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PERSPECTIVE

# Envisioning the scientific paper of the future

**Natalie M. Sopinka[a*], Laura E. Coristine[b], Maria C. DeRosa[c], Chelsea M. Rochman[d], Brian L. Owens[e], and Steven J. Cooke[f]**

[a]Canadian Science Publishing, 65 Auriga Drive, Suite 203, Ottawa, ON K2E 7W6, Canada; [b]Department of Biology, The University of British Columbia—Okanagan Campus, 1177 Research Road, Kelowna, BC V1V 1V7, Canada; [c]Department of Chemistry, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada; [d]Department of Ecology and Evolutionary Biology, University of Toronto, 25 Willcocks Street, Toronto, ON M5S 3B2, Canada; [e]Freelance Journalist, St. Stephen, NB, Canada; [f]Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada

*natsopinka@gmail.com

## Abstract

Consider for a moment the rate of advancement in the scientific understanding of DNA. It is formidable; from Fredrich Miescher's nuclein extraction in the 1860s to Rosalind Franklin's double helix X-ray in the 1950s to revolutionary next-generation sequencing in the late 2000s. Now consider the scientific paper, the medium used to describe and publish these advances. How is the scientific paper advancing to meet the needs of those who generate and use scientific information? We review four essential qualities for the scientific paper of the future: (*i*) a robust source of trustworthy information that remains peer reviewed and is (*ii*) communicated to diverse users in diverse ways, (*iii*) open access, and (*iv*) has a measurable impact beyond Impact Factor. Since its inception, scientific literature has proliferated. We discuss the continuation and expansion of practices already in place including: freely accessible data and analytical code, living research and reviews, changes to peer review to improve representation of under-represented groups, plain language summaries, preprint servers, evidence-informed decision-making, and altmetrics.

**Key words:** science communication, open science, scholarly publishing, peer review, science writing, science literacy

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## 1. Introduction

In the mid-17th century, the Royal Society of London began sharing letters that reported discoveries in their publication *Philosophical Transactions* (Harmon and Gross 2007). These published observations, read and scrutinized by the natural philosophers of the time, were among the first formalized disseminations of scientific information in article format. Over three and a half centuries later, subject experts review articles through the peer-review process and before publication in scientific journals. Collectively, articles are the primary source of vetted and reputable scientific information (Bornmann 2011). Although the peer-review process (Weber et al. 2002; Smith 2006; Resnik 2011) and publication enterprise (Lortie 2011) are not without criticism, such articles remain the bread and butter of contemporary knowledge sharing within the scholarly community (Kassirer and Campion 1994). The substance of journal articles (hereinafter, paper(s)) drives the scientific endeavour (Robertson 2009; Bornmann 2011).

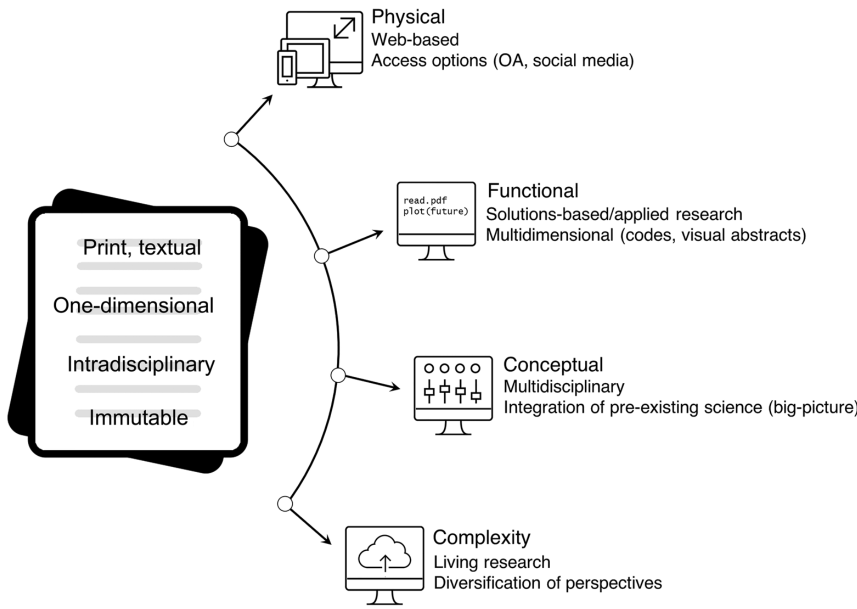


**Fig. 1.** Expanding facets (physical, functional, conceptual, complexity) of the scientific paper. OA, open access.

Not that long ago, printed and bound journals lined seemingly endless shelves and rows in library "stacks"—the repository for scientific papers. With the advent of the digital era, physical and functional aspects of scholarly publishing and science communication have begun to shift (see **Fig. 1**). Publishers and authors are embracing digitally based practices including social media (Darling et al. 2013) and multimedia abstracts (Spicer 2014). Despite efforts to advance digitization (for a discussion, see Owen 2007; Aalbersberg et al. 2014), today's scientific paper remains rooted in print traditions; a multi-page document with text and static images that is now considered by some to be "obsolete" (Somers 2018). As the number of researchers and journals is steadily increasing (Ware and Mabe 2005; Jinha 2010), the number of papers is doubling approximately every nine years (Bornmann and Mutz 2015). This tremendous growth in publication rate has led to information overload for both producers and users of scientific knowledge (Piñero 2018). How can today's scientific papers remain the bedrock of evidence for society in an ever-evolving science and science publishing environment?

We summarize perspectives, discussions, and graphical outputs (**Figs. S1**–**S3**) from the 2017 Canadian Science Policy Conference panel on "Designing the scientific paper of the future". We do not propose earth-shattering or revolutionary ideas around how scientific papers are likely to evolve. Instead, we pinpoint current trends and innovative approaches to crafting and disseminating scientific papers—tools that increase the rate and ways in which science can progress. The novelty of the paper of the future (compared with today's paper) will arise from a combination of approaches that increase the impact and reach of research. Herein, we discuss four qualities—that address the physical, functional, conceptual, and complexity requirements—the scientific paper of the future should embody (**Fig. 1**). Our discussion is not meant to be exhaustive. The qualities of the scientific paper of the future currently exist, but adoption is not universal. For each quality, we offer some of the most promising recommendations for publishing authors to consider; we also offer recommendations for publishers and institutions to further inform authors who may be part of editorial boards or have administrative roles at their institutions (**Table 1**). However, definitive solutions to issues raised are beyond the scope of this paper. Numerous other ideas are worthy of discussion; because of space

**Table 1.** Potential actors and action items that will contribute to the development of the paper of the future.

| Actor | Publisher | Author | Institution |
|---|---|---|---|
| A robust source of trustworthy information | • Support technological platforms to embed analysis code<br>• Support open review and other standards of openness (e.g., develop open data – open code policy)<br>• Develop peer review methods that reduce bias and increase representation<br>• Support post peer-review technology<br>• Support platforms for living research documents<br>• Moderate discussions and revisions to living research documents | • Share data and code freely<br>• Create and share visualization of methods (e.g., video)<br>• Engage in post-peer review discourse<br>• Contribute to living research documents<br>• Synthesize evidence by doing systematic reviews or meta-analyses<br>• Explore peer-review initiatives (e.g., Peer Review Week; Peer Reviewers' Openness Initiative) | • Support creation and sharing of visualizations of methods<br>• Provide researcher training for systematic reviews and meta-analysis<br>• Provide current news and information on open data and peer review |
| Communicated to diverse users in diverse ways | • Finance translation services<br>• Create toolkits on communicating published research with nonexpert audiences<br>• Be open to new paper structures<br>• Hire writers for plain language summaries<br>• Ensure digital accessibility | • Participate in writing workshops (e.g., in-person, webinar)<br>• Use inverted pyramid or front-load<br>• Avoid noun strings and jargon<br>• Write in the active voice<br>• Write plain language summaries<br>• Budget for creative professionals in funding applications or reach out to in-house creative professionals<br>• Explore online and social media trends in science communication for inspiration | • Provide training for students and researchers to write in plain language<br>• Support creation and sharing of nontraditional science communication materials |
| Open access | • Adopt open access standards to meet funder requirement<br>• Develop a business model for open access publishing that prevents predatory journals<br>• Develop policies for submitted papers on preprint servers | • Be vigilant of predatory publishers<br>• Familiarize yourself with preprint servers to support early release of high impact findings<br>• Explore open access initiatives (e.g., Open Access Week) | • Help support open access publication fees<br>• Provide approved journal lists for researchers<br>• Provide current news and information on open access publishing |
| A measurable impact beyond Impact Factor | • Adopt publishing standards that enhance machine reading<br>• Link all media to original DOI | • Include action items and recommendations in paper on use for policy or other decisions<br>• When applicable, identify and pursue scenario-specific research<br>• Explore and track altmetrics | • Develop nontraditional impact evaluation (e.g., for tenure and promotion)<br>• Provide opportunities for researchers to learn how to communicate research relevance<br>• Require research preregistration |

limitations we do not include all ideas in this paper (but see **Figs. S1**–**S3**). For example, we find merit in the potential for blockchain technology and "decentralized" scholarly publishing (van Rossum 2017), poetic abstracts (Illingworth 2016), revised authorship practices (e.g., CRediT; https://www.casrai.org/credit.html), and the use of artificial intelligence to tailor literature searches (e.g., Meta, www.meta.org). The reader may want to delve into these topics.

Our paper seeks to provoke thought, dialogue, and the action necessary to ensure the long-term viability of science. The science community is continuously inundated with new journals, ideas, and innovations. Linking reliable information, diverse ideas and audiences, accessibility, and impact will require the combined efforts of publishers, authors, and scientific institutions (**Table 1**). The reward: a science of the future, communicated by a paper of the future, and limited only by imagination.

## 2. A robust source of trustworthy information

Science plays a critical role in society through the development of knowledge. Irrespective of whether curiosity or problem-solving drives research, the scientific paper of the future (hereinafter, paper of the future) has a fundamental obligation to remain a reliable, objective, credible, and verifiable source of information. Over recent decades, scientists have shifted roles, progressing from information gatekeepers to information purveyors; information has become a commodity used to inform individual, societal, and global decisions (e.g., Baron 2010; **Fig. 2**).

Peer review serves a vital role in preserving the integrity of scientific information (Mulligan et al. 2013); it will continue to do so for the paper of the future. Already, there are efforts to make peer review more effective. In some cases, reviewers are being asked to "apply certain minimal open research standards to the manuscripts they review" (e.g., Peer Reviewers' Openness Initiative; Morey et al. 2016) or the peer-review process itself is now open. Referees can comment on the final or revised version of a paper (e.g., *Ideas in Ecology and Evolution*; https://ojs.library.queensu.ca/index.php/IEE), thus contributing to collaborative refinement of scientific knowledge. Other journals now publish the reviews of invited referees along with responses from the authors while also providing a forum where the broader community can comment on a paper in a courteous and open manner. At present, women are under-represented in the peer-review process across 142 journals from a broad cross-section of scientific disciplines (Helmer et al. 2017). Only 20% of referees for American Geophysical Union journals are female, well below rates of membership and first authored publication acceptance (Lerback and Hanson 2017). Open review (see Discussion in Lundine et al. (2019)), double-blind reviewing (Fox et al. 2019), and diverse editorial boards (Berenbaum 2019) might improve representation for under-represented groups for the paper of the future, but science studies evaluating such changes to peer review are needed to confirm improvement.

Changes to peer review, such as increasing openness, will likely change the nature of the paper itself (BioMed 2017). Today's paper, once published online in a copyedited form with a citable DOI, is complete. The paper of the future may be a digital-only document that is not only discussed openly after the peer-review process but also regularly updated with time-stamped versions (Singh Chawla 2015) and complementary research by different authors (Shanahan 2015). Such compilations (i.e., living research) can assist with the development of theory and reduction of scientific uncertainty (**Fig. 2**). The technology already exists for living research and post peer-review discourse (e.g., hypothesis; https://web.hypothes.is/). Living systematic reviews are another valuable way to keep research up to date in rapidly evolving fields (Brock 2019). The papers of the future that take the form of living reviews can help our understanding of a topic keep pace with the research but will also add complexities (**Fig. 1**); for example, publishers will have to provide the technology and editors will have to moderate new revisions (Brock 2019).

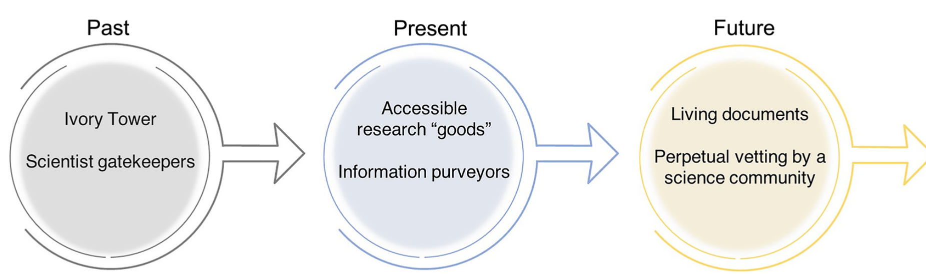


**Fig. 2.** Progression in the view of scientific information relied upon by producers and users of science.

When papers include interlinked content that supports data verification, research gains in transparency, repeatability, and replicability. For example, imagery of research methods (e.g., photography or videography; the journal *JoVE* produces videos of new research methods; www.jove.com), freely available data (i.e., open data) uploaded to publicly accessible databases, and freely available coding or programming used for statistical analyses (e.g., the *eLife* Reproducible Document Stack embeds code in the online version of a paper; https://repro.elifesciences.org/example.html) all provide an opportunity for other researchers to examine data, methods, and results in greater depth (Gross and Harmon 2016). When considering the paper of the future, the capacity to manipulate and interact with content will enhance the reliability of scientific information.

The paper of the future will also curate vast bodies of literature and determine the weight of evidence-supporting hypotheses. Two paper formats—systematic reviews and meta-analyses—can accomplish this and provide decision-makers (e.g., individuals or governing bodies) with evidence syntheses that they need (Sutherland et al. 2004; Walsh et al. 2015). Centres for evidence synthesis can further amplify the capacity for scientists to refine and distil knowledge by focusing on broad trends and patterns within specific research fields. Systematic reviews, meta-analyses, and centres for evidence synthesis can improve the potential for new research to expand upon and incorporate pre-existing scientific knowledge (Nosek et al. 2015; Gil et al. 2016; Cooke et al. 2017a; Piñero 2018).

# 3. Communicated to diverse users in diverse ways

Communication with diverse audiences can help to fill gaps in knowledge, enhance trust in science (Baron 2016; Dudo and Besley 2016), and reduce barriers to the use of scientific knowledge by non-experts (Baron 2010; see "5. A measurable impact beyond Impact Factor"). When considering large-scale patterns of publishing, language is one of the primary barriers to scientific access and use by diverse audiences (Amano et al. 2016). Translations increase inclusivity so that people from around the world can read, understand, and build on prior research (Huttner-Koros 2015). Resolving language barriers will ensure that the paper of the future is more readily accessible to researchers the world over. Similarly, a technologically complex paper of the future, which lives exclusively in the digital realm, needs digital accessibility. The internet bandwidth available to users (e.g., narrow bandwidths in developing countries and Indigenous communities of northern North America), as well as the device used to access the paper (i.e., mobile, tablet, or desktop), will determine digital accessibility (in addition to whether a user can even view the full paper, see "4. Open access"). Reaching diverse audiences requires a broader recognition of accessibility—whether this arises from process barriers such as language or functional barriers such as digital capacity.

When considering the particulars of publishing, a more radical consideration involves changing the style and fundamental structure of scientific papers so that the experience of consuming science is more enjoyable, direct, and intuitive. Stylistically, using the passive voice can improve accessibility (Alvin 2014), clarity, and brevity (Heard 2016). Active voice is easier to understand and uses fewer words (Bostian 1983). Yet, within academia the use of passive voice doubled between the 17th and 20th century (Harmon and Gross 2007). Eliminating technical jargon, such as noun strings, is another way to write more clearly and concisely (Heatwole 2008). Instead of starting with background and methods, and ending with results and main conclusions, the paper of the future might better appeal to users by adopting the inverted pyramid which front-loads the most critical information (main conclusions and results before background). Changes in fundamental structure are likely to evolve over generations of scientists and require that both publisher and researcher embrace the idea. Publishers and journal editors can consider and suggest alternative ways to structure papers, and researchers can experiment with writing in different styles (e.g., by participating in online or in-person writing workshops).

To some degree, the structure of the scientific paper is already changing. Some publications now include a freely available plain language summary written for nonexperts (Kuehne and Olden 2015). A plain language summary could improve communication of key findings when the reading level of the core text exceeds that of a global public. There are several resources authors can use to summarize scientific findings for nonscientists (e.g., Up-Goer Five, https://splasho.com/upgoer5/; Munroe 2015). However, consistency in quality of plain language summaries will be essential for the paper of the future. What process will best support consistency? Publishers can hire writers. Scientific institutions might train students and researchers how to write in plain language.

Increasing the reach of science communication is also likely to become integral to the paper of the future and can help counter public susceptibility to "fake news" (Chan et al. 2017; Lazer et al. 2018) and anti-science positions (e.g., anti-vaccination or climate change denial) (van der Linden 2019). Disinformation spreads among the public when scientists fail to rebut incorrect statements and science denial, whereas public rebuttals that address the logical or scientific errors of science denial lessen the spread of disinformation (Schmid and Betsch 2019). Already, researchers are seeking out nontraditional ways to reach a broader audience and inform public discourse. Trends in science communication include: online and social media (e.g., Instagram stories, podcasting, and live blogging or live tweeting events; see Gross and Buehl (2016)), op-eds that connect research to current policy, perspective pieces published in freely accessible digital spaces (e.g., online newspapers, blogging platforms such as *The Conversation*: www.theconversation.com), and science outreach with schools and the public. Professional societies and other organizations offer guidelines and training forums for scientists interested in sharing their research in these formats (e.g., American Association for the Advancement of Science (AAAS; https://www.aaas.org/page/writing-op-ed)).

Visual outputs of research now go beyond the standard graph. Infographics, animations, and interactive visualizations supply abbreviated communication materials that accompany the peer-reviewed paper (Aalbersberg et al. 2014; Gross and Buehl 2016; Cooke et al. 2017b); however, these outputs are not necessarily coordinated through the publisher but may instead be produced independently by the researcher. To produce these outputs, scientists can incorporate money for hiring creative professionals into grant proposals; scientific institutions sometimes have in-house professionals that can assist. Open source tools to create interactive or static visualizations also abound (Perkel 2018).

A toolkit to guide authors in disseminating the paper of the future will be essential. Many resources—scattered across published literature and the internet—are available to assist researchers with the process of disseminating published research. A single compendium on science communication theory and best practices could assist published authors with developing communication materials and approaches for diverse users. Redefining the roles of those involved in publishing (e.g., authors, publishers, scientific institutions) may be necessary (see **Table 1**). At present, the parties responsible for financing and creating the science communication materials vary. Sometimes the author supplies science communication materials, at other times the publisher or scientific institution does (Baron 2010; King et al. 2017). If communication materials become a required part of the paper, publishers should be responsible for co-creating, vetting, and promoting the materials and determining promotional strategies.

Communicating in diverse ways and to diverse audiences requires implementing several straightforward and readily adopted ideas, from language translation to improved writing structure and style to the use of multimedia and digital media platforms for sharing information with the public. And yet, to meaningfully reach diverse audiences, the institutions of science must overcome one additional overarching barrier. Science has long been a privileged, male endeavour (Larivière et al. 2013). The present lack of diversity and inclusion within science limits the capacity for science to reach diverse audiences through diverse mediums (Puritty et al. 2017). Only when science itself is a diverse and inclusive enterprise, will the discipline be capable of maximizing discovery and innovation (Valantine and Collins 2015) and effectively communicating to diverse users in diverse ways (Puritty et al. 2017).

# 4. Open access

Over the past two decades, there has been a steadily growing buzz around moving academic research out from behind a paywall to make it open access. This would represent a significant change to the physical nature of the paper of the future (see **Fig. 1**). Conceptually, open access has the potential to facilitate big science (i.e., large-scale research) and projects that rely on big data (i.e., large-scale data sets; Marx 2013). The arguments for open access are varied and nuanced. In general, open access is one solution to the ethical dilemma of science accountability; research scientists are funded by and accountable to governments, the public (i.e., taxpayers), and granting agencies. Responsible use of research funds requires that research findings remain accessible. Open access papers are discoverable and accessible to everyone; some evidence suggests that open access research has a higher readership (Tang et al. 2017). It is too early to know if there will eventually be a tipping point whereby all papers move towards open access (beyond university repositories; see Bankier and Perciali (2008)), as many papers are still published under the subscription model. Some funders are taking bold steps to ensure research remains accountable via open access. Recently, a group of European national funding organizations launched an open access initiative known as Plan S, set to begin in 2021. Under Plan S, scientific publications that stem from publicly funded research must be open access as soon as they are published (Schiltz 2018, see discussion in Burgman (2018) and Lehtomäki et al. (2018)) and the funder or university would cover publication fees. Plan S would mean that about 85% of journals, *Nature* and *Science* among them, would no longer be acceptable venues for publication given their current policies on paywalls.

For open access to be sustainable and widespread, much needs to happen. At the core of discussions: Who will provide financial support for open access publishing? And, what does an open access business model look like? At present, publishers transfer the cost of open access to authors with accepted papers; the financial barriers for students and early-career researchers can be insurmountable (Van Noorden 2013). In addition, an explosive emergence of predatory publishers followed the advent of open access publishing (Beall 2012, 2013). Further, many scholars and end users believe that the author pay model is inherently biased and interpret open access payment by authors as an incentive for publishers to accept lower quality papers (Swan and Brown 2004). However, it would be possible to shift open access publishing to a not-for-profit business model (Haspelmath 2013) such as universal green access (i.e., the accepted paper is freely available in a digital repository) (James 2017).

Research can also be publicly available before editorial screening or a peer-review process (viz. a preprint) (Singh Chawla 2015). A preprint is a way to make research accessible faster and can inform time-sensitive policy decisions (Desjardins-Proulx et al. 2013) (but see "2. A robust source of trustworthy information"). Indeed, preprint servers are gaining in popularity (Barry 2018). Increasing numbers of journals are changing their "prior publication" policies to allow for the submission of papers after posting onto a preprint server. Although peer review does not catch or correct all errors, there are pros and cons of disseminating data and research before peer review is complete. For one, media may sensationalize research before it is vetted as sound science (Tennant et al. 2017), or worse, policy decisions may be based on research where flaws have not yet been corrected during peer review. However, preprint servers also support a new intermediary research step—one of scientific debate informing complex research ideas in advance of peer review and publication. In this sense, preprint servers may offer a way to support living research documents (see "2. A robust source of trustworthy information").

## 5. A measurable impact beyond Impact Factor

Science informs our understanding of the world around us. Yet, to inform our understanding of the world the paper of the future must have a measurable impact—and be both discovered (see "3. Communicated to diverse users in diverse ways") and used (e.g., for policy, theoretical contribution, or innovation). Decision-making, or the use of information to inform choices, affects all facets of daily life—from consumer purchases to social programs to medical treatment to government policies. Using scientific evidence improves our ability to understand the costs and benefits to decisions. Despite this, scientists and decision-makers often view science and decision-making as separate (Baron 2010), which means that science is neither discovered nor used to inform decisions. The low likelihood that scientific evidence informs decisions limits the progression of innovation and hinders effective responses to problems (Pullin et al. 2004; Saltelli and Giampietro 2017).

Strategies to enhance research discoverability remain an actively discussed topic in scientific publishing (e.g., Zhu 2017). Physical changes to the paper of the future to improve discoverability include changes to the HTML versions that improve machine or computer readability (see Shotton et al. 2009 for details on semantic markup). A conceptual aspect of paper of the future to improve discoverability is the preregistration of research, creating centralized research repositories that track new directions in research (Munafò et al. 2017). Linking related research, varied research outputs, and multiple digital spaces might also enhance discoverability for the paper of the future (Shotton et al. 2009).

For research that provides solutions to society (e.g., informing political decision-making) the paper of the future should emphasize scientific evidence and practical recommendations (Cairney and Oliver 2018). For example, researchers can present results that are sensitive to user requirements (see Coristine et al. 2018). Including a brief list of action items or recommendations for decision-makers is another simple but powerful step towards improving evidence-informed decision-making (Choi et al. 2003). Ultimately, for the paper of the future to be usable, the context and focus of the research itself needs to be tailored (Wall et al. 2017), for example when researchers identify scenarios for a specific research problem or solution (Sutherland et al. 2011; Saltelli and Giampietro 2017).

How will the impact of the paper of the future be measured? Current citation metrics have inherent shortcomings that fail to consider the shifting facets (see **Fig. 1**) and real-world impact of today's papers and provide an imperfect evaluation of research influence (Trueger et al. 2015). The merit of a paper cannot be based only on the journal and journal Impact Factor. Altmetrics, a recent addition to citation metrics, goes beyond academia to assess a research publication's online dissemination and influence on society (e.g., social media shares, news media coverage, blogs). PlumX combines traditional citation metrics with altmetrics (Lindsay 2016), providing an integrated measure of impact. But in general, the societal impact of a paper is not well captured by incentives within scientific institutions. Grant evaluations (Samuel and Derrick 2015), hiring, tenure, and promotion activities (see Terämä et al. 2016) are all suitable avenues for redefining how research impact is assessed. As well, multi-dimensional assessment of impact using typical indicators (e.g., citations per article, H-index; see Moed and Halevi (2015)) may be a viable way to evaluate scientific relevance in society. Through the use of various bibliometric, network analysis, and data mining activities (summarized in Penfield et al. (2014)) it may be possible to map the role of individual papers on the science community, or even link the contribution of individual papers to specific policy decisions or innovations in health or technology (Greenhalgh et al. 2016).

## 6. Conclusion

In the end, we likely raise more questions for the reader than we answer. While the direction of change for a paper of the future is apparent, suitable ways to bring about these changes are not. Ultimately, the process of change will shape the form of the paper of the future. In chemistry, the rate-limiting step of a reaction determines the reaction rate. So too, for the evolution of scientific advances. At present, scientific advances are limited by: the quantity of literature and lack of capacity to verify data (see "2. A robust source of trustworthy information"), the global nature of the science endeavour (see "3. Communicated to diverse users in diverse ways"), the need for transparency and scientific debate in shaping new science frontiers (see "4. Open access"), and the importance of evidence-informed debate when making decisions that affect local and global society (see "5. A measurable impact beyond Impact Factor").

For each change to the paper of the present, questions arise: Who pays? Who takes on ownership for implementation? What will drive adoption by the broader scientific community? For example, translating papers (see "3. Communicated to diverse users in diverse ways") costs money. Researchers relying on grants or scientific institutions with constrained budgets are less able to absorb the costs of translation. For-profit publishers could more readily absorb the costs and translate online papers into multiple languages. Venture capitalists could also invest in the creation of free (or low-cost) technologies or apps that translate papers. We encourage scientists, publishers, and scientific institutions to actively engage with changes to the paper of the present to support a more thoughtful and effective form for the paper of the future (see **Table 1**).

There is little doubt that the scientific paper of the future will not only look different but will also provide different ways for users to engage with content. The obvious question is—when? There is already evidence of small incremental change, but not at a scale that is sufficient to keep pace with the pace of scientific discovery. Although volunteers are at the core of the scientific peer-review process, it is primarily multinational publishers who control (or constrain) the scientific publishing world. It is only very recently that some of the largest (profit-motivated) publishers are being pushed to change or face being boxed out of the scientific publishing world (see developments in Europe in 2018, Bastian 2018). What is clear is that the paper of the future will redefine the relationship between all involved parties (writers, reviewers, editors, publishers, libraries and repositories, readers, the media) (**Table 1**). We also recognize that academic institutional norms continue to (over) value scientific publications (both quantity and quality) with relatively little regard for influence or impact (Donaldson and Cooke 2014). Forward-thinking leadership by all involved parties will be a prerequisite for meaningful changes in the measurement, valuation, and evaluation (e.g., for hiring, tenure, promotion, and grantsmanship) of research impacts. We need to revisit the traditional incentives for publishing to better align with the new reality of a more diverse and engaged science community that expects openness, transparency, and accountability.

No matter the changes on the horizon, some elements of the scientific paper must remain intact. For example, publishing a paper creates an inherent legacy whereby the content should theoretically be findable and accessible for centuries to come. Moreover, aspects of scientific rigour and peer review need to persist, although the future model of peer review may be quite different. We anticipate a future where the scientific paper is functionally alive—something that researchers may interrogate, revise, or build upon in perpetuity. Artificial intelligence and sophisticated human–computer interfaces set the stage for papers that are indeed alive; not only sources of knowledge but also platforms for interactive and immersive knowledge exchange. Such a future is both exciting and awe-inspiring. The present radical and rapid unfolding of science provides an opportune time to reflect on the past and work collectively towards a future whose limits are matched only by science and scientific endeavour.

The scientific paper of the future, no matter the form, has an even greater role in defining a future where evidence informs policy, practice, and decision-making.

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## Author contributions

NMS, LEC, MCD, CMR, BLO, and SJC drafted or revised the manuscript.

## Competing interests

NMS is an employee of Canadian Science Publishing (CSP), publisher of *FACETS*, and co-organized the Canadian Science Policy Conference panel. SJC is currently serving as a Subject Editor for *FACETS* and is on the Editorial Board of another CSP journal but was not involved in review or editorial decisions regarding this manuscript. SJC is also involved with other scientific journals in various editorial capacities. BLO frequently writes for the news sections of traditional scientific journals. None of the authors involved in the manuscript were involved in the peer-review process nor is there any formal reporting relationship whereby one of the co-authors supervises any of the editorial team that handled the manuscript. We publicly share the ideas generated in this paper so that the material can be used by scientists, editors, and publishers around the globe.

## Data availability statement

All relevant data are within the paper and Supplementary Material.

## Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2019-0012

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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