieved in seconds. Bibliographies link newer work to older sources. Google and Web of Knowledge's citation indexing [21] [23] provides links to more recent work. Such knowledge processing technologies are becoming ever more sophisticated. Processing power, transmission speed and storage capacity per dollar are increasing exponentially at rates approximating 37, 19, and 26 percent per year, respectively – with no evidence that technological limits will be met soon [44] [48] [9]. In this radically changed technological environment for constructing scientific knowledge, we next consider who is a publisher in the new paradigm and what do they do?

Publishers. As noted above, nothing now prevents an individual scientist from publishing claims directly to the Web. However, the conventional editorial and publishing activities of selection, quality control and aggregation will probably remain useful. "Publishers" will provide these services, and would seem to require the following functions to achieve these aims:

- Editors – to select and monitor reviewers for each submission, track and assess reviews, notify/correspond with authors re editorial requirements, manage publishing process to post article to a formal repository; and
- Reviewer(s) – as selected and monitored by editor(s), who know their fields, who are ethical and responsible, and who are prompt.

Costs for such publishers should be minimal. Disciplinary societies may appoint and monitor editors. Academic institutions normally provide editors and reviewers with release time for what is considered meritorious services to a discipline that adds to institutional prestige.

Preparation for publication. This task can easily be removed from the publisher. Formats can be standardized at the author level through the strict use of word processing templates or, preferably, working in a structured authoring tool [73] [78] – something that technical communicators have done for a decade [29] [63]. Suitably structured documents can be automatically converted to PDF and HTML.

Assembly and issue of formal document. This will involve little more than supplying "journal" metadata around the approved article and uploading it (i.e., release) to a formal repository indexed by search engines. There will be no costs for printing and physical distribution or production of reprints and maintenance of back copies. Authors will retain copyright under Creative Commons [10].

Repositories. Publication will be to one or more established repositories that must be paid for, managed and maintained. Ideally repository costs will be treated as a "social good", e.g., as is the case for the Internet Archive [45], and arXiv [20].

Residual problems. As demonstrated, the technological resources for the new paradigm of scientific publishing already exist. There are only a few residual problems:

- Interoperability. Interoperability refers to semantic difficulties converting content across computational platforms [77], but most problems would disappear if the initial authoring was done in controlled and standardized environments. An example of the difficulties is that in converting between Google Docs' HTML and MS Word's .doc and .docx formats [38].

- Integrity of review process. As noted above, both authors and reviewers can game the peer reviewing process to unethically advance their own causes. Using capabilities of the new technology reviewing can easily and inexpensively be made open and visible to allow the easy identification of such gaming.
- Speed of reviews. Documents can be exchanged at light speed, and there are a variety of inexpensive content management applications that track overdue workflows.
- Who owns/pays for repository services? We think this is a public good that should be supported by the state. The (comparatively minimal) costs could also be covered by disciplinary society memberships or author page charges.
- Legacy documents. How to make legacy documents owned by commercial publishers free is a major issue. Publishers have paid significant costs to scan and make their backfiles on which they hold copyright indexable for electronic retrieval. Understandably, these files are only available to those who have paid to subscribe to the services. We argue that all scientific knowledge should be freely accessible via the internet, and accept that commercial publishers who achieved their ownership of source documents in good faith should be bought out. This is an issue for governments, granting agencies, universities and the research establishment in general to consider.
- *Books*. Books are a different issue from scientific papers. Authors normally expect some return on their huge effort for actually producing a book, with commercial publication representing the normal pathway to achieve this. Where the epistemology of scientific knowledge is concerned, there are also obvious differences between monographs, text books, technical publications, and general literature that are beyond the scope of this paper. However, mechanically, the holdings of major libraries are being scanned by Google [40] [68], and book content is already available on-line or will be so soon – with the main issue being how material still in copyright should be handled.
- *Existing publishers*. As well as their roles in quality control and aggregation, existing publishers still have important roles in the distribution of news and commentary. Much work still needs to be done re models (1) for supporting or buying them out and, (2) dealing with the copyright status of scientific works that should properly be freely accessible to the community of knowledge.

CONCLUSION

The existing paradigm of paper-based publishing of scientific journals has been made untenable by ever-increasing numbers of papers seeking publication and unrealistic expectations from the editorial peer review processes associated with journal publication. Editorial peer review doesn't certify published knowledge, and is not a good guide as to the eventual value of published content to society. New electronic technology facilitating the expression, circulation, testing, publishing, linking and discovery of knowledge claims supports the development of a much less expensive and far more responsive paradigm for disseminating scientific knowledge. By understanding the four epistemological cycles involved in formalizing knowledge within the knowledge society, creation, collaboration, publication and assimilation, perhaps we can replace paper journals with a better system for supporting the growth of scientific knowledge.

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