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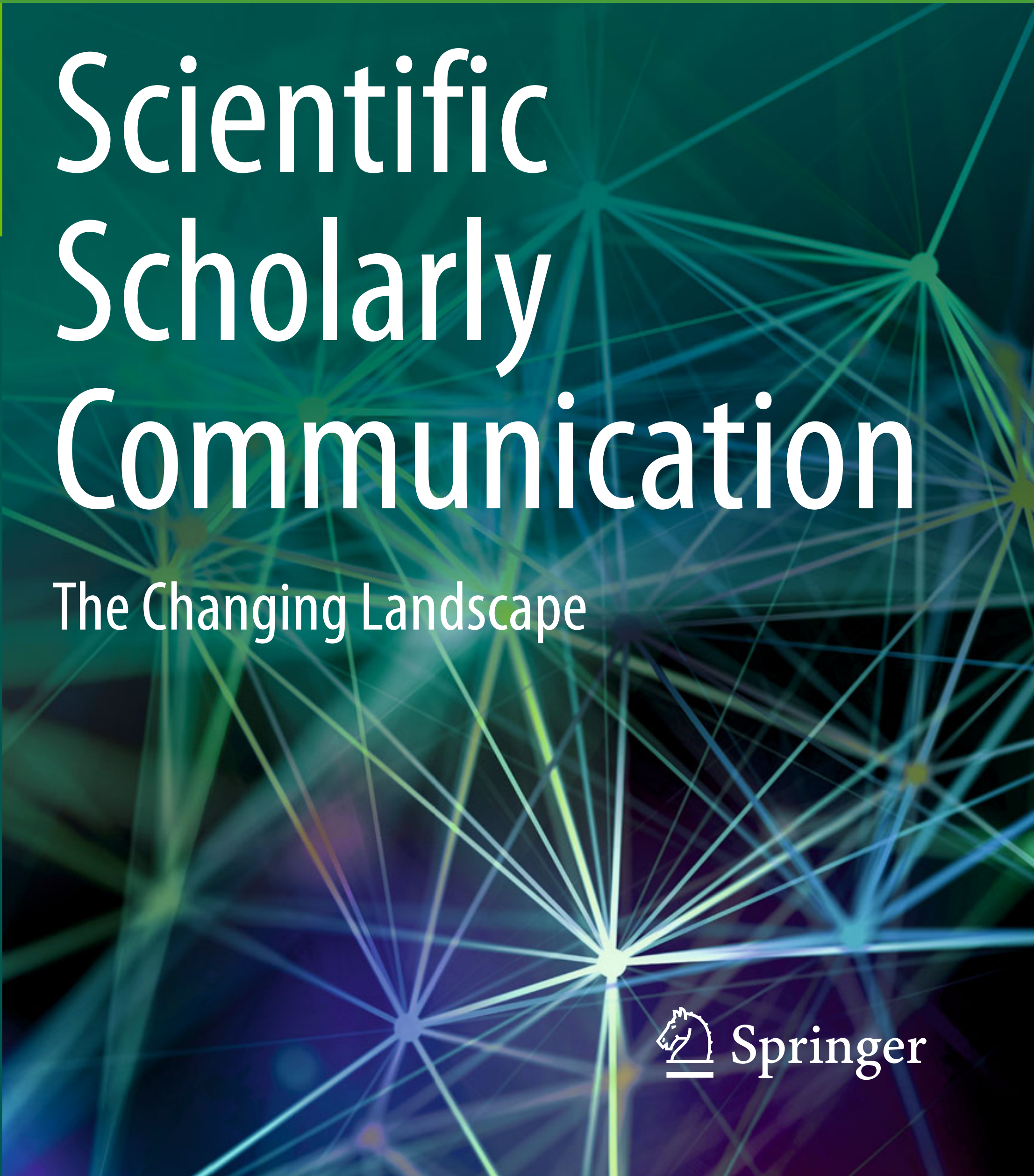
Pali U.K. De Silva
Candace K. Vance

Scientific Scholarly Communication

The Changing Landscape



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Pali U.K. De Silva · Candace K. Vance

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Springer

Pali U.K. De Silva
Murray State University
Murray, KY
USA

Candace K. Vance
Murray State University
Murray, KY
USA

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Preface

The formal scientific scholarly communication system that emerged 350 years ago changed at a slow pace until the last few decades, during which we have witnessed a tremendous state of transformation over a relatively short period. During this time period, many opposing viewpoints have been heard about the direction of the scientific scholarly communication system. The call for information to be freely and openly available is heard alongside the equally strong desire to profit from it. The well-established subscription-based journal publishing model for sharing scholarly information steadily evolved, but increasing subscription rates made many stake holders of scientific information unhappy. Voices of resistance were heard and the open access movement was born, promoting the norms of free and unrestricted access to scientific knowledge. Although the open dissemination and access to scientific information would ensure greater expansion of the knowledge base and enhance scientific progress, there are critical questions pertaining to the economics of open access publishing as well as other issues unique to unrestricted access to scientific information.

Data is considered the foundation of science, and there is growing interest in making scientific data readily accessible. The quest for "open data" is taking shape in parallel to the open access publishing movement, which will revolutionize the way science is documented. Advances in technology have made data collecting, archiving, sharing, and accessing more feasible. Although the advantages of scientific data sharing are increasingly acknowledged, it has not been adopted equally across scientific disciplines due to a variety of reasons such as the cost involved, culture, lack of data management skills, or technological difficulties. Then, there are issues unique to some types of scientific data that require an understanding of ethical and social factors, privacy, and safety and security concerns when openly sharing it.

The idea of democratization of scientific knowledge, one of the facets of the "open science" movement, is gaining attention within many scientific communities, and the benefits of sharing scientific knowledge are almost universally accepted. At the same time, the importance of transforming scientific discoveries into technologies benefiting the society at large has been similarly acknowledged. Two contradicting ethos—the free flow of scientific information and the commercialization of scientific discoveries—have become a topic of spirited debate, which demands the attention of the scientific communities as well as the society at large.

The astounding rate of technological advancement not only shapes the way we disseminate, share, and access, but also assesses the quality of scholarly information. Quantitative tools facilitated by computer and communication technologies are combined with the traditional pre-publication peer-reviewing in measuring the impact of scientific research. While discussions and conscientious debates to improve existing time-tested measures persist, the pursuit of developing better and more efficient means also continues. There are questions not only about the effectiveness and reliability of assessment methods but also about the efficiency and the time it may take. Is faster better when assessing the quality of scientific research, and if so, at what cost? In addition to measuring scientific quality, should we also be determining the impact of science on society? And if so, how?

The changes in the scientific scholarly communication system are varied and complex, and the numerous participants involved in the debate about its future direction have different opinions. Scientists, probably the most important participants in this discussion, spend a great deal of time and effort to stay current in their respective scientific fields but may fail to stay current regarding the changes in the scholarly communication system. An understanding of the complex nature of these changes will enable them to more easily navigate this evolving landscape when seeking research funding, publishing their work, and managing issues related to their career enhancement. Beyond mere understanding, they must become advocates for the future of scientific scholarly communication—one that is inclusive and sustainable. This requires a sense of responsibility for shaping its future direction, not simply watching it unfold at the hands of publishers and commercial entities whose agendas may be at odds with the public good and the expansion of scientific knowledge.

The objective of this book is to provide scientists, science educators, university administrators, government entities, research funders, and other interested groups with an overview and critical analysis of historical and current developments and ongoing discussions regarding several important aspects of the scientific scholarly communication system based on thorough examination of the published literature on these topics. Therefore, we believe this book will provide an incentive for readers to become informed, join the conversation, and become active participants in helping transform the future of the scientific scholarly communication system that anchors the scientific endeavor, benefiting all of us and the environment in which we live.

Murray, KY, USA Pali U.K. De Silva
Murray, KY, USA Candace K. Vance

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Chapter 1
Scientific Scholarly Communication: Moving Forward Through Open Discussions

Abstract The formal scientific communication system has continued to evolve over the last 350 years, shaped by economic factors, geopolitical events, and technological advances that are taking place at an unprecedented pace. However, throughout this evolutionary process, the discussions, debates, and deliberations that have taken place can be considered the most significant factors in improving the quality of the scientific scholarly communication system. This chapter touches on some of the discussions, debates, and conscientious deliberations that have occurred and currently taking place influencing toward a more efficient scholarly communication system needed to enhance the quality and the speed of scientific progress.

Keywords Scientific communication · Open access · Open data · Genetic data sharing · Scientific scholarly impact · Intellectual property rights

1.1 Introduction

Formation of the first scientific society and the introduction of scientific journals in the 1660s together mark the birth of the formal scientific scholarly communication system. The evolution of this system during the three and a half centuries since then is fascinating; at times it was shaped and directed by geopolitical events, at times it was heavily influenced by economic issues, and at times it has even been in a crisis mode. However, most striking are the technological advances that have caused revolutionary changes in scholarly communication during the past few decades which are continuing and still evolving.

Formal and informal communication among scientists to exchange ideas and discuss research is a significant part of the scientific research process. Therefore, for a robust scientific research system it is essential that all researchers have access to the scientific knowledge base facilitating their active participation; any factor that restricts the dissemination of and access to knowledge impedes the progress of scientific research. Robert K. Morton, the founder of the modern sociology of

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science, says scientific knowledge should be considered as "public knowledge" accessible to not just scientists and students, but to the general public as well, a viewpoint that resonates among many others (Merton 1973). This idea of democratization of scientific knowledge is one of the facets of the "open science" movement, a concept which is becoming a buzzword in many scientific communities. Scientific research is becoming increasingly interdisciplinary, demanding the global collaboration of scientists, and unprecedented technological advances make these collaborations possible. More openness in sharing scientific information undoubtedly expands the "pool of researchers" and promotes cross-breeding of ideas which opens up new approaches, broadening and diversifying the scientific research process.

1.2 Open and Unrestricted Access to Scientific Information

After the formal system of sharing scientific research findings began with the publication of the *Philosophical Transactions of the Royal Society* in 1965, scholarly journal publishing developed into a subscription-based model controlled exclusively by commercial publishers and scientific societies. However, the domination of a few players in journal publishing caused access to scientific knowledge to become increasingly unaffordable and restricted, which alarmed scientific and academic communities. In response to these developments, challenging the traditional subscription-based model, the open access (OA) publishing movement was born toward the end of twentieth century, marking a significant milestone in scholarly scientific communication.

Another noteworthy aspect of this development is that it also sparked invigorating and open discussions related to many other aspects of scientific communication among stakeholders of scientific research. Progress in OA publishing facilitated by technological advances, gained attention and support among many groups, including policymakers and research funders. As a result, bold experimentation on different OA publishing models has produced promising options, such as the green (self-archiving) and gold (author-pay) OA publishing models. Although these models show high potential, they are still in the early stages of development. The open discussion among many stakeholders regarding the promises, limitations, and shortcomings of OA publishing is continuing and should continue. Important issues that are being discussed include the economic sustainability of these models, and, most importantly, maintaining high standards of scientific journal quality. The predatory journal publishing practices that exploit the gold OA publishing model have become a sticking point in an otherwise very promising publishing model that has reported many successes.

1.2.1 Concerns with Openly Sharing Sensitive Scientific Information

Unrestricted access to scientific information has many advantages, and certainly it accelerates scientific progress. However, the current trend toward openness in scientific information sharing sometimes collides with economic interests, scientific cultures, and individual professional ambitions. Additionally, there may be instances in which the level of openness in information sharing needs to be carefully assessed. For example, sharing of certain scientific information would harm individuals (e.g., research participants) or the society at large. Research in some scientific fields (e.g., nuclear weapons) has always been considered as sensitive, and restrictions on sharing research findings have been justified on the basis of national security and the risk of proliferation of nuclear weapons. There are other instances that exemplify the need for critical assessment of potential risks versus benefits of sharing scientific information (Resnik 2013). In a notable example, a multinational debate erupted in 2011 when two groups of scientists attempted to publish their research on the H5N1 virus in *Science* and *Nature*. These two studies were conducted in two countries, and one project was funded by the National Institute of Health (NIH) in the US. The concern was that if the details of these genetically engineered H5N1 strains of avian influenza virus, which now had the capability to infect humans, were openly shared, the virus could be used as a bioweapon by terrorist groups. Although the initial recommendation was to publish the papers without the methodological details and share them only with "responsible" scientists, after a year-long conscientious debate, it was ultimately decided to publish the complete articles (Malakoff 2013). This incident persuaded NIH to impose new rules on NIH grant funding requirements, making researchers identify studies that might lead to "dual use" findings (i.e., with the potential for both benefit and harm) and, if so, to create risk mitigation plans. Additionally, NIH examination of abstracts or manuscripts is required prior to conference presentations or submission to journals resulting from such studies. These developments, some argue, not only restrict dissemination and access to knowledge, but even obstruct the freedom of scientific inquiry (Resnik 2013; Malakoff 2013). An open and honest discussion is needed about how to maintain the delicate balance of ethos of openly sharing information and controlling access to scientific information that can be misused to harm human life and the environment.

1.3 Sharing Scientific Data

As science becomes increasingly collaborative, the need for data sharing becomes more apparent, and its advantages have been greatly acknowledged in many scientific disciplines. Therefore, there is a push toward making scientific data readily and broadly available. One of the best examples that highlighted the significance of this is the human genome sequence project. Rapid release of human genomic data enabled global collaborations of scientists to work on causes of rare human diseases and find new insights into other important health conditions (Birney et al. 2009; Danielsson et al. 2014). Some data-intensive scientific fields, sometimes referred to as “big science,” are equipped with data collection and management infrastructures that also support data sharing among dispersed groups of scientists (Kaye et al. 2009; Borgman 2012). However, data sharing is not prevalent in many disciplines, especially in hypothesis-driven, small-scale scientific research fields known as “small science,” for reasons such as data heterogeneity, inaccessibility, lack of proper understanding of scientists regarding correct data management practices, and the absence of a data sharing culture.

In many instances, having data unavailable in accessible form is a major concern. This issue is prevalent in some scientific fields such as ecology. For example, environmental and ecological disasters are becoming more frequent and a scientific examination of the ecological impact of such a disaster requires access to a variety of datasets related to multiple disciplines including marine biology (benthic, planktonic, and pelagic organisms), chemistry (for oil and dispersants), toxicology, oceanography, and atmospheric science. Scientists study these incidents and collect enormous amounts of data in diverse forms, and these data sets may be collected to answer specific research questions. However, preserving and making them available in accessible form is important, as these may be useful in another related ecological disaster in a different location or time. Reichman et al. (2011) discussed this issue by highlighting the Deepwater Horizon oil spill in the Gulf of Mexico in 2010. According to them, most current and historical data collected by numerous studies related to oil spills are not available in accessible form or have been completely lost except for data available from a few well-organized research groups. This lack of information (or access to information) limits scientists’ ability to examine the short- and long-term ecological effects of oil spills (Reichman et al. 2011). There may be many similar incidents—some that have received attention and many more that have passed unnoticed—that need to be highlighted in order to activate open discussions within scientific communities of different disciplines. Such discussions and debates will lead to increased awareness and promote the culture of data sharing within disciplines where it is lacking.

Sharing data in accessible and reusable forms allows others to recheck the validity of inferences made based on collected data. The ability to scrutinize research findings after formal publication is considered a form of peer reviewing. This post-publication review can be even more important than pre-publication peer reviewing, the traditional quality evaluation measure used in scholarly communication. The openness in data allows confirmation of research findings and self-correction of scientific mistakes. Begley and Ellis (2012) reported disturbing realities revealed through an examination of some preclinical cancer research studies. Out of 53 studies examined, the findings of only 11% could be confirmed.[1]

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[1] Scientists at the biotechnology firm Amgen in Thousand Oaks, California.

Another group of scientists reported similar findings; only 25% of the preclinical studies they checked could be validated (Begley and Ellis 2012). To promote self-correction of scientific research, Boulton (2014) argues that data should be discoverable, accessible, intelligible, assessable, and reusable (Boulton 2014). Only such intelligent openness of data sharing would accomplish underlying objectives and enhance and accelerate scientific advances.

Nonetheless, casting a shadow on the advantages of data sharing, there are unintended consequences of open data that do not receive much attention. The vulnerability of large multivariable data sets to data dredging[2] is a concern. In addition, there are more opportunities (due to the analytical flexibility of large datasets) for secondary analysis of data testing new hypotheses that are different from original hypotheses of studies, which can give spurious findings. Bishop (2016) raised concerns of publication bias resulting from the unrestricted analytical possibilities provided by large datasets. Setting up data sharing agreements for secondary use, masking some codes, and blind data analysis (as is widely adopted in physics to avoid experimenter bias) are mentioned as ways to keep investigators who use open datasets honest and to reduce the chances of analytical error (Bishop 2016).

1.3.1 Privacy and Genetic Data Sharing

The advantages of sharing genetic data have been highlighted by many success stories, and the trend toward openly sharing data is continuing. However, because of the unique issues associated with genetic data, the tension continues between two major goals: maximizing genetic data sharing with an aim toward improving human well-being, and minimizing data misuse and privacy violations of genetic research participants. The genetic data of individuals holds vital information not just about the individuals but also about their extended families. The sickle cell anemia screening program targeting African Americans in the 1970s in the United States demonstrates how genetic information can be used to discriminate against a certain population group in a society. The sickle cell screening of African American ethnic groups was mandated by twelve states in the 1970s (Roberts 2010) although this genetic disease affected only 0.2% of that population. There were serious issues with this screening program: quality control measures for test methods and laboratory facilities were not followed; confidentiality of test results was ignored; mishandling of information distinguishing between “carrier status” and “disease status” by screening laboratories and public education programs resulted in stigmatizing both statuses, often resulting in individuals being denied health insurance, life insurance, and/or employment; and those diagnosed with the disease did not

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[2] Data dredging is described as uncovering statistically significant patterns in data without first defining an initial hypothesis of an underlying cause.

receive adequate counseling (Markel 1997). By the 1980s, newborn screening for sickle cell anemia became advantageous because of the availability of antibiotic treatments to prevent infections in children with the disease, although the memory of the previous decade's screening debacle still weighed on parents' minds. As this example illustrates providing guidelines, setting standards, and devising and implementing adequate federal regulations to protect the privacy of research participants and prevent data misuse are undoubtedly needed.

An equally important element is awareness among researchers regarding the importance of correctly and truthfully informing research participants, prior to sample collection, about the extent of personal information that can be obtained from their DNA. To do this effectively, researchers need to be sensitive about the unique sociocultural backgrounds of the human research subjects. The dispute involving a Native American tribe (the Havasupai people) and Arizona State University (ASU) researchers regarding the "Havasupai diabetes project," conducted in 1990–1994, illustrates both the need to fully inform research participants about the extent of a study and the need for researchers to recognize the sociocultural issues associated with the population groups being studied. Although this study was originally intended to identify genetic clues about the prevalence of diabetes in the tribe, it was revealed that researchers at ASU and other institutions used the Havasupai blood samples to conduct research on schizophrenia, inbreeding, and the tribe's population migration patterns, issues unrelated to diabetes (Harmon 2010; Levenson 2010; Pacheco et al. 2013). After spending nearly $1.7 million fighting the case, ASU reached a settlement by paying $700,000 to 41 tribal members and returning the remaining blood samples. Incidents similar to these have sparked debate over issues related to the misuse of genetic data. The introduction of the Genetic Information Nondiscrimination Act (GINA) of 2008[3] in the US is considered a positive step toward addressing some aspects of the potential harm that can be caused by misuse of genetic data (McGuire and Majumder 2009; Roberts 2010), although this law may not apply to gene expression profiling (Schadt et al. 2012). The discussions and debates regarding these issues need to be continued as the genetic and biomedical information landscape, powered by advances in information technology, is fast evolving.

1.4 Intellectual Property Rights and Scientific Scholarly Communication

The clash between scientific scholarly communication and intellectual property rights (IPRs) is ongoing as these two systems have contradicting ethos: one system promotes free and open communication devoted to seeking knowledge, while the other is a closed system designed for financial gain. These two systems collide at

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[3] http://www.eeoc.gov/laws/statutes/gina.cfm.

several points in the scholarly communication process, generating vigorous and ongoing discussions and debates.

Scientists build their research on previous knowledge; Isaac Newton famously described this concept as "standing on the shoulder of giants.[4]" This process leads to new insights or new discoveries, and the body of scientific knowledge expands. Historically, academic researchers, unlike their industry counterparts, allowed others to build on their research findings. However, in the 1980s, commercialization of academic research was promoted by introducing government legislation in several countries. In the US, the Bayh-Dole Act and the Stevenson-Wydler Act, both passed in the 1980s, are considered significant in this regard. Following the passage of those acts, technology transfer offices were established in universities and government laboratories to facilitate patenting and licensing of scientific discoveries (Mowery et al. 2001; Grushcow 2004).

The positive and negative effects of commercialization of academic scientific research on sharing of scientific knowledge have been forcefully debated. The argument against the emphasis on commercialization of scientific research, especially publicly funded research is that it directly conflicts with the mission of a research university. Some scholars argue that this represents privatization of "scientific commons," preventing or slowing down the free flow of scientific knowledge, and is detrimental to scientific progress (Azoulay et al. 2007; Merrill and Mazza 2011). Patenting involves secrecy, and the timing of disclosure is complex and varies in different countries. There is even ambiguity regarding whether sharing information at a conference, a common practice scientists traditionally use during the pre-publication phase to discuss their findings and exchange ideas, would bar patentability of a discovery. Empirical evidence shows that scientists are compelled to maintain secrecy, even from their colleagues, until the work is ready for patent application (Murray and Stern 2007; Bentwich 2010). The level of secrecy is higher for industry-funded research, delaying public sharing of information (Czarnitzki et al. 2014). The argument is that IPR-associated knowledge sharing delays and secrecy conflict with the norms of openness of science (Fabrizio and Di Minin 2008), slowing down scientific progress. Another negative effect of patenting widely discussed, is the shifting research priorities from fundamental research toward applied research, which reduces the diversity of basic research.

The impacts of IPR on scientific research are more prominently seen in some scientific fields, and biomedical fields are among those. There are instances where gene patent holders are accused of exploiting IPRs for financial gain. Human gene patenting is a topic that has sparked debate among many groups, and a legal case challenging gene patenting, *Association for molecular pathology* versus *Myriad Genetics*, led to a landmark Supreme Court decision[5] in 2013 that was considered a

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[4] In his letter to Robert Hooke in 1675, Isaac Newton stated, "If I have seen further it is by standing on the shoulders of Giants."

[5] No. 12-398 https://www.supremecourt.gov/opinions/12pdf/12-398_1b7d.pdf.

win for challengers of gene patenting (Andrews 2002; Liptak 2013). While proponents of IPR argue that patenting and licensing of upstream discoveries in biomedical research provide financial incentives that encourage scientists to start on challenging research projects, opponents use the “tragedy of anti-commons” metaphor to describe the undesirable aspects. Heller and Eisenberg argue (1998) that reach-through license agreements (RTLAs)[6] on patented research tools by upstream patent holders claiming potential downstream products, impede scientific discovery (Heller and Eisenberg 1998). A prominent example in the late 1980s exemplified this argument. The OncoMouse, engineered by scientists at Harvard University in 1984, represented a significant scientific breakthrough in mouse genetics becoming the center of controversy and debate. The scientists shared their findings by publishing a peer-reviewed scientific article (Stewart et al. 1984), but also patented[7] their discovery and licensed the patent to DuPont. Using reach-through clauses, DuPont aggressively enforced the IP rights of the OncoMouse patent to control products and publications developed by others using these technologies. Scientists strongly opposed DuPont’s actions because of the limitations imposed, and NIH reached an agreement with DuPont in 1999 on the terms of use of OncoMouse technology and research tools, and signed a Memorandum of Understanding (MoU) easing the restrictions for research sponsored by NIH (Murray and Stern 2007). Using citation rates, Murray et al. (2009) investigated the effect of the MoU and observed a significant increase in citations for mouse articles and an increase in follow-on research that used OncoMouse and Cre-Lox[8] mouse technologies and research tools after the MoU was signed. They suggest that these increases resulted from the greater diversity of research paths, providing evidence that openness intensifies scientific research progress by opening up new research directions (Murray et al. 2009). In the citation patterns of articles published as “dual knowledge disclosure”[9] or patent–paper pair disclosure, a significant decline in citations was reported compared with the control group (i.e., articles that were not published as dual knowledge disclosure), and even a statistically significant decline in forward citations that become more pronounced with

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[6] There are three types of reach-through licenses: exclusive license (permits only the person receiving the license to make use of the invention), sole license (only the patent holder and the person receiving the license can use the invention), and nonexclusive license (the patent holder and anyone else that the patent holder chooses can use the invention).

[7] In 1988, Associated Press reported that *Fortune* had named OncoMouse™ as the “Product of the Year” and stated that, “For the first time, the business magazine has named an animal to its annual list of the nation’s hottest products,” Associated Press, Nov 16th, 1988. http://www.apnewsarchive.com/1988/Fortune-Names-Its-88-Products-of-the-Year/id-222b847b58f9552763a1c252b260f50e.

[8] Cre-Lox Technology provides a system that can be used to introduce gene deletions, inversions, and translocations on specific target sites in organisms.

[9] Disclosing a commercially applicable scientific discovery through both research publication and obtaining patent.

the number of years after granting IPR. These findings, according to investigators, demonstrate the anti-commons effect of IPRs on scientific progress (Huang and Murray 2009; Murray and Stern 2007). However, other investigators have challenged the anti-commons arguments (Biddle 2012). Interestingly, opinion surveys of biomedical researchers do not indicate that they are concerned about the abundance of patents in their scientific fields (Murdoch and Caulfield 2009; Walsh et al. 2007). Results also show a lack of understanding, and a level of confusion, or indifference about the issue among scientists (McBratney et al. 2004; Walsh et al. 2007).

Agricultural biotechnology is another scientific field challenged by the dynamic IPR landscape. According to some, due to the complexity of the IPR situation and the fragmentation of IPR ownership can create anti-commons effects. The impact of IPR becomes critical with genetically modified (GM) crops. Scientists have expressed concerns over requiring permission from patent holders for seeds and negotiating access to scientific data, and the requiring seed company approval to publish research findings. A group of scientists from US universities demonstrated this, when they submitted a statement regarding their concerns to the Environmental Protection Agency in 2009. These developments led some seed companies into discussions with scientists who had publicly expressed their concerns (Waltz 2009). While there are conscientious discussions going on about the constraints imposed by proliferation of IPRs on agricultural research, especially with the situation created from the introduction of GM crops, the opposing arguments regarding the need of expansion of IPR in agriculture to promote research investments is continuing (Grimes et al. 2011).

1.4.1 Impact of IPR on Sharing Data

The impact of IPRs on data sharing and data use is another debated topic. The consequences of private ownership of scientific data were illustrated clearly by the transfer of the control of the Landsat system of remote sensing images collected by the US National Oceanic and Atmospheric Administration (NOAA) to Earth Observation Satellites (EOSAT) Company in 1985, with the introduction of the Land-Remote Sensing Commercialization Act (1984). With this transfer, the price of these images increased from US$ 400 per image to US$ 4000, and David (2004) described this as a result of “ill-designed policies and programs to promote proprietary exploitation of public knowledge resources.” David also argues that this privatization move forced these research groups from a “data rich” condition into a “data non-entitlement” status (David 2004). Similarly damaging outcomes for academic scientific research data are plausible with private ownership of scientific databases under the legal rights granted by indefinitely renewable copyright protection, regardless of whether the data themselves are copyrightable (David 2004).

1.5 Measuring Impact of Scientific Research

Scientific research is built on knowledge assimilated through previous research findings. Therefore, to have a strong foundation, assessing the quality and the impact of scientific research is essential. Because of the complexity of this task, it has become the center of a major discussion among stakeholders of scientific research. Traditionally, peer reviewing has been used as the pre-publication quality assessment measure. Although the quality of scientific research cannot be quantified, quantitative measures based on citation metrics using journal articles as proxies are being developed to measure the impact and influence of scientific research. Garfield (1955) introduced the concept of using citation metrics as a quantitative measure to assess the relative importance of scientific articles and journals (Garfield 1955) and in 1972, Garfield proposed using the impact factor (IF)[10] as a measure of journal quality (Garfield 1976). The journal impact factor (JIF) is widely used and considered an objective measure with a relatively simple calculation that can be computed to depict the performance of a journal over a period of time; JIF values are promptly available in the Journal Citation Report (JCR) . However, there are several limitations of the JIF that are being extensively discussed. One of the most critically emphasized aspects of the JIF is its vulnerability to manipulation. For example, JIF values can be inflated by the inclusion of non-source items (such as letters, editorials, and meeting abstracts) in the numerator but not in the denominator (which generally includes original research articles and reviews in the denominator), publication of more review articles (which attract more citations), and increasing journal self-citations[11] (Chew et al. 2007; Garfield 1999). Journals are sometimes accused of deliberately inflating JIF by using these as well as other tactics such as prereleasing articles, adjusting the timing of article publication, and breaking manuscripts into “least publishable units” (Mavrogenis et al. 2010). The manipulation of IF by journals is critically discussed as these unethical practices undermine the credibility of this assessment indicator. Discussions prompted by these issues have raised the need for other complementary measures, and new measures such as SCimago Journal Rank (SJR) and the Eigenfactor Score were developed as a result.

Finding effective and objective measures to assess the performance of individual researchers is important for a variety reasons, including evaluations for competitive research grants. Citation metrics are becoming increasingly used in this regard, but it needs to be stressed that proper understanding of the limitations of each measure is critical because the use of inappropriate measures might provide incorrect assessment. Moreover, it is disturbing to see that funding agencies, promotion

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[10] The impact factor (IF) of a journal is derived by adding the number of citations in the current year of items published in a journal in the previous two years and dividing it by the total number of articles published in the same two years.

[11] Journal self-citation refers to the situation when articles in a particular journal cites articles published in the same journal during the previous two years.

committees, and scientists often use JIF to assess the scientific contributions of individual scientists and institutions, although it was designed to measure the influence of journals, not scientists. To overcome the shortcomings of bibliometric indicators in assessing individual scientists, Hirsch (2005) proposed the *Hirsch* index (*h*-index)[12] (Hirsch 2005), which takes into account both the quantity and the impact of a researcher's publications (Bornmann and Daniel 2007) and can be used to assess the impact of research groups and institutions as well (Egghe and Rousseau 2008; Molinari and Molinari 2008). Ease of computing and objectivity are considered strengths of the *h*-index, but it has several limitations, and many different variants (e.g., *g*-index, *hm*-index, *r*-index, etc.) have been proposed to address those limitations.

Bibliometric measures can be considered the best quantitative tools yet implemented to assess the quality and influence of scientific research. Because of the complexity of the scientific communication landscape, measuring the impact of scientific research is extremely challenging, and the discussions and debates on widely used bibliometric measures reflect these challenges. Moreover, because citation metrics rely on scientists citing previous work that influenced their research, these measures mainly assess the scientific impact of research. Although the assessment of scientific impact is critical, consensus is building among stakeholders of scientific research regarding the importance of measuring the societal benefits, as well, to get an overall assessment of the impact of scientific research.

Measuring societal benefits of scientific research can be even more challenging than assessing the scientific impact due to a variety of reasons. For example, "societal benefit" cannot be clearly defined as it may mean different things to different people, and the impacts of research vary with the scientific discipline, the nature of the research project, and the target group, etc. Because of these complexities, the need to use different indicators or combination of metrics depending on circumstances is clearly understood. In spite of ongoing international efforts and discussions on identifying the best measures to assess the societal impact of research projects when allocating public research funds, a clear consensus does not seem to have been reached yet. However, there are new developments on the horizon.

As the publication and access of scholarly literature moves exclusively into the online environment, and with the increasing popularity of quantitative metrics,[13] some social web tools are gaining attention for assessing the "quality" of scholarly publications. In addition, since the social web has a wide audience outside of science, it may offer an alternative way of assessing the societal impact of scientific research (Thelwall et al. 2013). Tapping into this potential, PLoS started collecting article level metrics (ALMs) for its articles in 2009, and the potentials of alternative

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[12] "A scientist has index h if h of his or her Np papers have at least h citations each and the other (Np _ h) papers have _h citations each" (Hirsch 2005).

[13] Advantages of quantitative metrics are, cost effectiveness, ease of collection, transparency of collection process, objectivity, verifiability, and ability to use data in comparative and benchmarking studies (Donovan 2007).

metrics for measuring the level of user-reach and engagement became a topic of discussion. Consequently, the term "altmetrics,"[14,15] a term that encompasses a variety of web-based alternative metrics including social media interaction data providing immediate feedback was proposed.

There are several advantages of altmetrics as assessment metrics when compared to the traditional bibliometric system. The speed—enhanced by social media—at which altmetrics become available (in some instances even before the formal publication of scholarly work when preprints are available) in comparison to traditional citations is considered a major advantage. However, as the quality of scientific research needs to be assessed after careful examination and with scholarly insight, which takes time, the most important question raised is what these instant responses tell us about the quality or impact of research work, and how to interpret them. Poor data quality due to the fluidity of the web environment is a major issue with altmetrics. Another criticism of altmetrics is the emergence of dishonest practices such as gaming (i.e., artificially increasing the number of views of an article, automated paper downloads, robot tweeting, etc.), because of the ease with which web-based data can be manipulated. Therefore, interpreting altmetric data in assessing scientific research needs to go beyond just highlighting the counts and must be done with utmost care until these data sets are reasonably defined, characterized, codified, and standardized. The use of altmetrics is still at an early developmental stage, and continued discussions and deliberations are needed to improve their data quality and trustworthiness. Starting this process, the National Information Standards Organization (NISO) of the United States initiated the Alternative Assessment Metrics Project in 2013 to address issues related to altmetric data quality and to identify best practices and standards.

1.6 Concluding Remarks

The dissemination and access to scientific information is an ever-evolving story. The information presented in this chapter illustrates the discussions and invigorating debates regarding the many facets of the complex scientific scholarly system. To make it a better and more efficient, these discussions, debates, and deliberations need to go on with the involvement of all stakeholders—scientists, funders, publishers, governments, universities and research organizations, private industry, and concerned citizens—with a greater understanding about the intricacies of this dynamic system. The proceeding chapters of this book are intended to examine several of the important aspects of the scientific scholarly communication system to

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[14] The altmetrics manifesto was published in October 2010. It is available at: http://altmetrics.org/manifesto/.

[15] "Influmetrics" (Rousseau and Ye 2013) or "social media metrics" (Haustein et al. 2015), are other terms suggested for alternative metrics.

help stakeholders understand the roles they have to play individually and collaboratively to improve the scientific communication system as it impacts the progress of science.

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Chapter 2
Access to Scientific Knowledge: A Historical Perspective

Abstract The scientific communication system familiar to us today has evolved over several centuries. Journal articles became the conventional means for publishing ideas, theories, and research findings and journals became the formal "dissemination carriers." Although learned societies played a dominant role in journal publishing at the beginning, toward the end of the twentieth century, both societies and commercial publishers controlled journal publishing, but commercial publishers became dominant players in the twenty-first century. While the subscription-based journal access model persisted overtime, issues related to restrictions imposed upon accessing scientific knowledge which is essential to the progress of science and the sustainability of this system gained attention toward the end of the twentieth century and continued to the twenty-first century. Continuously increasing scientific journal subscription rates, publishers offering package deals reducing journal selection options, and publisher merges increasing oligopolistic control of journal publishing created the "serial crisis" in which university libraries struggle to provide access of scientific journals to their academic communities. These developments, how the university communities and academic libraries reacted to the situation, and how advances in the computer and communication technologies started reshaping the entire scholarly communication landscape, opening up new horizons in the quest for seeking alternative journal publishing models are discussed.

Keywords Electronic journals · Electronic publishing · Scientific scholarly communication · Scientific societies · Commercial journal publishers · Scholarly journals · Subscription-based journal access model

2.1 Introduction

Communication is an essential facet of the pursuit and advancement of science. Scientists communicate to exchange ideas and discuss their findings with other scientists at different stages of the scientific research process; these exchanges

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Fascinating Life Sciences, DOI 10.1007/978-3-319-50627-2_2

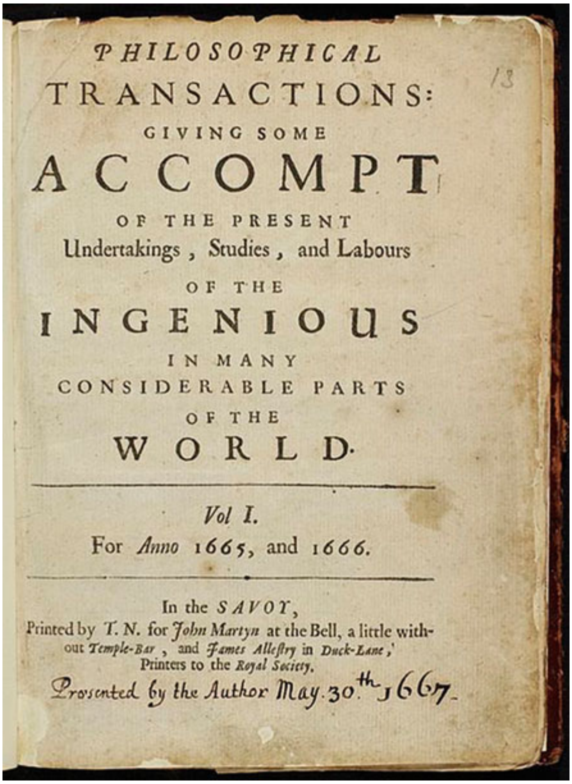
include both formal and informal communications. The dissemination of and access to scientific information are the two main aspects of the scientific scholarly communication process.

2.2 Scientific Scholarly Information Sharing: 1600–1900

The scientific communication system familiar to us today has evolved over several centuries. Paisley, in his 1972 article, discussed the role played by the informal social relationships among scientists, referred to as the "invisible college," in transfer of scientific information during the 100 years or so after the formation of "the Royal Society for Promoting Practical Knowledge" in 1668 (Paisley 1972). The formation of scientific societies was the earliest significant juncture in the history of scientific scholarly communication. In the 1660s, the Royal Society of Science and the Paris Academy of Science were being reported as the first scientific societies created. Between 1660 and 1793, nearly 70 official scientific societies or academies were formed; these followed the model of either the Royal Society or the Paris Academy. In addition to these two major types, other societies based on the scientific institutions, such as observatories and botanical gardens thrived during this period (McClellan 1985, p. xix). These societies promoted science through a variety of institutional activities, including conferences to facilitate communication within their respective scientific communities. Over time, scientific conferences became an important channel, not only for sharing but also for reexamining findings of scientific research prior to formal publication.

Some of the early societies established the first formal scientific journals in the seventeenth century. In 1665, the Royal Society of London published the *Philosophical Transactions for the Royal Society*, the world's first and longest-running scientific journal (Fig. 2.1) (Oldenburg 1673).

This was followed by various types of scientific and technical publications introduced by other scientific societies. There were mainly two types of scientific society publications: transactions (e.g., the *Philosophical Transactions*), which were published quarterly or trimestrally, and *Mémoires* (e.g., *Histoire et Mémoires* of the Paris Academy), which were published annually (with some lapses) and were generally restricted to members of the society. This trend continued into the eighteenth century, and both of these types of society publications were considered as primary places for the sharing of original scientific research (McClellan 1985, pp. 10–11). Although some journals originated as individual initiatives, scientific societies were the institutional centers that facilitated formal scientific communication and gave rise to scientific journals (Singleton 1981) and journal articles became the conventional means for publishing ideas, theories, and research findings. Ziman (1969) identified this as "a mechanism for the systematic publication of fragments of scientific knowledge" and described this arrangement as the "technique of soliciting many modest contributions to the vast store of human knowledge" (Ziman 1969).



13

PHILOSOPHICAL
TRANSACTIONS:
GIVING SOME
ACCOMPT
OF THE PRESENT
Undertakings, Studies, and Labours
OF THE
INGENIOUS
IN MANY
CONSIDERABLE PARTS
OF THE
WORLD.

Vol I.
For *Anno* 1665, and 1666.

In the *SAVOY*,
Printed by *T. N.* for *John Martyn* at the Bell, a little without *Temple-Bar*, and *James Alleſtry* in *Duck-Lane*,
Printers to the *Royal Society*.
Presented by the Author May.30th 1667.

Fig. 2.1 The Philosophical Transactions of The Royal Society, Vol. 1, 1665 and 1666. Story of the formal scientific scholarly communication began with this momentous publication

The prominent role played by the scientific societies in journal publishing diminished as commercial publishers entered the scientific scholarly communication arena during the nineteenth century. The goals and strengths of these two groups in the scholarly communication system may not have always been complementary. For example, commercial publishers may have more resources to promote and expand worldwide sales of journals, thereby enabling efficient dissemination of research findings. However, it can be argued that, since commercial publishers are motivated by financial reasons, they might tend to expand their enterprises regardless of the demands, needs, and affordability of the publications they provide. On the other hand, learned societies might be more interested in maintaining the standard of their publications and promoting their subject disciplines rather than increasing their profit margins. However, since the learned societies promote their specific disciplines, they might not be responsive to the needs of emerging interdisciplinary specializations. In addition, limitations in resources and manpower needed to market their publications can also limit the growth of the scholarly communication system (Singleton 1981).

2.3 Scholarly Communication Developments in the Twentieth and Twenty-First Centuries

As the scholarly communication system was evolving during the eighteenth and nineteenth centuries, a steady journal growth was observed. Based on the scientific journal data from the 1650 to 1950 period, de Solla Price and Page (1961) reported the number of scientific papers published annually doubled every 10–15 years (de Solla Price and Page 1961). The journal growth in the twentieth century was influenced by a variety of external factors. In the first four decades of the century, funding for scientific research was mainly from governments, and the scholarly communication system was controlled by the scientific societies even though there were some commercial players (Mabe and Amin 2001). Due to geopolitical events such as the expansion of nuclear weapon development and the space race, the next few decades saw an increase in research funding for science and technology fields by the governments of many developed countries, resulting in a high rate of growth in scientific research worldwide. There was an upsurge in publication of scientific scholarly articles after World War II. Taking scholarly output of mathematics as an example, Odlyzko (1995) estimated the number of published articles doubled about every 10 years from the end of World War II until 1990 (Odlyzko 1995).

The scholarly communication system at this particular juncture moved to a mixed model controlled by both societies and commercial publishers (Mabe and Amin 2001) (Craig et al. 2007). The rapid growth phase of journal titles was followed by slower growth after the 1970s, especially in general and physical science, and in technology fields (Mabe and Amin 2001) (Archibald and Line 1991). Even under a different geo-social environment in the twentieth century, a compounded annual journal increase of 3.3% was observed (Mabe and Amin 2001). However, according to another study, the number of journal titles as well as the number of articles in each journal declined during the period 1980–1987 (Archibald and Line 1991). Meanwhile, the journal publishing market continued with ownership by both commercial enterprises and scientific societies. Singleton (1981) discussed the perceived and actual roles of societies and others in journal publishing and showed a substantial amount of cooperation between these sectors (Singleton 1981).

The scholarly communication system evolved to become a more formalized journal publishing structure by adding complementary abstracting and indexing tools, as well as other services. This system was accepted as the fastest, convenient, and trusted way to disseminate and access scientific research findings. The scholarly communication system based on journal access by subscription-based model progressed and persisted. However, concerns about the restrictions imposed on the sharing and access to scientific knowledge and the sustainability of this system started gaining attention towards the end of the twentieth century and the debate continued into the twenty-first century. Meanwhile, revolutions in information technology, developments in higher education and scientific research communities, and the growth, modifications, and challenges in the publishing sector continued to shape the scholarly communication landscape in the first decade of the twenty-first century.

2.4 Journal Subscription Debates

In the 1970s and 1980s, as the cost of journal subscriptions was rising, the economics of journal publishing became an important topic of discussion. According to Cummings et al. (1992), scientific and technical journal subscription prices increased at an average rate of 13.5% per year from 1970 to 1990, exceeding the rate of inflation. The factors for this increase, according to the authors, were the high production cost of scientific journals; the higher subscription rates charged by commercial publishers; the increase in new specialized journal titles which tend to have smaller subscription bases at the inception; and the concentration of science journals within a few publishers (Cummings et al. 1992). According to the annual Periodicals Price Survey in 1997, 13 scientific, technical and medical (STM) fields (physics, chemistry, astronomy, biology, math and computer science, engineering, technology, geology, botany, zoology, health science, food science) had the highest subscription prices. These same 13 disciplines, with minor changes, topped the subscription pricing ladder for the eight years of data available (Ketcham and Born 1997). A subscription price increase of more than 40% was observed in these fields (except astronomy) during 1993–1994. Because of increasing science journal subscription prices, the dwindling budgets of research libraries were not able to retain their purchasing power: they were forced to allocate larger portions of their acquisitions budgets into science journal subscriptions, resulting in cancelation of some journal titles and reduction in monograph purchasing.

The scholarly communication system underwent an unprecedented transformation during the last decade of the twentieth century. One of the major factors in this transformation was the developments in information technologies, resulting in the emergence of electronic journals (e-journals) in the mid-1990s. In 1995, the Association of Research Libraries' Directory of Electronic Journals listed 139 peer-reviewed e-journals, but only 9% charged a subscription fee, with the highest rates in the scientific and medical fields (Van Orsdel and Born 1996). The percentage of e-journals in the Science Citation Index was 24% by 1997 (Van Orsdel and Born 1997) and, persuaded by authors, the larger STM journal publishers began to invest heavily in technology. Some publishers, including Blackwell Science, MCB University Press, and Taylor and Francis (T&F) experimented with different access models, such as providing user gateways for their journal products instead of using the traditional system. Meanwhile, publisher mergers continued to reduce competition, which was not encouraging news for libraries faced with shrinking budget situations and increasing demands to provide access to scholarly information to their academic and research communities.

To exert pressure on commercial publishers and shape the scholarly communication marketplace, libraries, universities, and learned societies experimented with alternative measures. The Scholarly Publishing and Academic Resources Coalition (SPARC), founded by the Association of Research Libraries, created a fund to support nonprofit scholarly publishing and initiated several scientific e-journals (Van Orsdel and Born 1999). The HighWire Press, started by Stanford University Library in the mid-1990s, introduced an e-publishing platform to help societies with electronic journal publishing; they had early success with publishing high-quality STM journals and expanding the market within and outside the United States (Van Orsdel and Born 1999). Another attempt by learned societies, universities, and government research organizations was to start creating databases with features appreciated by scholars (such as linking journals and scholarly papers) and offer them at a much lower price than commercial publishers. These competitive efforts by the nonprofit players and the demand for better deals forced successful STM publishers to provide more value-added products. In late 1999, 12 STM publishers—John Wiley and Academic Press, American Association for the Advancement of Science, American Institute of Physics, Association for Computing Machinery, Blackwell Science, Elsevier, IEEE, Kluwer, *Nature,* Oxford University Press, and Springer-Verlag—collaborated with each other to link citations to full-text articles across their collections (Van Orsdel and Born 2000).

Amidst these developments, the high-cost of journal subscriptions continued (Fig. 2.2), compelling libraries to cancel print journal subscriptions and divert that money to accessing e-journals and related products (Van Orsdel and Born 1999). In addition, journal publishers started offering package deals. The continued concentration of scientific publishing among a limited number of publishers was a concern for consumers of scientific information. The dominating

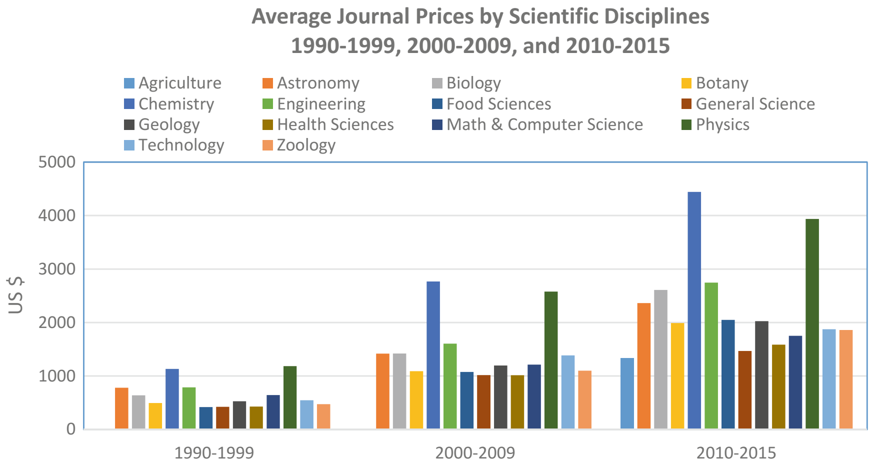


Fig. 2.2 The rise of average journal prices by Scientific Discipline from 1990–2015. *Data source* “Periodicals price surveys” from 1990–2015 published by the *Library Journal*

commercial STM journal publishers in 2006 were Elsevier, Wiley, Springer, T&F, Kluwer Medical, Thomson, and Blackwell (Van Orsdel and Born 2007). By 2011, half of the journal titles were from five major commercial publishers—Elsevier, Wiley, Springer, T&F, and SAGE—and all of them offered "Big Deal" journal packages in which cost increases were dictated by contracts (Bosch and Henderson 2012). Dissatisfied with the journal package deals offered by commercial publishers, high-profile university libraries spoke on behalf of many institutions about their intention to reject package deals and instead to choose journals, title by title, the way it was done traditionally, meeting the needs of their academic communities in a cost effective manner (Mayor 2004).

With the introduction of e-journals, the article acquisition system appeared to change to article-by-article acquisition or "Pay-Per-View" (PPV) as an alternative to subscribing to an entire journal (Bosch and Henderson 2012). However, the oligopoly of the commercial publishers continued even in the e-journal environment. By examining nearly 4.5 million of all document types published by various journals between 1973–2013 period, Larivière et al. (2015) reported that, in natural and medical sciences, Reed-Elsevier, Wiley-Blackwell, Springer, and T&F together with the American Chemical Society were the top five publishers with the highest number of scientific documents in 2013. A striking drop was observed in the percentage of articles and number of journal titles published by publishers *other* than the major ones (Larivière et al. 2015).

2.5 Concluding Remarks

Even though the traditional journal subscription model was a convenient method to deliver content in the print environment, its economic sustainability was being questioned. More importantly restrictions imposed by high subscription rates of scientific journals and other practices used by journal publishers for accessing research findings have become major concerns. The technological advances and entry of e-journals offered the potential to rethink the entire scholarly communication system. Against this backdrop, the exploration for alternative journal publishing models that promote unrestricted access to scientific knowledge began.

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Chapter 3
On the Road to Unrestricted Access to Scientific Information: The Open Access Movement

Abstract Unrestricted access to scientific literature is considered essential for the pursuit and advancement of science. The issues related to restrictions imposed by the traditional subscription-based journal access model on free and unrestricted access to scientific information prompted the pursuit of alternative journal publishing models, and the open access (OA) movement was born. The OA publishing model is evolving, gaining support of the academic and research communities, research funders, policymakers, and even the traditional journal publishers. The discussion in this chapter covers the developments related to unrestricted access to scientific information, different OA publishing models, strengths, and issues related to two major models—Green (self-archiving) model and Gold (author-paid) model, concerns related to the quality of OA journals, and the emergence of predatory journals that abuse the author-paid OA model. In addition, the findings of studies that examine the impact of OA journals related to subscription-based journals are discussed.

Keywords Scholarly journal publishing · Subscription-based journal publishing · Open access movement · Open access publishing models · Green open access · Gold open access · Subject repositories

3.1 Introduction

Science is a distributed system in which scientists operate independently or collaboratively. Scientific claims and evidence are shared with other scientists, allowing them to be evaluated, challenged, and to be modified or reused to pursue further investigations. The open sharing of scientific literature, therefore, is considered essential for the pursuit and advancement of science. With the publication of the first journal, the *Philosophical Transactions for the Royal Society* by the Royal Society of London in 1665 (Oldenburg 1673), journal articles became the accepted means for sharing research findings and journal publishing evolved over the next three and a half centuries giving rise to the well-established

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subscription-based model. However, because of the domination of a few players in the scholarly publishing industry, the subscription rates of journals, mainly in scientific disciplines continued to rise, hindering the access, and sharing of scholarly work. Therefore, academic libraries continuously struggle to provide access to scholarly literature in what has been described as the "serial crisis." To challenge this oligopolistic control of access to scientific information by the commercial publishers in Science, Technology, and Mathematics (STM) and reduce restrictions to access scientific research findings, the open access (OA) movement was born.

At the beginning, OA journals emerged as community efforts, and several were established in the 1980s: *New Horizons in Adult Education and Human Resource Development* (1987–present) and *The Public-Access Computer Systems Review* (1989–2000) are two examples of those pioneers. During the early years, the content (in plain text) of these journals was shared using mailing lists. The OA movement picked up momentum in the early 1990s. Several investigators measured the early growth of OA journals by using the average annual number of articles published per journal as a metric. The major challenge with measuring growth in this way, however, was the unavailability of reliable data on number of articles for the majority of OA journals (Solomon et al. 2013). In 2004, McVeigh identified 1190 unique OA journal titles, out of which nearly 33% were published in the Asia-Pacific region while 40% were published in North America and Western European countries, including the United Kingdom. Nearly 20% of all OA journals identified were being indexed in the ISI (Institute for Scientific Information, now Thomson Reuters) citation databases; however, 90% of those were published in North America and Western European countries (McVeigh 2004). Solomon et al. (2013) studied the growth of OA journals and articles as well as the impact averages of journals listed in the Scopus database from 1999 to 2010 (Solomon et al. 2013). They reported that although OA journals make up less than 12% of the journals in the Scopus database, OA journals and articles have grown faster than subscription-based journals. Two-year citation averages for "gold OA" journals (journals with an article processing charge [APC]; discussed later) have reached the same level as subscription-based journals, but the citation averages for OA journals funded by other means were much lower. They hypothesized that the lower value was not driven by quality, but possibly by the fact that these journals are published in languages other than English and outside of the major four publishing countries—USA, Great Britain, the Netherlands, and Germany (Solomon et al. 2013).

The sustainability of OA journals over time has been a concern since their early days. Crawford (2002) examined the status and activity of 86 OA journals identified in 1995 by the Association of Research Libraries and reported that only 49 journals (57%) were actively publishing after 6 years. He also observed that a journal often did well during the first 2 to 5 years, but in many instances, the publication volume did not increase after that, and would end up being inactive or publishing only one or two articles per year. Out of the journals that survived, Crawford identified "small successes," journals that published a low-level but steady stream of articles annually and "strong survivors," journals that had strong publishing volumes, some even reaching 100 articles per year (Crawford 2002). Laakso et al. (2011) conducted a comprehensive analysis of the historic development of OA journals from 1993 to 2009. They described three distinct phases during this time period: the pioneering years (1993–1999), the innovation years (2000–2004), and the consolidation years (2005–2009). According to the authors, during the pioneering years, modest year-to-year growth was observed in both the number of journals and the number of articles per journal. Stronger growth continued during the innovation period. During the consolidation period, although the year-to-year growth was reduced from the peak years, the growth of annual output volume was maintained at 20% (Laakso et al. 2011). However, according to Hedlund et al. (2004), the average number of OA articles published per year was low compared to that of articles published in major subscription-based scientific journals (Hedlund et al. 2004). Some OA journals had to change their policies due to financial difficulties (Sotudeh and Horri 2007). At the same time, some of the established subscription-based journals converted to OA journals by changing their article access policies.

3.2 Open Access to Scholarly Publications: Legislative and Other Supporting Initiatives

While the scholarly community and other concerned parties were taking action to promote free public access to scientific literature, legislative initiatives were shaping in the US and Britain to force authors to archive articles generated from publicly funded research. Initial setbacks occurred due to intertwined factors associated with providing free access to scientific research findings. For example, in November 2005 the British government seemed reluctant to act on recommendations proposed by the parliamentary committee to force authors to archive articles originating from publicly funded research. This was interpreted by some as the British government's unwillingness to upset the STM publishers, the largest of whom were headquartered in the UK (Van Orsdel and Born 2005). In the summer of 2004, the National Institutes of Health (NIH) in the US proposed a mandate that grant-funded research findings be placed into PubMed Central (PMC) (NIH's open archive) within six months of the article publication date; this was amended to extend the period to 12 months, probably in response to the influence of powerful commercial publishers (Van Orsdel and Born 2005). Even some society publishers were not very supportive of the OA movement in the early days. For example, the American Chemical Society (ACS) argued that making chemical information freely available by the government would create unfair competition and they tried to persuade the US Congress not to fund PubChem (an OA database established by the NIH), but their effort was unsuccessful (Van Orsdel and Born 2006). A bill signed in December 2007, which went into effect in April 2008, required peer-reviewed research articles generated from NIH grants to be shared publicly within 12 months of publication. It requires the final version of the peer-reviewed manuscript to be deposited in PMC as soon as the article is accepted for publication, which enables immediate release of its metadata and allows it to be discovered by other researchers. This bill is very significant for two reasons: it was the first OA in the world mandated by the law of a country, and NIH is the world's largest funder of scientific research, with a budget of US$28 billion in 2007 (Suber 2008) and nearly $31.4 billion in 2016.[1] However, some journal publishers such as the ACS, the Professional/Scholarly Publishing division of the Association of American Publishers (AAP/PSP), and the International Association of Scientific, Technical, and Medical Publishers quickly responded by issuing statements criticizing the NIH mandate (Van Orsdel and Born 2008). As a result of this opposition, the US Congress introduced the Fair Copyright in Research Works Act (H.R. 6845) in 2009 to amend the NIH mandate. The supporting argument for this act was that mandating the public sharing of research publications of federally funded projects is clearly in conflict with copyright and would threaten the commercial journal publishing sector. Providing counterarguments, 47 copyright experts disputed that the NIH mandate would cause copyright violations. The Research Work Act (H.R. 3699), introduced to the US Congress in 2011, was designed to revert the NIH Public Access Policy and block similar OA developments for other federally funded research. Interestingly, in February 2012, Elsevier withdrew its support for the bill and the bill's authors announced they would no longer pursue it.

In 2006, the US Congress introduced the Federal Research Public Access Act (FRPAA) which gained strong support from the high-profile US universities (Van Orsdel and Born 2007); this bill was reintroduced in 2010 and again in 2012. It would require that manuscripts of articles generated from government-agency-funded research projects over US$100 million be made publicly available within six months after publication in peer-reviewed journals. According to the Act, these articles would need to be deposited in a repository of the respective funding agency or any other suitable repository to facilitate long-term archiving of the manuscripts. In 2015, the Fair Access to Science and Technology Research Act (FASTR) succeeded FRPAA. This bill is under active consideration at the time of writing. If passed, this will be very important legislation because tens of billions of research dollars are spent annually by 11 US government agencies including NIH, the National Science Foundation (NSF), and the Department of Energy (DOE).

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[1] In 2016, NIH's research funding level remains only slightly higher than before sequestration, prior to FY 2013.

3.3 Initiatives by Scholars, Research Funders, and Other “Movers”

Copyright Law of the United States of America[2] grants authors the exclusive right (right of reproduction, distribution, and modification) to their respective writings and allows transfer of copyright to someone else by written agreement. When publishing with commercial publishers authors routinely transfer copyrights of their articles to journal publishers, in many instances due to lack of understanding about their legal rights as authors. Once authors transfer their exclusive rights to a commercial publisher, they lose the ability to openly share or deposit their work into public archives. The growth of the OA movement has elicited discussion about the consequences of exclusive transfer of copyrights to commercial journal publishers by authors and the importance of retaining full or partial copyright of their scholarly work. The vote of the faculty of Arts and Sciences at Harvard University to give permission to faculty members to post their peer-reviewed articles in an institutional repository, while requiring them to retain the right to archive their articles when signing publisher agreements, is considered the first university faculty–introduced OA initiative in the world (Van Orsdel and Born 2008). The Registry of Open Access Repositories Mandatory Archiving Policies (ROARMAP)[3] records the growth of OA mandates adopted by universities, research institutions, and research funders, and listed 574 research organizations (university or research institution) and 81 funders (as of October, 2016).

Parallel to the OA related developments in the US, significant happenings took place in Europe. For example, the Welcome Trust, a major private research foundation in Britain, had already started mandating that articles originating from their grant-funded research be publicly available, which was an encouraging move (Van Orsdel and Born 2005). By 2007, self-archiving mandates for research grant recipients were adopted by five of the eight Research Councils in Britain (Van Orsdel and Born 2007). In January 2008, the first EU-wide mandate by the European Research Council went further, requesting researchers to make research articles and related data generated from research grants available on the web within six months of publication. This was followed by nearly 800 universities in 46 European countries supporting mandates of free access to publicly funded research (Van Orsdel and Born 2008).

The Budapest OA Initiative[4] (2002), the Bethesda Statement on OA Publishing[5] (2003), and the Berlin Declaration on OA to Knowledge in the Sciences and

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[2] (U.S. Const. Art. I, § 8)—The Congress shall have Power …. To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries.

[3] Registry of Open Access Repositories Mandatory Archiving Policies (ROARMAP) http://roarmap.eprints.org.

[4] Budapest OA Initiative http://www.budapestopenaccessinitiative.org/.

[5] Bethesda Statement on OA Publishing http://legacy.earlham.edu/~peters/fos/bethesda.htm.

Humanities[6] (2003) provide detailed information, including definitions, on the OA initiative. More organizational improvement supporting OA journals continued. The Directory of Open Access Journals (DOAJ) launched in 2003 with 300 titles, can be considered the primary index of OA journals. In 2005 the number of OA journals in DOAJ amounted to 1483, with a considerable number of peer-reviewed journals in biology (61), chemistry (40), general medicine (164), neurology (31), public health (58), geology (22), and computer science (45) (Van Orsdel and Born 2005). By the end of 2015, 1558 science and 2001 medicine journals were listed, including peer-reviewed titles in biology (38), chemistry (36), and geology (106). Although DOAJ is growing rapidly, there are criticisms regarding the ambiguity of criteria used when adding a journal to the index (Bohannon 2013). In October 2008, the Open Access Scholarly Publishers Association (OASPA) launched with the purpose of developing standards, exchanging information, and educating and promoting OA publishing.

Although some publishers opposed the open sharing of scientific research findings, more and more publishers moved toward adopting OA-friendly practices. The percentage of publishers offering OA options to authors grew from 9% in 2005 to 30% in 2008 (Cox and Cox 2008). By 2009, more than 500 journals agreed with NIH to deposit published versions of articles generated from NIH-funded projects into PMC on behalf of the authors. Springer decided to deposit all the research articles in the journal *Genomic Medicine*, regardless of funding source, to PMC (Van Orsdel and Born 2009).

3.4 Measuring the Impact of OA Journals

As OA publishing is proving its potential in the field of scholarly communication, its benefits and deficiencies are being debated. Continued thorough examination is needed to clearly understand the impact of OA journals, which is undoubtedly influencing the scientific scholarly communication system. Comparisons of the impact of OA versus non-OA journals have been performed over nearly two decades by examining usage and citation data. Based on studies conducted using journal transaction log data, it is clear that OA to scientific articles increases the number of article downloads, indicating increased readership (Nicholas et al. 2007; Davis et al. 2008; Davis 2010, 2011; Davis and Walters 2011). Nevertheless, in spite of higher article download volume, OA articles did not show a clear citation advantage in several of those studies (Davis et al. 2008; Davis 2011). These observations suggest that "communities of practice" benefit from OA publishing but that its contribution to expanding the body of knowledge is minimal (Davis 2011).

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[6] Berlin Declaration on OA to Knowledge in the Sciences and Humanities https://www.madrimasd.org/cienciaysociedad/documentos/doc/berlin_declaration.pdf.

On the other hand, some studies indicate that OA articles in scientific disciplines have significantly higher article citation numbers than non-OA articles (Hajjem et al. 2006; Antelman 2004; Schwarz and Kennicutt 2004; Metcalfe 2005, 2006). To measure the citation impact, McVeigh (2004) studied OA journals listed in the Journal Citation Report (JCR) published by Thomson Reuters (formerly ISI) and reported that in spite of the presence of top-ranking OA titles in the JCR, OA journals generally ranked in the lower half of each subject category. McVeigh also observed they tend to be ranked higher by the Immediacy Index[7] than by the Impact Factor (IF)[8] (McVeigh 2004). However, Giglia (2010) reported that science OA journals ranked in the top 50th percentile in the JCR report in 2008, with 38% considering the IF, 39% considering the Immediacy Index, and 40% considering the 5-year IF (Giglia 2010). Another study conducted using JCR and Scopus data revealed that OA journals are lagging behind subscription-based journals in IF; however, OA journals founded in the last decade had an IF roughly similar to that of subscription-based journals of the same age (Bjork and Solomon 2012). Several investigators argued that free and early access to articles is responsible for the increased citation levels (Eysenbach 2006; Moed 2007; Kurtz et al. 2005; Kurtz and Henneken 2007). Based on their findings, Gargouri et al. (2010) argued that the increase in number of citations of OA articles is due to users having the advantage of selecting and citing high-quality articles because they are freed from the constraint of selective accessibility of subscription-only articles (Gargouri et al. 2010). However, Craig et al. (2007) in their critical review of previous work examining whether OA access articles have greater citation impact, highlighted methodological shortcomings of those studies and concluded that there is little or no evidence to support the hypothesis that the OA status of articles per se results in a citation advantage (Craig et al. 2007). A number of studies have shown that it is difficult to clearly demonstrate whether OA (or free access) has an independent effect on citation (Kurtz et al. 2005; Moed 2007; Kurtz and Henneken 2007; Davis et al. 2008; Henneken et al. 2006). The lack of clear citation advantage of OA over non-OA articles was explained as a result of the concentration of scientific authors in research universities with unrestricted access to scientific literature (Davis 2011). Some authors even argued that the large citation effects reported in some studies might be mere artifacts resulting from deficiencies in study methodologies (McCabe and Snyder 2011). Interestingly, McCabe and Snyder (2014) reported based on a sample of 100 journals in ecology, botany, and multidisciplinary science and biology that the OA benefit was concentrated among the top-ranked journals in the scientific fields they examined; in fact, they observed a statistically significant reduction in citations in the bottom-ranked journals in their sample (McCabe and Snyder 2014).

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[7] Journal Citation Report defines it as “the measures how frequently the average article from a journal is cited within the same year as publication”.

[8] The impact factor (IF) is a citation-based journal quality assessment measure; IF of a journal is calculated by adding up the number of citations in the current year of any items published in that journal in the previous 2 years and dividing by the total number of articles published in the same two years.

3.5 OA Influence in the Developing World

The influence of OA on scientific communication can be expected to be more significant in developing countries where access to subscription-based journals is limited, and the citation behaviors of scientists in developing countries might be predicted to reflect that. Although this aspect has not been well examined, the limited number of studies conducted so far has been inconclusive. Two studies that examined the citation behavior of scientists in biological sciences in developing countries did not reveal a strong impact of OA on their citation behavior (Faber Frandsen 2009; Calver and Bradley 2010). Because small sample sizes with high variabilities were used in these studies, detecting small significant effects would have not been possible. A study conducted by Gaulé (2009) comparing Swiss and Indian researchers and using a larger sample size reported that Indian scientists are 50% more likely to cite articles from OA journals than their Swiss counterparts (Gaulé 2009). Evans and Reimer (2009) examined the influence of OA on developing world participation in global science and showed that the influence of OA was more than twice as strong in the developing world, but was hampered by limited electronic access in the poorest countries (Evans and Reimer 2009).

For financial reasons, access to subscription-based high-impact scientific journals is very limited for scholars and researchers in some of the developing world (Arunachalam 2003). These obstacles limit their active participation in scientific progress and hinder finding solutions to problems faced by communities in these countries. To help ease this problem, there are programs such as Health InterNetwork Access to Research Initiative (HINARI),[9] Access to Global Online Research in Agriculture (AGORA),[10] Online Access to Research in the Environment (OARE),[11] and Access to Research for Development and Innovation (ARDI)[12]—four programs now collectively known as "Research4Life"[13]—through which journal publishers donate electronic subscriptions to low-income developing countries (Bartol 2013).

For researchers in developing countries, OA solves two problems at once: making their own research more visible to researchers elsewhere, and making research elsewhere more accessible to them. OA, if adopted widely, can raise the profile of an entire nation's research output. There are many successful OA initiatives in the developing world including Bioline International,[14] SciELO,[15] which hosts more than 80 journals published in Latin American countries and Spain; and

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[9] Health InterNetwork Access to Research Initiative (HINARI) http://www.who.int/hinari/en/.

[10] Global Online Research in Agriculture (AGORA) http://agora-journals.fao.org/content/en/journals.php.

[11] Online Access to Research in the Environment (OARE) http://www.unep.org/oare/.

[12] Access to Research for Development and Innovation (ARDI) http://www.wipo.int/ardi/en/.

[13] Research4Life http://www.research4life.org/.

[14] Bioline International http://www.bioline.org.br/.

[15] SciELO http://scielo.org/php/index.php?lang=en.

African Journals Online (AJOL),[16] which provides free online access to titles and abstracts of more than 60 African journals and full-text upon request.

3.6 OA Publishing Models: Green, Gold, and Other Models

OA publishing is at a disadvantage when competing with traditional subscription-based publishing, and its sustainability depends on adopting successful business models strong enough to preserve the quality and standard of articles that scholarly OA journals publish as well as the viability of the journals themselves. Two distinct OA journal publishing models have emerged, referred to as "Green OA" and "Gold OA."

3.6.1 Green OA Model

In the Green OA model, authors self-archive accepted manuscripts or published articles on a publicly accessible website, or they deposit preprint versions of accepted manuscripts or published articles in a preprint archive. Moreover, authors can publish articles in subscription-based (non-OA) journals and self-archive them to make them OA (Harnad et al. 2008). According to Björk et al. (2014) the proportion of Green OA of all published journal articles, by 2013 was around 12% (Björk et al. 2014). There are several issues related to self-archiving of publications by authors. For example, when authors self-archive their publications by posting them on their own websites or on university websites, the long-term preservation of those articles may be at risk. There may also be instances of authors posting the exact published copy of their articles without the publisher's permission resulting in copyright infringement. Another concern is the time delay in sharing publications via Green OA owing to publisher-imposed embargo periods or delays caused by authors' archiving practices. Authors' behavior was identified as a significant barrier to the expansion of Green OA (Björk et al. 2014). However, with institutional repositories swiftly increasing in number, the technical foundation of Green OA is becoming stronger, and such repositories are becoming a viable option for Green OA upload. Benefits to self-archiving in an institutional repository from a survey conducted by Kim in 2010 included accessibility, publicity, and professional recognition. The time and effort required to upload articles was cited as an impediment to participation (Kim 2011).

Subject repositories play a significant role in the Green OA model. At the time when scholarly journals were distributed primarily in paper format, sharing of

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[16] African Journals Online http://www.ajol.info/.

manuscripts in a systematic way in some subject disciplines occurred first in paper format and later on email list servers. This activity, which occurred even before the World Wide Web, can be considered as the origination of subject repositories. For example, arXiv, a repository of physics and related disciplines, started as an email interface in 1991 and added the web interface in 1993, which has been hosted by Cornell University since 2001. As of mid-2003, arXiv was a repository of roughly 250,000 full-text research articles with 20 million full-text downloads in 2002 (Ginsparg 2004). Now, arXiv has expanded to include mathematics, nonlinear science, computer science, and quantitative biology, and holds nearly 1.2 million articles (as of October, 2016). PMC, which was launched in 2000 by the US National Library of Medicine, is the leading repository in biomedical fields and serves as a leading force for the OA movement. It provides OA to manuscript copies of published articles, and some publishers allow the submission of the exact copies of published articles after an embargo period. The percentage of biomedical science OA articles available from PMC increased significantly, from 26.1% in 2006 to 36.8% in 2010 (Kurata et al. 2013). By 2014, PMC held over 2 million OA articles, and sister sites have also been created in Canada [PMC Canada] and UK [UK PMC] (Bjork 2014). In fact, by 2009 43% of self-archived article manuscripts were reported to be held in subject repositories (Björk et al. 2010). Björk et al. (2014) conducted a study of 56 repositories to examine the size distribution, topical range, services, country of origin, and information technology (IT) platforms used, and found that major subject repositories played a highly significant role in Green OA, with arXiv or PMC holding 94% of the self-archived manuscripts (Björk et al. 2014). Some commercial publishers also permit authors to self-archive their articles or authors can negotiate rights before signing copyright agreements. It was reported that over 55% of subscription-based journals permitted some form of self-archiving and that over 65% of articles indexed in Web of Science in 2003 were published in such journals (McVeigh 2004). Miguel et al. (2011) showed that "green road journals", i.e., journals that permit self-archiving options, achieve greater visibility with self-archiving than "gold road journals". They suggest that this may be the reason why more of the prestigious subscription-based journals are now providing article self-archiving options (Miguel et al. 2011).

3.6.2 Gold OA Model

The Gold OA journal publishing model is based on APCs. In this model, articles are freely accessible to everyone immediately after publication. The author charge for OA article publishing was initiated by BioMed Central (Butler 1999). This business model has been successfully used by a diverse array of journals, ranging from very small to very large, including the leading Public Library of Science (PLoS) journals. PLoS launched its first OA journal in 2003, and it was reported that the PLoS website received 500,000 hits in the first eight hours, indicating the scientific community's high level of interest (Van Orsdel and Born 2004). Moreover, the

Gold OA model gained prominence with the help of powerful advocates; several major US universities such as Cornell, Dartmouth, Harvard, MIT, and University of California, Berkeley agreed to support "A Compact" in 2009, promoting the author-pay option to ease the financial disadvantages of OA publishing (Henderson and Bosch 2010). The OA policies adopted in the UK, the Research Councils UK (RCUK), and France seem to back the Gold model (Hadro 2009).

Based on findings of a survey conducted in 2010, Solomon and Björk (2012) reported that there were large differences in sources of financing for APCs and that research grants and institutional funding are the main sources for higher level APCs (above US$1000). The level of the APC charges was strongly related to the objective or perceived quality of the journal: those with high IFs charged higher APCs. Professionally published journals charged substantially higher APCs than those published by societies, universities, or scholars/researchers (Solomon and Björk 2012). Solomon et al. (2013) observed steady growth in the number of OA journals that do not charge APCs between 1999 and 2010. They also reported a sharp increase in the number of APC-funded OA journals as well as the number of articles published in these journals after 2004, reflecting the success of some OA publishers, such as PLoS, BioMed Central, and Hindawi (Solomon et al. 2013). Based on their study findings, Davis and Walters (2011) suggested that APCs hinder broader participation in OA initiatives. However, they also observed that although *PLoS Biology* and *PLoS Medicine* charge relatively high APCs, these high IF-journals do not seem to have difficulty attracting article submissions (Davis and Walters 2011).

Meanwhile, other business models are being tested to pay the publication fees of articles to make them OA. The Compact for Open Access Publishing Equity (COPE)[17] (Shieber 2009) invites universities to commit to equitable support of the APC model of open access by subsidizing faculty fees for publishing in OA journals. COPE argues that universities subsidize the subscription-based publishing model with their subscriptions. If enough universities agreed to subsidize the APC model with open access funding pools for faculty they would support equity between the two models, helping sustain open access publication. Similarly, the Sponsoring Consortium for OA Publishing in Particle Physics (SCOAP^3)[18] was established in 2014 to support OA publishing in high-energy physics. SCOAP^3 relies on an international partnership of libraries, funding agencies, and research centers to convert journals in the field of high-energy physics to OA by paying the publishing cost; in return, the publishers reduce journal subscription fees to these organizations allowing them to redirect that money to SCOAP^3. The sustainability of this business model and its potential replicability to other disciplines is worth following (Bosch and Henderson 2014).

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[17] Compact for Open Access Publishing Equity—http://www.oacompact.org/.

[18] Sponsoring Consortium for Open Access Publishing in Particle Physics—https://scoap3.org.

3.6.3 Other OA Models

Journals that publish as OA without any limitations are referred to as “direct OA” , and those that make content freely available after an embargo period are called “delayed OA”. A third group, identified as “hybrid OA” journals, includes subscription-based journals that allow authors to pay to make their articles freely accessible. Björk et al. (2010) reported that in 2008, 62% of all Gold OA journals were direct OA, about 14% were delayed OA, and 24% were hybrid OA (Björk et al. 2010). Interestingly, some commercial publishers joined the OA movement by offering hybrid journals, giving authors the option of paying up front to make their articles free and openly available on the web; Springer Open Choice is an example. By 2006, 13 publishers (including Springer, the American Institute of Physics, Blackwell, Oxford University Press (OUP), Elsevier, Wiley, and T&F offered hybrid OA options. However, there were concerns about returning copyrights to authors, as expected in the true nature of “open access” (Van Orsdel and Born 2007). Meanwhile, prominent STM commercial publishers continued to enter into OA publishing. For example, *Nature* continued to increase OA options in 80% of their journals (Bosch et al. 2011) and launched their first fully OA journals in 2014. Another notable development was a move by some commercial publishers to acquire OA publishers; for example, in 2008 Springer acquired BioMed Central, one of the largest biomedical OA journal publishers, and in 2010 De Gruyter bought Versita.

3.7 Maintaining the Quality and Integrity of OA Journals

Quality in scientific publications is a critical but difficult concept to measure. Traditionally, journals use the peer-review process to maintain scholarly quality, and rigorous peer-reviewing needs to be part of scientific journal article publication. With the number of peer-reviewed articles published in OA journals at around 190,000 in 2009 and growing at an annual rate of 30% (Laakso et al. 2011), doubts are being raised about the quality of peer-reviewing performed by some OA journals (Björk et al. 2010). One author even described OA journals as “little more than vehicles for vanity publication with ineffective peer review” (Bohannon 2013). These concerns were brought to the forefront by incidents such as when Bentham Science Publishing accepted a hoax article for publication without the consent of the journal editors (Gilbert 2009, June 15).

An unintended consequence of the promising APC-based business model (Gold OA model) is the emergence of predatory publishing companies (Beall 2012). Some consider these developments as the dark side of OA publishing (Pickler et al. 2014) and call for action to protect the integrity of the scholarly publishing system. Predatory journals have unacceptable editorial oversight and lack of quality peer-review practices, making them ill-equipped to safeguard against unethical authoring practices. These predatory publishers have become very sophisticated, and even experienced scientists have been tricked into submitting articles and even joining the editorial boards of the fake or substandard journals they maintain (Kolata 2013, April 7) (Bartholomew 2014). Informing authors, reviewers, editors, and consumers of scientific articles about these unethical publishing practices and substandard publications is becoming critically important. To prevent the damage that can be caused by these predatory publishing practices, attempts have been made on several fronts: these include creating lists of journals with unethical practices (e.g., Jeffrey Beall's list) and creating guidelines for best publishing practices, as has been done by OASPA. As there are criticisms against the criteria used by DOAJ in indexing journals, it is crucial to tighten and improve its indexing to address the invasion of the OA journal landscape by low-quality predatory journals.

3.8 Concluding Remarks

Free and unrestricted access to scientific research findings is quintessential to scientific progress. The current digital environment allows for easy sharing and access to scientific information like never before in the history of scientific scholarly communication. As the sustainability of the traditional scholarly publishing is being questioned, the OA publishing model emerged promoting the norms of free and unrestricted access to scientific knowledge. Although barriers do exist, especially the economic interests of publishers, OA publishing has many potentials including reaching and promoting active participation of scientific communities all over the world including those in the developing world. There are concerns about the emergence of predatory journals that abuse the Gold (author-paid) publishing model impacting the quality of the scientific scholarly communication system. In addition, there are issues related to openly sharing some sensitive information that implicate individual privacy, safety, and national security that need to be resolved with conscientious deliberations. However, OA publishing can be considered as a major step toward the free and unrestricted scientific scholarly communication system that penetrates through geographical and socioeconomic boundaries, expediting scientific progress.

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Chapter 4
Sharing Scientific Data: Moving Toward "Open Data"

Abstract As the advantages of data sharing are increasingly recognized, the issues surrounding sharing and accessibility of scientific data are being widely discussed. Meanwhile, an "open data" revolution is taking shape in parallel to the open access movement for scientific publishing. The developments and contributions of a variety of stakeholders in shaping the dialog concerning scientific data sharing are discussed in this chapter. Data sharing issues and challenges are unique to each scientific discipline; highlighting these dissimilarities associated with two distinctly different disciplines, ecology and genomics are examined. In addition, challenges associated with openly sharing genomic data are discussed in detail.

Keywords Open data · Scientific data sharing · Genetic data · Ecological data · Data sharing initiatives · Data publication · Data citation

4.1 Introduction

Data can be considered as the foundation of science: a major part of the scientific research process involves collection and analysis of research data to make inferences. "Research data" is defined in many different ways reflecting the associated complexity (Wessels et al. 2014). Traditionally, scientists have considered their research data as private property, but have shared some data as tables, graphs, and summaries in their scientific publications. When publications were primarily in print format, access to complete sets of original data was usually not feasible. With advances in computer and communication technologies, however, tasks such as collection, storing/archiving, dissemination, retrieving, and analyzing data are becoming easier and faster. In this changing environment, "data sharing" has become a topic of lively discussion in the scientific scholarly communication arena.

There is growing interest in making scientific data readily accessible, as the advantages of data sharing are increasingly acknowledged. Sharing maximizes the

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value (Fischer and Zigmond 2010) and use of data by promoting follow-up research, and it facilitates combining data from multiple sources and locations, as well as across different time spans to answer new questions. The rapid release of human genome sequence data is one of the best examples demonstrating the value of broad and early sharing of data. This sharing enabled a worldwide community of scientists to work collaboratively, leading to discoveries of the causes of rare diseases and new insights into other important health conditions (Birney et al. 2009; Danielsson et al. 2014). In some fields such as clinical research, data sharing would minimize duplicative collection activities, leading to reductions in cost and effort (Ross and Krumholz 2013). The concept of sharing research data is being accepted by various stakeholders of scientific research including funding agencies, publishers, peer reviewers of research publications, scientists who are interested in reexamining research concepts, and citizens who are interested in rechecking and questioning scientific inferences (Ross and Krumholz 2013). Moreover, there is a strong argument supporting the idea that data collected through publicly funded research should be openly accessible (Borgman 2012). Thus far, however, data sharing is concentrated in a limited number of scientific fields, and there are inconsistencies in sharing practices even within those fields (Cragin et al. 2010; Henneken 2015).

Depending on the scientific discipline, research data may take various forms or be collected in diverse ways, and therefore may need to be handled differently. Furthermore, the infrastructure already available for data sharing can vary significantly depending on the scientific discipline. For example, in data-intensive fields such as astronomy and physics, sometimes referred to as "big science," data collection mechanisms are equipped with data management infrastructural support, so simultaneous data sharing with other researchers is not difficult (Kaye et al. 2009; Borgman 2012). On the other end of the spectrum is "small science," hypothesis-driven small-scale research projects led by individuals or small groups of investigators. Data collected by these projects are more heterogeneous in nature and, in many instances, may not be readily available in accessible formats. In addition to the inherent complexities of scientific data, many other barriers must be overcome when making data sharing a reality. Scientists themselves, for a variety of reasons, may resist sharing the research data they collect. Restrictions imposed by funders and data providers, as well as intellectual property (IP) restrictions, can also be considered as barriers to scientific data sharing. Cost is a major issue because storing and effectively sharing scientific data in reusable form are expensive endeavors. The misuse and misinterpretation of data, referred to by Gurstein (2011) as "triggering of spurious findings from data," are considered as potential risks of openly sharing data (Gurstein 2011).

4.2 Policy Initiatives Supporting Data Sharing

In response to increasing demand, policy initiatives supporting data sharing were first introduced in the late 1990s. The Bermuda Principles,[1] launched in 1996, established that sequencing data for DNA segments longer than 1 kb from the human genomic sequencing project to be released within 24 h of generation, making them freely available in the public domain to maximize benefits by promoting research and development. This was a significant departure from the previous policy of releasing data within six months (Arias et al. 2015). The Fort Lauderdale meeting[2] held in 2003 outlined the roles of various stakeholders—resource producers, resource users, and the funding agencies (Birney et al. 2009). The Toronto Statement[3] which was formulated during the Data Release Workshop held in 2009, included a set of suggested “best practices” for funding organizations, scientists (as data producers, data users, and manuscript reviewers), and journal editors. The possibility of extending prepublication data release policies to large biological data sets in areas other than genomics and proteomics was also discussed (Birney et al. 2009). Other developments were associated with sharing different types of data and providing descriptive information including protocols, study manuals, and other supporting documents about research projects along with data submissions. For example, the Committee on Responsibilities of Authorship in the Biological Sciences identified five principles associated with sharing publication-related data, software, and materials by authors, thus clarifying the expectations of the life science community (Committee on Responsibilities of Authorship in the Biological Sciences 2003). The Genomic Data Sharing (GDS) policy introduced by National Institute of Health (NIH) in 2014[4] differentiated the timing and mechanism of data release based on the data type (Arias et al. 2015).

4.3 Involvement of Funding Organizations and Journal Publishers

Public funding organizations play active roles in promoting data sharing endeavors, with the goal of sharing data generated by those research funds in a timely manner and with the least possible restrictions. NIH adopted a policy in 2003[5] requiring all NIH-funded researchers to submit a data sharing plan along with their grant applications for grants over US$500,000. Although the National Science Foundation

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[1] Bermuda Principles http://www.casimir.org.uk/storyfiles/64.0.summary_of_bermuda_principles.pdf.

[2] Fort Lauderdale meeting https://www.genome.gov/pages/research/wellcomereport0303.pdf.

[3] Toronto Statement http://www.nature.com/nature/journal/v461/n7261/box/461168a_BX1.html.

[4] NIH Genomic Data Sharing (GDS) policy introduced in 2014 http://grants.nih.gov/grants/guide/notice-files/NOT-OD-14-111.html.

[5] NIH Data Sharing Policy adopted in 2003 https://grants.nih.gov/grants/policy/data_sharing/data_sharing_guidance.htm.

(NSF) has had a data sharing requirement in grant contracts since 2001, in 2010 they announced a more comprehensive data management plan requirement for grant proposals. Inclusion of the peer review requirement in the NSF data management plan was a significant improvement compared to the NIH data management plan (Borgman 2012). Similar data sharing policies were formulated by the major funding organization in the UK, the Wellcome Trust, in 1997, 2001, and 2003 (Lyon 2007; Borgman 2012). Three higher educational funding councils in the UK collaborated to establish the Digital Curation Center (DCC) to focus on data sharing research and related issues; similar initiatives were pursued by other European organizations as well (Nature Editorial 2009). By now, almost all large funding organizations require some form of data sharing for all projects, including ones that focus on specific research questions (i.e., hypothesis-driven projects) (Kaye et al. 2009). In 2013, the Office of Science and Technology (OSTP) released a memorandum ordering US federal agencies with over US$100 million in annual R&D expenditures to develop public access plans to share scientific data resulting from unclassified research, making the data available to validate research findings and support scholarly publication.

The involvement of journal publishers in this endeavor is significant. In 2011, *Science* published a special issue exclusively on data, discussing the challenges and opportunities of data sharing. Emphasizing the importance of appropriate descriptions, standardizing, and archiving of data accompanying research articles, *Science* extended their data access requirements to include "computer codes involved in the creation or analysis of data" and "a specific statement regarding the availability and curation of data" (Hanson et al. 2011). In 2011, a group of major journals in evolution and ecology (e.g., *The American Naturalist*, *Evolution*, *Journal of Evolutionary Biology*, *Molecular Ecology*, and *Heredity*) adopted a policy requiring or encouraging data deposit in public archives, the Joint Data Archiving Policy (JDAP) (Borgman 2012). Other journals are similarly adopting, to varying degrees, requirements for publication-related data sharing policies. Although these are positive developments, the extent to which authors comply with the data sharing requirements of these journals has not been well examined (Savage and Vickers 2009).

4.4 Data Sharing Habits of Scientists

Openly sharing their data with others allows researchers to participate in and influence scientific endeavors far beyond their own research goals. Some empirical evidence shows that research articles with publicly available data have higher citation levels than those without it (Piwowar et al. 2007; Piwowar and Vision 2013). However, the idea of sharing research data is not always enthusiastically embraced by all scientists. Some reasons reported for the refusal or reluctance to share data by scientists include, intentions of future publishing, the desire to maintain control of data they have collected, and patient privacy concerns (for medical fields) (Savage and Vickers 2009; Tenopir et al. 2011). Tenopir et al. (2011) reported that a majority of the participants in an international survey they conducted, expressed willingness to share their data if certain restrictions were imposed on data use. Getting credit through formal citations, receiving copies of published articles, and learning about products developed by using their data were identified as some of the conditions that would possibly encourage data sharing by scientists. Low satisfaction with metadata[6] creation and data preservation tools and lack of organizational support for long-term data preservation were among main concerns expressed by survey participants. The lack of awareness among scientists about the importance of using metadata (data that describe research data) is considered a serious concern that needs to be addressed to improve data management practices and data retrieval capabilities (Tenopir et al. 2011).

Although, traditional reward and performance measures of scientists are built on research publication citation metrics, there is no similar well-developed reward system currently available for data creators (Kaye and Hawkins 2014). However, discussions on how to improve reward systems to encourage scientists to share their data and on reviewing systems to improve data quality are underway (Poline et al. 2012; Kratz and Strasser 2015).

4.5 Data Sharing in Different Scientific Disciplines

Different subject disciplines or subdisciplines may have different data sharing cultures (Savage and Vickers 2009; Tenopir et al. 2011; Reichman et al. 2011). For example, some disciplines such as astronomy, oceanography, and taxonomy possess data sharing traditions. In some disciplines (e.g., astronomy and oceanography), sharing can be easy as data collection is done using massive shared infrastructures. In Genomics, homogeneity of data and availability of established shared repositories make data sharing easy, although it has other types of challenges. Due to technological, sociocultural, and other reasons, data sharing is not yet prevalent in many other scientific disciplines, but a paradigm shift toward higher data sharing in sciences is evident. As data informatics possess challenges unique to each discipline, those need to be identified and examined carefully. The issues and challenges pertaining to data sharing in two distinctly different disciplines will be examined in the following sections.

4.5.1 Sharing Ecological Data

Some scientific subject areas are essentially multidisciplinary and require integration of data sets of a variety of forms from diverse sources. Ecology is an example

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[6] Metadata is "data about data" providing information about a dataset (why and how it was generated, who created it and when) and other technical information describing its structure, licensing terms, and standards it conforms to.

of such a field which evolved from small-scale experiments conducted by individual scientists to large multidisciplinary projects that involve the interaction of related scientific disciplines (e.g., evolution, genomics, geology, oceanography, and climatology) and even disciplines that are distinctly different (e.g., economics and epidemiology). Moreover, ecological data take different forms (i.e., text, numbers, images, and videos) and consist of not just counts, but also measurements of processes (that may require specialized expertise to document and interpret) etc. All these aspects contribute to the heterogeneity, dispersion, and provenance (origin and history) of data and are considered major challenges in accessing, interpreting, and sharing ecological data (Reichman et al. 2011). In addition to these, sociological and legal reasons, and a variety of experimental conditions unique to ecology and related disciplines can hamper access and integration of data (Jones et al. 2006).

Structured metadata systems such as Ecological Metadata Language (EML) and Biological Data Profile are used to characterize heterogeneous data. Reichman et al. (2011) discussed issues related to using structured metadata for data sets in ecology and environmental sciences. They emphasized the value in the use of controlled vocabularies to improve the system assisting researchers in locating and processing these data sets (Reichman et al. 2011). Dispersed data is another challenge unique to ecological data. The large projects that collect massive environmental and ecological data sets using sophisticated instruments are conducted by research institutes and agencies. However, most ecological data are collected and managed by independent researchers dispersed all over the world. There are large regional and subject-oriented data integration initiatives such as Global Biodiversity Information Facility,[7] the Knowledge Network for Biocomplexity[8] (Andelman et al. 2004), the Dryad repository,[9] and the National Biological Information Infrastructure Metadata Clearinghouse[10] to merge these dispersed data sets; these efforts, however are scattered and are not comprehensive.

Data repositories[11] are an essential aspect of data preservation and sharing. There are several prominent ones related to ecology and environmental sciences. Michener (2015) in his article "Ecological data sharing," listed most prominent repositories relevant for the ecological sciences that cover climate, terrestrial, and marine biodiversity data (Michener 2015). As the number of data repositories are increasing, identifying the most appropriate repository to deposit data and to locate data can be challenging. The Registry of Research Data Repositories[12] is a

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[7] Global Biodiversity Facility http://www.gbif.org/ Chavan et al. (2010).

[8] Knowledge Network for Biocomplexity https://knb.ecoinformatics.org.

[9] Dryad repository http://datadryad.org/.

[10] National Biological Information Infrastructure Metadata Clearinghouse http://ri.ijc.org/project/4008.

[11] "A permanent collection of data sets with accompanying metadata such that a variety of users can readily acquire, understand, and use the data" (Olson and McCord 2000).

[12] Registry of Research Data Repositories https://re3data.org.

searchable database of repositories covering almost all scientific fields. Additionally, there are initiatives to facilitate federated access to all independent data collections and repositories; the DataOne[13] project is an example of such initiative that provides federated access to some earth and environmental data networks. The Global Earth Observation System of Systems (GEOSS), is another example of a federation which "facilitates the sharing of environmental data and information collected from the large array of observing systems contributed by countries and organizations within the Group of Earth Observations."[14] Eventually, seamless access and interoperability of a variety of data sets related to environmental sciences would be achievable by cross-linking these large federations (Reichman et al. 2011).

As discussed previously, different disciplines have their own unique data sharing cultures. However, according to Peters et al. (2014), there is no prevalent data sharing culture in ecology and they observed that ecologists are "unevenly prepared to address regional-to continental-scale questions" (Peters et al. 2014). Michener (2015) discussed concerns ecologists have that might cause impediments to data sharing. These concerns include; time, labor, and expertise involved, lack of awareness of standards, unavailability of effective and easy-to-use metadata management tools, lack of experience with data management and not having necessary training, and inadequate institutional support. In addition, ecologists have reservations regarding the potential for misinterpretation and misuse of data (Michener 2015).

4.5.2 Sharing Genomic Data

The historic Human Genomic Project (HGP), started in 1990 and completed in 2001, relied on a worldwide collaboration of scientists, institutions, and funders. The success of this project was based on open access and sharing of data and "marked the beginning of a new way of doing genomic research" (Kaye 2012). Propelled by these successes, genomic research is now even more dependent on sharing data and materials (research samples) and international funding agencies facilitate large collaborative projects requiring large-scale data sharing. However, with these new trends, tension continues to develop between two major issues: (i) how to maximize the benefits of data sharing by promoting global research networks and, (ii) how to minimize privacy violations of human subject research participants and potential harm arising from data misuse. As genetic data can provide vital information not only about individuals, but also about members of their extended families, it is important to provide guidelines, set standards, and formulate federal regulations to protect confidentiality of research participants and prevent data misuse (Resnik 2010).

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[13] DataOne https://www.dataone.org/.

[14] Global Earth Observation System of Systems (GEOSS) http://www.earthobservations.org/geoss.php.

In 2007, the first genome-specific framework for data sharing for genome-wide association studies (GWAS) was created by NIH and a data sharing policy was introduced to address privacy protections for research participants (Paltoo et al. 2014). A central repository, the Database of Genotype and Phenotype (dbGaP), was established to store and distribute GWAS data for secondary research (Mailman et al. 2007) and individual-level data sets are being "deidentified" (made anonymous) by researchers before submission. However, the findings of Homer et al. (2008) challenged the assumption that identifying DNA of an individual would be impossible from a DNA mixture of many individuals (Homer et al. 2008). This revelation prompted NIH to move unrestricted access aggregate data sets in dbGaP into controlled access and prompted similar changes by other repositories (e.g., the Wellcome Trust Case Control Consortium) (Couzin 2008; Paltoo et al. 2014). Despite these changes, the potential for GWAS data misuse remains and continues to be a topic of discussion (Couzin 2008; Paltoo et al. 2014). The risks of identifying specific research participants (Johnson et al. 2011), the ability to infer family relationships and to reconstruct entire pedigrees from gene expression data (Schadt et al. 2012), and the ability to reveal the full genetic identity of genetic research participants have all been reported (Gymrek et al. 2013).

The debate about open sharing of genetic data and privacy came to the forefront when Landry et al. (2013) publicly shared the HeLa genome sequence in open access databases (Landry et al. 2013). HeLa, the first human cancer cell line, originated from a biospecimen taken from cancer patient Henrietta Lacks in 1951 without her knowledge or permission. Although she passed away later that year, the immortal HeLa cells have been used since then in many biomedical research projects all over the world. When family members of Lacks raised concerns regarding openly sharing the HeLa genome data, NIH had many discussions with concerned parties and agreed to provide controlled access to the HeLa genome through dbGaP (Hudson and Collins 2013).

The uniqueness of the HeLa cell line highlighted several important issues regarding genomic data sharing. A good understanding of these issues is essential to formulate measures to minimize privacy violations of genetic research participants. The concerns expressed by genetic research participants (or prospective research participants) regarding sharing their genetic data include; lack of control over their own genetic information (Kaufman et al. 2009; Oliver et al. 2012), concerns about genetic discrimination (Trinidad et al. 2010; Lemke et al. 2010), worries about possible misuse of data and potential commercialization (Ludman et al. 2010; Oliver et al. 2012), and reluctance to share their data with for-profit organizations (Critchley et al. 2015; Trinidad et al. 2010). Several investigators reported that study participants recognized the value of contributing to the advancement of research, and considered this even more important than potential privacy concerns (Ludman et al. 2010; Trinidad et al. 2010; Oliver et al. 2012; Critchley et al. 2015; Pullman et al. 2012). However, according to some investigators, study participants in spite of recognizing the value of research, still had reservations about the notion of publicly releasing genetic information without getting explicit consent from genetic research participants (Trinidad et al. 2010; Ludman et al. 2010; McGuire et al. 2008).

The privacy and misuse of data can be particularly sensitive issues in some communities shaped by unique historical events and societal circumstances. The legal dispute involving the Havasupai people (a Native American tribe) and Arizona State University[15] researchers regarding the “Havasupai diabetes project” illustrates the importance of understanding the social and cultural experiences of genetic research participants (Levenson 2010) (Pacheco et al. 2013). A form of racially targeted genetic discrimination was practiced in the United State in the 1970s, when genetic screening of African Americans for sickle cell anemia was mandated by some states (Roberts 2010).[16] A federal law introduced in 2008, the Genetic Information Nondiscrimination Act (GINA), addressed some aspects of genetic discrimination and is considered a step in the right direction (Roberts 2010; McGuire and Majumder 2009), although it may not apply to gene expression profiling (Schadt et al. 2012).

Genetic research has evolved from studies of traditional single-gene disorders and linkage analysis into genomics, where technologies are progressing from SNP chip microarray technology into exome sequencing (ES) and whole genome sequencing (WGS). The sequencing data generated by these techniques will be able to reveal many traits of an individual, including potential health risks. The rapidly changing genetic research landscape represented by ES/WGS studies challenges standard ethical issues and may warrant deeper discussion among all interested parties including researchers, institutional review boards (IRBs), research participants, and policy makers. Some argue that these decisions should not be based on individual researcher’s desire to “publish first”, or pressure from funders, institutions, journals, and other stakeholders (Schadt et al. 2012). However, faced with the reality of potential reidentification of research participants, there are arguments suggesting that in these dynamic environment high levels of privacy and confidentiality protection norms are unattainable. Consistent with these views, the Personal Genomic Project (PGP) was established using an “open consent” model: the data are collected from informed participants who know that their privacy cannot be guaranteed and that their data will be openly accessible, shared, and linked to other databases (Lunshof et al. 2008).

4.6 Data Publication and Data Citation

Publication of supporting research data together with the article promotes transparency of the research process and allows conclusions to be verified independently. With the call for openness and transparency in scientific research, there is

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[15] See Chap. 1, pp. 8–9 for more information.

[16] See Chap. 1, p. 8 for more information.

increased interest in data publication. A trend is emerging to embrace “publishing data” instead of “sharing data” (Lawrence et al. 2011) and application of principles of “publication” instead of “sharing” has been proposed to address issues related to research data availability (Costello 2009). A formal method for data publication would enable researchers to be rewarded for their useful, well-documented research data. “Data papers” are a type of data publication similar to articles published in peer-reviewed journals except that they describe datasets, collection methods, and other documentation without analyzing data and making conclusions. These data papers are published in regular peer-reviewed journals (e.g., *F1000Research*) or in dedicated peer-reviewed “data journals” (e.g., *Earth System Science Data*, Nature Publishing Group’s *Scientific Data*) that publish primarily data articles. Such journals represent a new development in scientific publishing (Costello 2009).

With data publishing becoming an important aspect of scientific scholarly communication, data citation is a topic gaining interest motivated by several reasons. The widespread application of data citation through formal citation mechanisms would provide a means of assessing the use and impact of datasets, similar to the way article citation works today. Data publication provides an opportunity for data creators to get credit when their data are cited, which in turn provides an incentive for scientists to publish their data. However, data citation is not yet widely practiced, and the lack of interest within research communities has been discussed. Reasons for researchers not publishing or citing data have been identified as their lack of know-how or the lack of a requirement to do so, as well as the vagueness associated with data citation and the absence of consistent, well-established citation approaches (Mayernik 2012). Since the tools needed to make this task easier are becoming widely available, attitudes and habits of researchers regarding data citation may change (Pepe et al. 2010). In addition, there are other stakeholders in scientific scholarly communication, such as libraries and scholarly publishers, who have joined in data citation initiatives by bringing their knowledge and experience (e.g., with digital object identifiers [DOIs] and other persistent linking mechanisms).

Data archiving is critically important to making data citations persistent over time. For this reason, some journal publishers clearly specify that datasets that have not been appropriately curated and archived may not be cited in their publications (e.g., “AGU Publications Data Policy”[17] of the American Geophysical Union-AGU). The fact that most researchers store their datasets on lab servers, without properly archiving them has been highlighted (Staff 2011). Therefore, data archiving should be given high priority and promoted in any data citation initiative. Difficulty in defining a dataset and finding the correct identifier are among other challenging issues. Scientific communities are becoming more familiar with the use of DOIs and other unique and persistent identifiers; however, some scientific datasets are highly dynamic, making it more difficult to establish distinct identifiers, and an identifier scheme with all the requirements of scientific data publication has

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[17] AGU Publications Data Policy https://publications.agu.org/author-resource-center/publication-policies/data-policy/.

yet to emerge. Wynholds (2011) proposed four identity functions[18] of a dataset to make it recognizable and unique (Wynholds 2011), but Mayernik (2012) discussed challenges in meeting each of these characteristics in relation to data citation. As many datasets have very fluid identities, citation recommendations must be flexible (Mayernik 2012). At the same time, because of the complex nature of scientific datasets, data citation recommendations must be very clear for data users, instructing them what, when, and how they need to cite. Data repositories can help data users by providing citation suggestions and built-in tools to help users to find appropriate citations for datasets and import citations into citation management programs.

Along with the developments in data publication and data citation, interest in data peer review is also increasing. As peer review enables assessing the quality of datasets and increases the trustworthiness of scientific data, it is significantly important to the way science is progressing today. In many ways, this is uncharted territory and may be even more challenging than data citation. Therefore, the peer reviewing of scientific data needs careful examination of the complexity of the rapidly changing scientific data landscape and the issues related to the peer review system.

4.7 Moving Toward "Open Data"?

The "open data" revolution, which is taking shape in parallel to the open access movement for scientific literature, will have a huge impact on the way science is documented. Increasingly, various scientific communities are discussing the value of "open data" in promoting the progress of their specific disciplines (Reichman et al. 2011). The "open data" approach, which calls for immediate release of research data, is a significant departure from the way findings have been shared through traditional scholarly publications. Some research fields such as genetics, clinical research, and ecology and environmental sciences benefit more from "open data" than others and therefore are promoted by many stakeholders including academic scientists, research funding organizations, patient groups, and other interest groups. Initiatives designed to study complex biological systems are moving toward "open data" practices to increase collaboration of scientists worldwide (Caso and Ducato 2014). The HapMap Project is an early example of a collaborative project in life science that used the "open data" model. In this project, an international consortium of research centers in Canada, China, Japan, Nigeria, the UK, and the USA was established with the objective of creating a map of

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[18] "(i) The dataset is constructed as a semantically and logically concrete object, (ii) the identity of the dataset is embedded, inherent and/or inseparable, (iii) the identity embodies a framework of authorship, rights and limitations, and (iv) the identity translates into an actionable mechanism for retrieval or reference."

human genetic variations and releasing all data immediately into the public domain. The data can be freely used by accepting the terms of a "quick-wrap" agreement not to restrict access to data by others and to share data with others who have accepted the same agreement. Although the possibility of patenting "specific utility" was not completely excluded by the project guidelines, it was stipulated that patenting of the utility of an SNP or haplotype should be done only if it would not prevent others from accessing project data (International HapMap 2003; International HapMap Consortium 2005).

The public–private partnerships formed as part of scientific data sharing initiatives are considered as positive developments in enhancing the quality of data resources. Partnerships involving both industry and public or nonprofit partners for pre-competitive research collaborations such as the Structural Genomic Consortium (SGC), Sage Bionetworks, the European Bioinformatics Institute (EBI) Industry Program, the Predictive Safety Testing Consortium (PSTC), the International Union of Basic and Clinical Pharmacology (IUPHAR), Life Science Grid—Eli Lilly, Pistoia, and the Innovative Medicines Initiative (IMI) demonstrate the participants' recognition of the value of sharing high-quality data (Barnes et al. 2009). Public–private partnerships for data sharing, which are different from traditional academic-industry partnerships, include both "closed-consortium" and "open-consortium" models. In the open-consortium model, projects are funded collectively and data are openly available for anyone to use without restrictions (Weigelt 2009). The SGC, which is funded by charitable foundations, pharmaceutical companies, and governmental organizations, is an example of the "open-consortium" model. It was created in 2004 with the objective of identifying the three-dimensional (3D) high-resolution structures of biomedically important human proteins and proteins of human parasites (Cottingham 2008). Although the value of releasing that data into the public domain was not widely accepted at the beginning, with time, both academic and industry partners recognized its advantages (Weigelt 2009). Perkmann and Schildt (2015) identified challenges for private companies in open data partnerships; they discussed how to address them and offered suggestions to policy makers on promoting more industry participation in open data initiatives (Perkmann and Schildt 2015).

In addition to the many reported public–private partnerships in fields related to human biology, there is one well-documented example of open sharing of data in the plant biotechnology field by a private company. Cereon Genomics (established by Monsanto in 1997) released and provided unrestricted access to their Arabidopsis sequencing data to the academic community (Marden and Godfrey 2012) by partnering with the NSF-funded Arabidopsis community database, the Arabidopsis Information Resource (TAIR). This effort undoubtedly accelerated the progress of research in related fields, benefitting both academic and company researchers, and it was considered a productive move for Cereon and Monsanto to improve their relationships with plant biologists to further their agricultural biotechnology research collaborations (Rounsley 2003).

Because of the complexity of the scientific data ecosystem, appropriate legal tools and governance structures need to be designed with the involvement of all stakeholders to ensure the sustainability of “open data” initiatives. Likewise, without properly addressing the technological requirements for managing, sharing, curating, and using data, it will be impossible to move forward to an “open data” model (Wessels et al. 2014). Issues unique to some subject disciplines in adopting an “open data” model are already being discussed (Wessels et al. 2014; Poline et al. 2012; Cummings et al. 2015; Reichman et al. 2011). An important outcome of these and future discussions will be to ensure that “open data” are clearly described by the data providers and well understood by stakeholders, especially those who access and use the data (Boulton et al. 2012; Poline et al. 2012).

4.8 Concluding Remarks

Data is considered the foundation of science and as the advantages of scientific data sharing are increasingly recognized, interest toward data sharing in sciences is intensifying. Data sharing in some scientific disciplines is becoming successful and prevalent. However, due to a variety of reasons, data sharing is not yet prevalent in many other scientific disciplines. As these challenges are mostly discipline-specific, these need to be carefully examined and openly discussed to find solutions. The discussion presented in this chapter highlighted some of the issues related to two distinctly different scientific subject disciplines.

In addition, the value of “open data” in promoting the progress of their specific disciplines is being actively discussed by scientific communities. This approach is progressing with proven successes in some disciplines. However, there may be many questions to be answered and many issues to be resolved when we are moving along this revolutionary path, which is a significant departure from the way findings have been shared through traditional scholarly publications. In conclusion, there is a need for conscientious deliberations and dedicated collaborations of all stakeholders to improve the complex and ever-evolving systems of scientific data sharing.

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Chapter 5
Free Flow of Scientific Information Versus Intellectual Property Rights

Abstract As science is considered a community endeavor, the benefits of sharing scientific knowledge are almost universally accepted. At the same time, the importance of transforming scientific discoveries into technologies benefiting the society at large has been similarly acknowledged. To promote and incentivize the latter, governments have adopted policies encouraging academic researchers to patent and license their discoveries. According to some, however, the privatization of academic research funded by public funding hinders the free flow of scientific knowledge, which is detrimental to the progress of science. This chapter reviews literature on the topic and discusses the complexity of these seemingly contradicting objectives—free flow of scientific information and commercialization of scientific discoveries—and covers recent developments regarding this vigorously debated topic, particularly in the fields of human genomics and other life sciences.

Keywords Bayh-Dole Act · Intellectual property rights · Technology transfer · Publicly funded research · Gene patents

5.1 Introduction

Science is traditionally viewed as an endeavor devoted to seeking knowledge. Although the value of sharing scientific knowledge and its benefits is almost universally accepted,[1] the complexity of contradicting ethos and policies confuses this collectively acknowledged purpose. When the governments of most industrialized countries began (in the 1950s) to invest in science, the conduct of scientific research and sharing of data were generally viewed as being intended for the public good, and the primary motivations of scientists were to advance knowledge, professional recognition, and human well-being (Chapman 2009).

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[1] The Article 27 of the Universal Declaration of Human Rights, adopted by the UN in 1948, state that "everyone has the right ….to share in scientific advancement and its benefits"; and for scientists "the protection of the moral and material interests" resulting from their scientific innovations. (Article 27-http://www.un.org/en/documents/udhr/index.shtml#a27).

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The strength of the academic university system of the United States was a major driving force behind the U.S. technological advances that led to economic leadership in the world after World War II. Although the U.S. Patent Act granted authority to inventors to exclude others from making, using, importing, and selling a patented innovation for a limited period of time, scientists in U.S. universities were reluctant to patent or license their discoveries and inventions through the major part of the twentieth century. As the century progressed, university involvement with patenting and licensing steadily increased, which accelerated with the introduction of the Bayh-Dole Act in 1980 (Sampat 2006). The Bayh-Dole Act created a uniform federal policy for universities to claim intellectual property rights (IPRs) and negotiate licensing arrangements for discoveries and inventions generated from publicly funded research, facilitating commercialization of these inventions to benefit the greater society (Mowery et al. 2001). The introduction of the Bayh-Dole Act was identified as a "watershed moment" that led to more extensive university -industry collaborations (Chapman 2009). Another significant development in that same year was the passage of the Stevenson-Wydler Act, which mandated the establishment of technology transfer offices in government laboratories to facilitate transfer of inventions to the private sector (Grushcow 2004). Also in 1980 the U.S. Supreme Court delivered the decision allowing the patenting of genetically modified organisms (Grushcow 2004). The U.S. policy initiatives promoting university -industry technology transfers influenced the introduction of similar legislation in the Organization for Economic Co-operation and Development (OECD) nations (Sampat 2006). Caulfield et al. (2012) discussed these developments in the western world, primarily in the UK, Canada, and the United States (Caulfield et al. 2012).

Although a sharp increase of patenting in U.S. universities was observed in the early 1980s, some empirical evidence suggests that the Bayh-Dole Act was only one factor behind this increase (Henderson et al. 1998; Mowery et al. 2001). According to some scholars, this was an acceleration of a trend that already existed before the Bayh-Dole Act, resulting from a combination of increased industry funding of university research and more streamlined technology transfer processes in universities (Henderson et al. 1998; Colyvas et al. 2002). Although increases in patenting and licensing activities were observed in Europe (Lissoni et al. 2008; Piccaluga et al. 2012) as well, some considered these trends (both in the U.S. and Europe) to be due more to growth in the biotechnological and pharmaceutical fields than to policy changes (Mowery et al. 2001; Walsh et al. 2003a, 2007; Geuna and Nesta 2006).

5.2 University–Industry Collaborations or Commercialization of Academic Research?

5.2.1 Patenting and Licensing Academic Scientific Discoveries: Government Legislations

The importance of the stated purpose of the Bayh-Dole Act and related legislations in promoting the "technology transfer" of federally funded research to industry, has been questioned (Sampat 2006). One of the expected benefits of these policy changes was the potential for economic gain from patenting and licensing academic research. In some European countries, industrial funding of university research was positively associated with patenting discoveries by those universities (Geuna and Nesta 2006). However, some scholars question the level of economic gain that can be reached through patenting and licensing for many U.S. research universities (Feller 1990; Nelson 2001) and suggest that the economic value of academic research patenting is sometimes overestimated (Larsen 2011). There are several channels by which university research findings and discoveries can be disseminated to industry. According to surveys of academic researchers, industry researchers, and development (R&D) managers, academic patenting and licensing constitute only a small portion of knowledge transfer to industry (Agrawal and Henderson 2002; Cohen et al. 2002). Discussing their study findings, Cohen et al. (2002) reported that published research papers and reports, public conferences and meetings, informal information exchange, and consulting were the most important channels of public research knowledge sharing with industry: patents and licenses were not included among them. Although patents and licenses are considered moderately important means of public research knowledge transfer to the pharmaceutical industry, research publications are more important even in this sector. Thus, Cohen et al. argue that even though the intent of the Bayh-Dole Act was to "incentivize" sharing of public research with industry by using university patents and licensing, the "public expression of public research" and informal interactions are more important means of knowledge transfer to industry R&D (Cohen et al. 2002).

5.2.2 IPR and Academic Research: The Debate

The emphasis on commercialization of academic scientific research continues to be vigorously debated. Among the positive impacts of commercialization of academic research and patenting cited by scientists include the ability to make practical contributions through industry partnerships (Shibayama 2012) and to facilitate development of technologies for the benefit of society (Murdoch and Caulfield 2009). However, the opposing viewpoint is that efforts to commercialize academic research directly interfere with the core mission of research universities, i.e., to disseminate scientific research findings openly and promptly (Azoulay et al. 2007; Merrill and

Mazza 2011). Some argue that this situation leads to privatization of the "scientific commons" and is detrimental to scientific progress (Murray and Stern 2007; Nelson 2004). Advocates of "open science" describe the commercialization of academic research as "perceptibly encroaching upon the culture of academic research and challenging the ethos of collaborative, open science" (David 2004). Another view is that when basic scientific finding are patented, patent holders have the power to decide who may continue the research and are able to keep other researchers from participating, thereby reducing the involvement of many researchers with competing ideas and hindering scientific progress (Nelson 2006). However, others suggest based on empirical evidence that "academic entrepreneurship" and "open science" can coexist without impacting the benefits of either one (Shibayama 2012).

5.2.3 *Negative Effects of Patenting Scientific Research*

The secrecy related to patent application, and the increase in the costs of knowledge and material transfers are considered as negative impacts of commercialization of academic research (Jensen et al. 2011; Biddle 2012). The shifting of research priorities in research universities from fundamental research toward more and more applied research with financial returns is another troubling consequence (Krimsky and Nader 2004; Merrill and Mazza 2011; Jensen and Webster 2014). There is a question whether the "patenting effect" is a substitute for or a complement to the scientific knowledge production process; however, studies conducted in the United States and several European countries do not provide a definitive answer (Agrawal and Henderson 2002; Gulbrandsen and Smeby 2005; Geuna and Nesta 2006; Carayol 2007; Breschi et al. 2007; Crespi et al. 2011; Azoulay et al. 2007; Markiewicz and DiMinin 2004; Thursby and Thursby 2004). Financial relationships among industry, scientific investigators, and academic institutions were reported to be widespread, especially in biomedical fields, and there are possibilities of conflict of interest arising from these relationships influencing biomedical research (Bekelman et al. 2003; Krimsky and Nader 2004; Angell 2005). Serious doubts have been raised about the possibility of corporate funding promoting selective publication of favorable research findings and blocking the release of data about ineffective and harmful effects of products (Chapman 2009). Displeasure has also been expressed regarding lawmakers completely ignoring the potential negative effects of the law on scientific information sharing and other means of knowledge transfer, during the passing of the Bayh-Dole Act (Sampat 2006).

5.2.4 *Patent Documents as Source of Scientific Information*

There is a considerable body of literature discussing the impact of patenting on university research and knowledge production and sharing. Any form of IPR, such as copyright ("author's rights" in Europe) or patent, gives the holder(s) the right to define the terms of use of their work or inventions for a specific period of time. By patenting, inventors publish and share the results and methods of their discoveries. The patent documents are required to include detailed descriptions[2] of experimental procedures that may not be included in the journal articles and scientific literature relevant to a discovery. Since companies usually do not publish their work in scholarly journals, patents can be considered a main source of information about their scientific discoveries. However, for several reasons, use of the scientific information given in patent documents is considered challenging; the reasons include the difficulty and amount of time involved in finding patents and the difficulty in reading and understanding patent documents (Nottenburg and Rodríguez 2008). Moreover, although a patent is required to provide relevant information about the discovery, the information provided in the patent disclosures may not be sufficient to "practice the invention" (Dam 1999; Lichtman et al. 2000); thus patent holders also have the ability to restrict use by not providing more information than necessary (Larsen 2011). There is empirical evidence showing that some scientists do not consider patent disclosures to be useful sources of information for related research (Jensen and Webster 2014).

5.2.5 *Delay in Disclosure of Research Findings*

Sharing early data from research work at scientific conferences is a common practice among scientists. It provides opportunities to avoid duplication of research, which might save research expenditure and time; to meet other scientists working on similar projects, which might provide collaboration opportunities; and to get ideas and suggestions from other scientists on improving or modifying research procedures. Some argue that patenting laws interfere with the "community norms of scientists" and inhibit the free sharing of information, even with colleagues (Grushcow 2004). Clearly there is a secrecy factor involved in patenting because the timing of disclosure of an invention is complex and varies across countries. According to current U.S. patent law, inventors have a 1-year grace period between the public sharing of results as a presentation or a research article and patent filing, and there is ambiguity regarding whether sharing of information at conferences would bar patentability of a discovery. Evidence shows patent-seeking scientists are compelled to keep relevant information secret, until the work is close to completion and ready for patent application, causing publishing delays of findings (Grushcow 2004; Campbell et al. 2002; Murray and Stern 2007; Bentwich 2010). Other studies

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[2] "Sufficiency of disclosure" requirement in patent application may differ in different countries. For example, the European Patent application must "*disclose the invention in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art,*" whereas, in the U.S. patent specification disclosure needs information enough for a person of "*ordinary skill in the art*" can make and use the invention without "*undue experimentation*".

show industry sponsorship of scientific research promotes higher secrecy and significantly delays public sharing of research findings (Czarnitzki et al. 2014). Some survey-based studies reveal that scientists who are collaborating with industry or conducting industry-sponsored research are reluctant to communicate with colleagues and more likely to delay publishing their work (Blumenthal et al. 1996, 1997; Campbell et al. 2000; Murdoch and Caulfield 2009). All of these findings support the argument that IPR-associated knowledge-sharing delays and secrecy go against the norms of openness of science (Fabrizio and Di Minin 2008) and slow down scientific progress.

5.3 IPR in Life Sciences

5.3.1 IPR and Biomedical Research

The impacts of IPR are more prevalent in some scientific fields than in others, and biomedical fields are among those most heavily impacted. There is a long history of U.S. court involvement in IPR in the biomedical field since the beginning of the twentieth century: the Supreme Court ruling in *Parke-Davis v. Mulford* that pure adrenaline could be patented in 1911 was considered a very significant historical event (Matthews and Cuchiara 2014). This has been followed by several important court rulings related to biotechnology patenting since the early 1980s. The court ruling in the *Diamond v. Chakrabarty* case can be considered a landmark decision since it enabled the patenting of some life forms. These court rulings paved the way to patenting living organisms (e.g., transgenic mice such as the Oncomouse in 1988), living cells (e.g., human embryonic stem cells [hESCs] in 2001), genes, and gene fragments. Since then, patents have been granted for some forms of DNA (including cDNA) and for diagnostic tests based on gene sequences. Gene patenting is a controversial topic because genes fall within the boundaries of patentability, and the debate on legal and ethical aspects of gene patenting continues (Farrelly 2007; Resnik 2001; Calvert and Joly 2011; Eisenberg 2000). According to the UNESCO 1997 Universal Declaration on the Human Genome and Human Rights, “[the] human genome in its natural state shall not give rise to financial gains.” In some instances, gene patenting has been characterized as “biopiracy” (Sarma 1999).

The exploitation of IPR by some gene patent holders for economic gain can be detrimental to the free exchange of information (Bentwich 2010). Human gene patents owned by Myriad Genetics Inc., covering the isolated breast cancer genes *BRCA1* and *BRCA2* and methods for their use to detect breast and ovarian cancer risks, sparked a major debate about human gene patenting. Deliberations occurred regarding this case within and outside the U.S. court system for many years (Chahine 2010). Matthews and Cuchiara (2014) discussed developments related to the *Association for Molecular Pathology v. Myriad Genetics Inc* (the Myriad Genetics case) and related legal and scientific arguments for and against gene patents. In June 2013, the United States Supreme Court delivered the landmark ruling that “naturally occurring genes are not patentable” in the Myriad Genetics case. At the same time, the court ruled that complementary DNA (cDNA) is patentable because it is not naturally occurring (Matthews and Cuchiara 2014).

The secrecy associated with IPR in general is a widely discussed aspect of gene patenting in particular (Andrews 2002; Murdoch and Caulfield 2009) and is relevant to the topic of information sharing and scientific research progress. Proponents of IPR argue that patenting and licensing of upstream discoveries in biomedical research can be highly profitable and can provide incentives to researchers to embark on challenging research projects. The opposing viewpoint is that IPR will create a barrier to free flow of information, hindering future research, and thus the progress of this highly significant scientific field. The “tragedy of anti-commons” metaphor has been used to describe the undesirable effects of IPR on the free flow and dissemination of scientific knowledge, hindering the ability of scientists to build and use the pertinent knowledge base of a specific research field (Heller and Eisenberg 1998; Andrews 2002). Heller and Eisenberg (1998) discussed the anti-commons effect in the field of biomedical research, especially in the case of overlapping upstream patents (i.e., those covering basic research findings) with different owners, which can lead to complex barriers that impede downstream (i.e., applied) biomedical innovations and drug development (Berman and Dreyfuss 2005; Heller and Eisenberg 1998). Heller and Eisenberg (1998) identified some disturbing issues: (i) the increase in individual gene fragment patents held by different owners with diverse interests, (ii) long delays between patent filing and issuance, and (iii) the use of reach-through license agreements (RTLAs) on patented research tools by upstream patent holders claiming potential downstream products. As an example, they used the situation created by the DuPont Corporation as the exclusive licensee of the OncoMouse patent, awarded in 1984. DuPont aggressively enforced the IP rights conferred by the OncoMouse patent, using reach-through clauses to control products and publications developed by others using these technologies. Because of the far-reaching consequences of the limitations imposed by the DuPont license, scientists expressed their strong opposition to DuPont’s actions, and NIH stepped into ease the situation by endorsing a nonprofit laboratory as a repository for genetically modified (GM) mice strains to facilitate sharing. However, the licensing terms imposed by DuPont continued to bother scientists by restricting their publications (Marshall 2000); so NIH had to reach an agreement with DuPont in 1999 on the terms for use of OncoMouse technology, ensuring that the research tools were made available royalty free and cost free for biomedical research sponsored by NIH (Murray and Stern 2007). Murray et al. (2009) used citation rates to investigate how the openness resulting from the Memoranda of Understanding (MoU)[3] between DuPont and NIH changed the nature and the level of follow-on research that used OncoMouse and Cre-Lox

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[3] MoU between DuPont and the Public Health Service of the U.S. Department of Health and Human Service https://www.ott.nih.gov/sites/default/files/documents/pdfs/oncomouse.pdf.

mouse and research tools. They observed a significant increase in the citation rate of mouse articles indicating increased research activity, and a significant increase in follow-on research after the MoU was signed. The substantial increase in the rate of exploration of more diverse research paths would have caused the increase in follow-on-research according to them. Based on their findings, they argue that increased scientific openness fosters the intensification and opening-up of new lines of research, thus diversifying research directions (Murray et al. 2009).

The concept of "dual knowledge disclosure"—the sharing of a commercially applicable scientific discovery both by research publication and by obtaining IP—is not new and examples can be found from Pasture to Shockley, but it has become prevalent in some scientific fields (Murray 2002). The dual knowledge disclosure (or patent–paper pair disclosure) of landmark discoveries in biotechnology dates back to the 1970s. Construction of biologically functional bacterial plasmids in vitro can be considered a triumphant example. Cohen et al., published their findings in 1973 (Cohen et al. 1973) and submitted the patent application in 1974.[4]

Murray and Stern (2007) reported that nearly 50 percent of articles published in the journal *Nature Biotechnology* were associated with patent–paper pairs and suggested that this system of knowledge disclosure is important for high-quality research in the life sciences. They discussed the concept of dual knowledge and the significance of IPR on the "cumulative impact of scientific knowledge" by examining whether citation patterns are different for scientific research that is ultimately patented. The authors found a significant decline in the citation rate (10–20% compared to the control group) of scientific papers of the paper–patent pairs[5] after formal IP rights are granted. Their findings also revealed that patent granting is associated with a statistically significant decline in forward citations in academic publications that becomes more pronounced as the number of years after an IPR grant increases, thus demonstrating an anti-commons effect (i.e., IPRs impact the diffusion of scientific knowledge) (Murray and Stern 2007). Following a more comprehensive examination of patent–paper pair disclosure of 2637 gene sequences, Huang and Murray (2009) reported a negative impact of patent granting on future public knowledge production (Huang and Murray 2009). However, the anti-commons thesis was met with strong reaction: Biddle (2012) discussed the opposing arguments, especially from the biotech industry, and examined some empirical studies claiming to disprove the anti-commons thesis. Biddle critiqued the methodologies and inferences reached by those studies concluding that those "neither falsify nor disconfirm" the anti-commons thesis, and discussed his findings

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[4] *Process for producing biologically functional molecular chimeras* (U.S. Patent No. 4,237,224) granted in December 1980. Cohen-Boyer licensing program which produced US$ 255 million in licensing revenues for the Stanford and the University of California system over the 25 years is considered gold standard for university technology licensing (Feldman et al. 2007).

[5] In the patent–paper pair system, knowledge disclosure occurs in the pre-IPR grant phase and after-IPR grant phase. In the pre-grant phase knowledge is disseminated through paper publication prior to patent granting. If there is an anti-commons effect, the citation rate of a publication should fall after IPR grants.

showing that there are reasons to be concerned about the anti-commons effects in biomedical research (Biddle 2012).

It has also been suggested that continued patenting of genes will result in a “patent thicket,” a term referring to the difficult process researchers have to go through to search and analyze important patents related to their research studies (Nottenburg and Rodríguez 2008; Campo-Engelstein and Chan 2015). The negative effect is that researchers will be discouraged from doing further work on improving existing techniques or processes and will focus instead on areas with no or few existing patents (Nottenburg and Rodríguez 2008). But do researchers have a different view about the impact of IPR on their research? Based on opinion-survey responses from biomedical researchers, Walsh et al. (2007) found that there is no evidence to show that IP restricts access to knowledge or information inputs in biomedical research (Walsh et al. 2007). Murdoch and Caulfield (2009) reported similar results based on the experiences of Canadian stem cell researchers (Murdoch and Caulfield 2009). With the abundance of patents in these biomedical research fields, why do researchers not consider IPR as a concern? Walsh et al. (2007) suggest that one main reason for this may be that researchers are not aware of existing patents in their research areas, or they presume that they have research exemptions. As experimental use (research use) exemption is ill-defined (McBratney et al. 2004; Walsh et al. 2007); it can be very confusing and therefore misunderstood by many researchers.

The laws governing research use exemption also vary among jurisdictions: in Europe and Canada,[6] research use exemptions are allowed by law. The Federal Circuit’s rejection of an experimental use defense in a landmark case, *Madey v. Duke University*, proved that there is no research use exemption for academic researchers in the United States (Cai 2004). On the other hand, it was noted that research conducted in U.S. universities is rarely subjected to patent infringement lawsuits (Chi-Ham et al. 2012). Walsh et al. (2003a, b) reported that their interviews with researchers revealed that they use “working solutions” that include licensing, inventing around patents, going offshore, development and use of public databases and research tools, court challenges, and simply using the technology without a license (i.e., infringement) to proceed with their research (Walsh et al. 2003b).

5.3.2 IPR and Biotechnological Advances in Agriculture

IP protection is increasingly becoming associated with scientific discoveries in agricultural sciences, especially with the greater involvement of the private sector, which has become a major player in enhancing agricultural productivity in the

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[6] In certain countries, like Europe, research use exemptions are allowed by law. In other countries, like Canada, statute allows reasonable research use exemption during development and regulatory approval. The state of exemptions remains unclear in Australia, due to absence of case law or statutory exemption. In certain countries, like Europe, research use exemptions are allowed by law.

United States. In 1930 the U.S. Congress passed the Townsend-Purnell Plant Patent Act (PPA)[7], which introduced a patent-like system for plants. This protection was expanded by the Plant Variety Protection Act (PVPA) in 1970 (Rowe 2011). Unlike the PPA, the PVPA contained two significant exemptions: one for research and one for crops. The research exemption stated that "[t]he use and reproduction of a protected variety for plant breeding or other bona fide research shall not constitute an infringement of the protection provided under this chapter."[8] However, the crop exemption of the PVPA, which allowed farmers to sell their saved seeds to others, was repealed by Congress in 1994 (Rowe 2011). As the result of a U.S. Supreme Court decision, the utility-patent protection was extended to sexually and asexually reproduced plants, which led to GM crop patenting in agriculture. Although the use of GM crops is expanding rapidly, the effects of GM foods on human health and the environmental effects of GM crops are largely unknown and thus need to be thoroughly and continuously examined. The limitations imposed by GM crop patents are adversely affecting these lines of research. Since GM plants and seeds are protected by utility patents, patent holders have the ability to exert control over the production of GM crops and the knowledge surrounding them; for example, GM seed producers use "seed wrap licenses" to prevent farmers from saving and reselling seeds (Rowe 2011).

The agricultural biotechnology field is closely associated with an ever-changing IPR landscape and is continuously challenged by complex situations created by IPR ownership, including ownership by multiple owners. The best example in agriculture showing the complexity of fragmented IP ownership may be the case of Golden Rice, which has the potential of effectively solving vitamin A deficiency in Asia. Depending on the country where it will be used, 0–44 patents associated with Golden Rice have been identified; 40 patents associated with Golden Rice are applicable in the United States and most EU countries (Kryder et al. 2000). The situations arising from complexity in IPR ownerships can create anti-commons effects that jeopardize the progress of agricultural biotechnology and the scientific understanding associated with it. For example, scientists have expressed displeasure about their inability to grow GM crops for research purposes and the undue control of GM seed-producing companies over independent scientific research. Scientists complain that they require permission from patent holders of seeds or genes and negotiate access to related scientific data and that they are required to obtain seed company approval to publish their research findings (Waltz 2009). The discontent of scientists regarding this situation, which did not exist prior to GM crop patenting, was clearly revealed when a group of 24 scientists from public universities in 17 states submitted a statement to the U.S. Environmental Protection Agency (EPA) (Waltz 2009). These developments led several leading seed companies to have discussions with a group of entomologists who publicly expressed their displeasure about the restrictions imposed by the seed companies (Waltz 2009). Some scientists are worried that

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[7] 35 U.S.C. § 161 (2006).

[8] 7 U.S.C. § 2544 (2005).

adverse research findings about industry products are being concealed (Blumenthal et al. 1997; Rosenberg 1996; McGauran et al. 2010). These issues stress the need for much more research conducted by academic scientists, especially in areas such as the effects of GM crops on foods, where little knowledge exists. One suggestion to address these concerns, at least in the area of agricultural research, is to include research exemptions for plant utility patents that would allow patent holders to permit research while protecting their financial interests (Rowe 2011).

Although there are discussions about the constraints imposed by proliferation of IPRs on agricultural research, the opposing arguments for the need of expansion of IPR in agriculture to promote research investments continue (Grimes et al. 2011). Arguments are made for the need of an IPR system coupled with "a comprehensive transitional research paradigm" supporting public agricultural research (Chi-Ham et al. 2012). Chi-Ham et al. (2012) argue that public research institutions are often poorly equipped to handle the IPR system and are faced with difficulties assembling IPRs supporting freedom-to-operate (FTO) of research projects. The Public Intellectual Property Resource for Agriculture (PIPRA) was created in 2004 to address IP issues. To improve IP information access, PIPRA[9] created a public database containing thousands of agricultural patents owned by universities and public-sector research organizations. PIPRA provides expertise and resources to minimize IP restrictions and support active participation of the public sector in enhancing agricultural productivity (Chi-Ham et al. 2012).

5.4 Concluding Remarks

The continuing debate, with free and unrestricted access to scientific information on the one hand and commercialization of scientific discoveries on the other, helps us to understand the implications caused by the coexistence of these two seemingly conflicting objectives. Some argue that these two concepts are "not necessarily irreconcilable" (Caulfield et al. 2012). The best approach may be to create a system in which both objectives are complementary facets of a more inclusive system that can achieve the ultimate goal of scientific advancement for the benefit of the society. Therefore, the examination of the existing systems and discussions involving all stakeholders should continue toward that objective.

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[9] PIPRA http://www.pipra.org/en/page/Default/index.

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Chapter 6
Preserving the Quality of Scientific Research: Peer Review of Research Articles

Abstract Peer review of scholarly articles is a mechanism used to assess and preserve the trustworthiness of reporting of scientific findings. Since peer reviewing is a qualitative evaluation system that involves the judgment of experts in a field about the quality of research performed by their colleagues (and competitors), it inherently encompasses a strongly subjective element. Although this time-tested system, which has been evolving since the mid-eighteenth century, is being questioned and criticized for its deficiencies, it is still considered an integral part of the scholarly communication system, as no other procedure has been proposed to replace it. Therefore, to improve and strengthen the existing peer review process, it is important to understand its shortcomings and to continue the constructive deliberations of all participants within the scientific scholarly communication system. This chapter discusses the strengths, issues, and deficiencies of the peer review system, conventional closed models (single-blind and double-blind), and the new open peer review model and its variations that are being experimented with by some journals.

Keywords Article peer review system · Closed peer review · Open peer review · Scientific journal publishing · Single blind peer reviewing · Article retraction · Nonselective review · Post-publication review system · Double blind peer reviewing

6.1 Introduction

Scientists share their theories and research findings with other scientists, practitioners, and the public through scientific publications; at the same time adding these contributions to the scientific knowledge base, paving the way for other researchers to build on them. Critical and impartial evaluation of scientific claims and evidence by other experts in the field is essential to improve scientific quality as well as to maintain the credibility, trustworthiness, and robustness of scientific knowledge. This need is currently fulfilled by the peer review system, a documented critical

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review conducted by peers that has evolved in parallel with the formal scholarly communication system. In addition to its use in manuscript evaluation, peer reviewing has become an important assessment tool for evaluating the quality and impact of proposed and completed research projects (Langfeldt 2006), research proposals in awarding competitive grant funding, determining distinguished award winners (e.g., the Nobel Prize), and teaching and research performance in the tenure process in universities. Although "peer reviewing" is generally thought of as a step in the pre-publication process, it can also take place after an article is published in some form. The continuing intellectual discussion about peer reviewing in the context of scholarly communication is the main focus of this chapter.

6.2 History of Peer Review

The scientific learned societies were formed toward the latter part of the seventeenth century—the Royal Society of London in 1662 and the Académie Royale des Sciences of Paris in 1699—providing scholars with venues to discuss scientific theories and exchange experimental findings. Establishment of the first scientific journal, *Philosophical Transactions of the Royal Society* in 1665, formalized the sharing of scientific information, which previously took place almost exclusively through personal and informal correspondence. Henry Oldenburg, who was appointed the secretary to the Royal Society, became the first editor of the journal, and his responsibility was to gather, edit, and publish the work of others. This process continued until 1752, when the society took over the editorial responsibilities of the journal and adopted the procedures used by the Royal Society of Edinburgh as early as 1731, namely, review of each manuscript by a group of members who were knowledgeable about the topic. This is considered as the beginning of the formal journal peer review process, intended as a mechanism to preserve the trustworthiness of reporting scientific findings. Peer reviewing during the next 100 years, according to Spier (2002), was mainly each journal editor's opinion supported by special committees set up by societies when necessary (Spier 2002). However, institutionalization of peer reviewing took place in the twentieth century, with journal editors seeking the help of outside reviewers as the diversity of manuscripts submitted increased and new specializations emerged. This progression happened at different times for different journals. For example, although the *British Medical Journal* (*BMJ*) had a peer review process in the nineteenth century, *Science* did not use outside peer reviewers until the late 1930s (Burnham 1990), nor did *The Journal of the American Medical Association* until the late 1940s (Spier 2002) or *The American Practitioner* until 1962 (Burnham 1990). Since then, peer reviewing has become an integral part of the scholarly communication system. Although not much has changed since the formal peer reviewing process was first institutionalized by journals, it has become a major topic of discussion and the center of a spirited debate.

6.3 Criticism of the Peer Review Process

The peer reviewing process is in place to validate research findings before publication and is considered a time-tested, reliable mechanism to maintain the trustworthiness of scientific publications. However, questions have been raised regarding the reliability and accountability of the peer review process. One concern is that by its very nature, peer reviewing can in some instances restrict innovative research, as it judges the value of proposed research or submitted manuscripts against existing knowledge boundaries (Luukkonen 2012). While some argue that it is an "untested process with uncertain outcomes" as not much empirical evidence is available (Jefferson et al. 2002), there are extreme voices complaining that peer review is slow, expensive, a waste of academic time, highly subjective, prone to bias, and poor at detecting defects and scientific fraud (Smith 2006).

Going beyond criticism, it is essential to identify the strengths and limitations of the peer review system, as it has become an integral part of the scholarly communication system. Deficiencies identified in peer review practice include the inability to detect errors and scientific fraud; lack of reliability, objectivity, and transparency, which can lead to reviewer irresponsibility; potential for bias and unethical practices; and delay of publication.

6.4 Bias in Peer Review

In the ideal world, peer reviewing should be independent of authors' and reviewers' social identities and reviewers' cognitive and theoretical biases, and manuscripts should be judged purely on scientific value[1] (originality, innovativeness, impact, etc.). Although expert reviewers should arrive at similar decisions merely based on evaluative criteria identified by the journal, the impartiality of reviewer decisions has been questioned. Because of the strong subjective element involved, it may be unrealistic to expect a peer reviewing system with a high level of objectivity devoid of bias and conflict of interests associated with cultural identities, social interests, and the professional and intellectual expectations of the reviewers. Many different types of peer review bias have been discussed (Hojat et al. 2003; Lee et al. 2013), but the findings of empirical examinations do not provide a clear picture of the problem (Bornmann 2011). Although it may be impossible to completely eliminate reviewer bias, understanding the types and extent of bias involved in the practice might help to minimize reviewer bias and improve the trustworthiness and integrity of peer reviewing. Several of the main types of bias identified to affect peer reviewing are described below along with the evidence (or lack of evidence) for each type.

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[1] Evaluative criteria may also vary depending on the scope of the specific journal.

6.4.1 Prestige or Association Bias

Prestige or association bias is a type of bias associated with institutional relationships. There is a view that authors and reviewers enjoy formal or informal relationships built on institutional affiliations and that researchers affiliated with prestigious institutions have a better chance of their manuscripts being accepted than researchers from less prestigious ones. To test the validity of this view, Peters and Ceci (1982) selected previously reviewed and published (18–32 months earlier) research articles from journals with high reputations (and nonblind peer reviewing practices) by investigators from prestigious and highly productive institutions, and resubmitted them with fictitious author and institutional names to the same journals. Their findings revealed that 89% of the reviewers, together with editors, rejected these resubmitted articles, mentioning "serious methodological flaws" in many cases (Peters and Ceci 1982). Surveys of researchers applying for grants from the National Science Foundation (NSF) and National Institutes of Health (NIH) revealed their concerns about "old boys" networks (Gillespie et al. 1985; McCullough 1989) and bias against less prestigious universities (Gillespie et al. 1985). Bias against authors from non-English-speaking countries is another concern. Ross et al. (2006) discussed findings of a study conducted with abstracts submitted to the American Heart Association's annual scientific meetings and revealed bias in abstract acceptance that favored authors from the United States, English-speaking countries outside the United States, and prestigious academic institutions (Ross et al. 2006). Bornmann and Daniel (2009) reported findings of a study showing reviewer and editorial biases in the journal *Angewandte Chemie International Edition* toward authors affiliated with institutions in Germany (Bornmann and Daniel 2009). Tregenza (2002) observed a strong effect of country of affiliation on manuscript acceptance and found significantly higher acceptance rates of articles from wealthy English-speaking countries than of those from wealthy non-English-speaking countries at ecology and evolution journals (Tregenza 2002). Link (1998) reported that reviewers from within and outside the United States evaluate non-US papers similarly; however, US reviewers evaluate papers submitted by US authors more favorably. Another study reported that manuscripts from China had more negative reviewer recommendations (rejection and requests for major revisions) than those from English-speaking countries (Campos-Arceiz et al. 2015). However, Loonen et al. (2005) did not find bias against non-Anglo-American manuscript submissions to the journal *Plastic and Reconstructive Surgery* (Loonen et al. 2005).

6.4.2 Gender Bias

The possibility of gender bias in peer review has been raised because of the gender gap in science, technology, engineering, and medicine (STEM) in grant and manuscript reviewing, interviewing, and hiring (Ceci and Williams 2011). Evidence of gender bias in peer reviewing in grant applications has been reported by some studies (Bornmann et al. 2007), although empirical evidence supporting bias in manuscript reviewing is inconsistent. Ceci and Williams (2011) performed meta-analysis and found no gender bias in peer reviewing (Ceci and Williams 2011). Budden et al. (2008) reported that after the introduction of double-blind review by the journal *Behavioral Ecology* (BE) in 2001, there was a significant increase in the number of papers with female first authors, arguing that the gender bias against female authors could be corrected with double-blind peer reviewing (Budden et al. 2008). However, Webb et al. (2008) argued that the increase in female authorship rate in BE is not remarkably different from the changes at six other journals in the field that did not have double-blind reviewing during that period (Webb et al. 2008). There is other supporting evidence to discredit the hypothesis of gender bias against female authors in peer reviewing (Whittaker 2008; Nature Neuroscience Editorial 2006; Borsuk et al. 2009; Valkonen and Brooks 2011).

6.4.3 Confirmation Bias

In the context of peer reviewing, confirmation bias is described as reviewer bias against manuscripts that present findings inconsistent with reviewers' expectations (Jelicic and Merckelbach 2002). Strong advocates of certain theories might be particularly likely to show confirmation bias as reviewers. Sandström (2009) presented findings of a study rejecting the hypothesis that reviewers show a positive bias toward research similar to their own work (Sandström 2009). If it exists, this type of bias not only challenges the impartiality of peer reviewing practice but also obstructs scientific progress by preventing diversity of research.

6.4.4 Conservatism

The existence of "conservatism," i.e., bias against new innovative or unconventional research, is suspected to influence peer review of grant applications and manuscripts. It has been criticized as "epistemically problematic" (Shatz 2004) and impedes scientific progress by preventing the opening up of new and revolutionary research boundaries. There may be many examples of innovative research rejected by reviewing process: the description of the citric acid cycle by Hans Krebs[2] and the "mobile gene theory" presented by Barbara McClintock,[3] both rejected by *Nature* (Kilwein 1999), and the creation of radioimmunoassay (RIA) to measure

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[2] Krebs and Johnson (1937).

[3] McClintock (1950).

plasma insulin by Yalow and Berson, originally rejected by *Science* and the *Journal of Clinical Investigation*, are among such examples. A study of reviewer bias conducted by Resch et al. (2000) revealed that reviewers gave much higher ratings to fabricated studies with conventional treatments than to those with unconventional therapies, even when the latter showed strong supporting evidence (Resch et al. 2000). Understanding theoretical and intellectual conservatism in order to minimize its impact is extremely important, especially for reviewing grant applications (Luukkonen 2012).

6.4.5 Bias Against Interdisciplinary Research

There is a concern about bias against interdisciplinary research based on the argument that disciplinary reviewers prefer mainstream research (Travis and Collins 1991). If such bias exists, it would be particularly problematic because scientific research is becoming increasingly multidisciplinary. At the same time, identification of suitable peer reviewers for interdisciplinary research can be challenging because specialization continues to increase. To address this issue, several institutions (e.g., the Public Library of Science (PLOS) and the UK Research Integrity Office) have recommended using a group of reviewers with relevant expertise, a practice used by the Royal Society in the UK, instead of the traditional practice of using one to three reviewers. Because conservatism and risk-minimizing biases in peer reviewing would particularly impact interdisciplinary research, it is suggested that the peer review process adopt a more risk-taking mode to promote nonconventional interdisciplinary research (Langfeldt 2006). As peer reviewers with different expertise would view data and findings with a very different perspective from the author/researcher, Shimp (2004) suggests that reviewers must openly acknowledge those differences as conflicts of interest (Shimp 2004).

6.4.6 Publication Bias

The inclination of journals to publish research with “positive outcomes” and discriminate against articles reporting “negative outcomes” is referred to as publication bias. The existing “publish or perish” culture in academia is forcing researchers to produce “publishable” results with positive outcomes to avoid having their papers rejected because of publication bias. Fanelli (2010) tested this hypothesis by examining National Science Council (NSC) data on a state-by-state basis and found that authors from states in which the per capita publication rate was higher had published a higher percentage of papers with positive results. Based on the findings, Fanelli argues that researchers in highly competitive environments tend to publish more overall, but also tend to publish “negative results” less frequently than researchers in less competitive environments (Fanelli 2010). Emerson et al. (2010)

conducted a study using two versions of a well-designed randomized controlled trial that differed only in the direction of the finding, and reported that there was a significant difference in frequency of recommendation between the test manuscript version with positive outcomes and the version with no difference (97.3 vs. 80.0%, $P < 0.001$). Reviewers awarded a higher method score to the positive-outcome version (8.24 vs. 7.53, $P = 0.005$), and detected more errors in the no-difference version than in the positive-outcome version (0.85 vs. 0.41, $P < 0.001$) (Emerson et al. 2010). The negative effects of publication bias toward reporting positive outcomes have been discussed (Ioannidis 2005; Palmer 2000; Chan et al. 2004). However, when Olson et al. (2002) examined the publication bias toward positive results in the editorial decisions of *The Journal of the American Medical Association*, he did not find a significant difference in publication rates between articles reporting positive results and those reporting negative results (Olson et al. 2002).

6.5 Peer Review and Conflict of Interest[4]

Conflict of interest is another vigorously debated aspect of peer reviewing practice. Situations in which conflicts of interest (COI) have collided with impartiality of scientific knowledge sharing have been widely discussed in both intellectual and public forums. The possibility of financial COI influencing publishing in biomedical and pharmaceutical fields is becoming a major topic of these discussions, and the Vioxx debacle is one of the most discussed cases of financial COI in recent history. Although withdrawn from the market in 2004, the nonsteroidal anti-inflammatory drug rofecoxib (Vioxx®, then marketed by Merck & Co) became the center of academic discussion as well as mass media and legal campaigns (McIntyre and Evans 2014). According to James et al. (2007), the widespread use of Vioxx® for 4–5 years despite its known cardiovascular (CV) risks was achieved by Merck & Co in part because of insufficiently rigorous reviewing at the *New England Journal of Medicine*[5] ignoring the concerns of CV risks (James et al. 2007).

Strategies to minimize the influence of financial COI on peer reviewing have been widely discussed, and author disclosure of financial COI is mandated by the majority of biomedical journals (Bosch et al. 2013). In 1984, *NEJM*'s editor-in-chief instituted a COI policy for authors, which was considered the first at any major medical journal (Relman 1985). Disclosure of COI by authors provides reviewers and readers the opportunity to be aware of potential bias when assessing

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[4] Conflict of interest is defined as “a set of circumstances that creates a risk that professional judgment or actions regarding a primary interest will be unduly influenced by a secondary interest.” Lo and Field (2009).

[5] Bombardier et al. (2000).

the soundness of research findings. However, reporting of COI by reviewers and editors is not required by the majority of scientific journals, and Bosch et al. (2013) reported that only 40% of biomedical journals required COI disclosure by editors (Bosch et al. 2013). A study conducted to examine the extent of financial ties of editorial members of five leading medical journals revealed that 29% of members reported financial COI and 42% reported a financial relationship with industry of more than US $10,000 during the prior year (Janssen et al. 2015). Financial COI of reviewers and editors undoubtedly has the potential to influence the peer review practice of journals, so journals striving to maintain scientific integrity should consider mandating disclosure of financial COI not only by authors, but also by reviewers and editors. Based on their study findings, Lippert et al. (2011) recommended that authors disclose monetary amounts of all financial relationships and that reviewers disclose any financial ties to industry regardless of whether they are related to the manuscript under review (Lippert et al. 2011). Even with financial COI disclosure by authors, the peer review system may not have the ability to fully assess the impact of COI; thus, there are suggestions for establishing independent fee-based COI consultancy services for validating the integrity of research projects as the peer review system does not have the ability to check COIs (Charlton 2004).

In addition to financial COI, other competing interests (such as personal, political, academic, ideological, or religious) influence the professional judgment of reviewers and editors. A furious debate erupted when Cambridge University published *The Skeptical Environmentalist*, authored by Bjørn Lomborg. While it was popularized by the media and some political commentators, it was heavily criticized by the mainstream scientific community (Rennie and Chief 2002). The main criticisms against the book were that it contained many factual errors, misinterpreted data and misused statistics, used selective citations that rely on secondary and anecdotal information, and avoided primary peer-reviewed sources that reflect current scientific consensus. The critics claimed that the book had not gone through proper peer reviewing and that it reflected the author's political viewpoint rather than sound science. This book became the epicenter of a commotion in the scientific community because it challenged mainstream scientific understanding and was published by a highly acclaimed academic press. Harrison (2004) noted that the book was peer reviewed by four high-level researchers in environmental science even though the book was published by the social science publishing section, and defended the editorial decision to publish this controversial scientific viewpoint in spite of the intense pressure against publishing it (Harrison 2004). Although this example pertains to a book rather than to original research findings intended for journal publication, this incident highlights several forceful factors at play in scientific scholarly publishing, including effectiveness of the peer review process, pressure against publishing controversial topics, and the process of editorial decision-making. Is it also a case showing peer reviewers and editors acting independently of ideological and political interest, or just the opposite?

Compared to ideological and subjective biases, the impacts of financial interests on peer reviewing and editorial decisions may be easier to identify and regulate. Although it is important to take nonfinancial conflict of interests seriously and manage them, there are difficulties involved in setting up disclosure standards for these types of COI (PLOS MED Editors 2008). Although some COIs are more prominent and serious than others, even some less prominent ones can impact scientific reporting. Therefore, instead of ignoring peer-reviewed scientific contributions based on COI concerns, consider all of them but with skepticism, as suggested by Kozlowski (2016).

6.6 Different Models of Peer Review

There are several different types of journal peer review practices; these can be broadly grouped as "closed peer review" (single-blind and double-blind) and "open peer review" (open and post-publication peer review, etc.) (Ali and Watson 2016).

6.6.1 Closed Peer Review: Single- Versus Double-Blind

In the single-blind system, the identity of the author(s) is revealed to the reviewers, but identity of the reviewers is concealed from the author(s). The double-blind system, in which both authors and reviewers are anonymous, is highly valued because manuscripts are expected to be judged impartially by reviewers based on the quality of content without bias against author or author affiliation (Nature Editorial 2008; Ware 2008; Moylan et al. 2014; Mulligan et al. 2013; Okike et al. 2016). However, the openness to a double-blind system varies depending on the scientific field; in highly competitive scientific fields (e.g., neuroscience) and fields with high commercial interest (e.g., materials science and chemical engineering), it is preferred more enthusiastically than in fields with a tradition of openness (e.g., astronomy and mathematics) (Nature editorial, 2008). Since journals need to make considerable effort to conceal the identities of manuscript authors, the single-blind system is most commonly used, probably because it is less troublesome than the double-blind system. Difficulty in achieving perfect "blinding" of a manuscript is widely acknowledged (Moylan et al. 2014; Ware 2008; Baggs et al. 2008) and therefore considered by some as "pointless" (Brown 2007). Moreover, some journals with single-blind traditions (e.g., Nature research journals[6]) offer authors the option of choosing double-blind reviewing (Cressey 2014).

In both single- and double-blind systems, anonymity of reviewers allows them to critically evaluate manuscript freely without fear of intimidation, which can be important especially in the case of more junior reviewers who are judging the work of more experienced, senior scientists.

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[6] "Nature journals offer double-blind review" *Nature* announcement—http://www.nature.com/news/nature-journals-offer-double-blind-review-1.16931.

6.6.2 Open Peer Review

The closed and secretive nature of conventional peer review is being widely criticized and blamed for many shortcomings of an otherwise valued system. To add transparency to the system, opening up peer reviewing is being advocated by critics of the conventional system, and a consensus favoring open evaluation of scholarly work is emerging. In the open peer review (OPR) system, author and reviewer identities are revealed to one another. OPR emerged along with technological advances and open access (OA) publishing, and was first tried in the late 1990s, with the notable example of *BMJ* in 1999 revealing reviewer names to authors (Smith 1999). In 2000, OA medical journals published by BioMed Central (BMC) used OPR and published not only reviewers' names, but the "pre-publication history[7]" as well. There are several different variations—including a hybrid of closed and open review with public commentary—that are being adopted and experimented with by different journals.

Pro-OPR advocates argue that this system adds transparency needed in the peer review process, as a way to eliminate or minimize some unethical practices of reviewers and editors and to make reviewers and authors accountable for their communications. Generally, in the OPR system, reviewer identity and their review reports are directly available to the authors and scientific community, giving them opportunities to comment on reviews. These scientific communication exchanges provide in-depth understanding of the subject for readers outside the scientific field, which is an added advantage. It is also argued that OPR would discourage authors from submitting low-quality manuscripts (Pöschl and Koop 2008), expedite scientific information dissemination by reducing publication time, make it easier to identify scientific misconduct by authors, and provide reviewers the opportunity of getting credit by citing their contributions (Boldt 2011; Bornmann and Daniel 2010).

OPR is still an evolving practice; many journals are implementing or experimenting with it with varying success. Notable early examples include the effective implementation of OPR by *BMJ* since 1999 (as mentioned earlier) and the less successful OPR experimentations by MIT Press, *PLOS Medicine*, and *Nature*. In 2006, *Nature* conducted a peer review trial: during a four-month period, authors were given the option of submitting manuscripts through a preprint server for open comments in parallel with the conventional peer review process. Once the conventional peer review process was completed, the public "open peer review" process was closed and the editors made article publication decisions based on reviewers' reports and public comments. According to the report published by *Nature*, out of 1359 papers submitted during the trial period, only 5% of authors agreed to display their papers for public debate. Despite substantial interest in the trial and a considerable amount of online traffic, the average number of public

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[7] Contains all versions of the manuscript, named reviewer reports, author responses, and (where relevant) editors' comments (Moylan et al. 2014).

comments per article was low, while the distribution of comments was uneven, with some articles receiving a substantial amount while others received none, and the reluctance of researchers to post public comments was revealed through feedback (Greaves et al. 2006).

Field-specific differences in embracing OPR have been mentioned; for example, medical disciplines needing transparency with regard to patient treatment and competing interests are more open to OPR than are biological sciences. At the same time, there are differences even within biological sciences; some disciplines (e.g., bioinformatics and genomics) accept OPR more than traditional disciplines (e.g., immunology and physiology) (Koonin et al. 2013; Moylan et al. 2014). There is a reluctance in adopting OPR by journals in highly competitive research fields arguing that it may increase the risk of plagiarism (Dalton 2001).

Empirical evidence currently available on the value and advantages of OPR over the conventional closed peer review system are not convincing. Regarding the quality of review, there are no conclusive findings showing that peer reviewing quality improves with OPR. While some study findings show there is no difference (van Rooyen et al. 1999, 2010), other studies report an increase in quality with OPR (Walsh et al. 2000). Even empirical evidence regarding the inter-rater reliability between open and closed systems is inconclusive (Bornmann and Daniel 2010). It has been reported that peer reviewers took significantly longer to review manuscripts under OPR, even though this may not have resulted in higher quality review reports (Campbell 2006, 2008; van Rooyen et al. 2010; Walsh et al. 2000).

Disclosure of reviewer identity is an important facet of OPR, increasing the transparency of the peer review process compared to the closed system. The potential for higher reviewer refusal rate associated with OPR is being discussed, but the few study findings available provide contradicting views regarding the willingness of researchers and scientists to be reviewers in an OPR system. Although Ware (2008) reported that 47% of the respondents in their survey study expressed reluctance to be reviewers if their identities would be disclosed to authors (Ware 2008), a *BMJ* study revealed a much lower percentage of unwillingness (Tite and Schroter 2007). A peer review survey (2009)[8] revealed that over 50% of survey respondents would be less likely to review if their signed report would be published, and *PeerJ* (2014), a journal giving the option of signing the review reports (thus making the reviewer name known to authors), revealed that only 40% of reviewers choose to sign their reports (Bohannon 2013). A survey of *BMJ* editors showed that more early career researchers (as potential authors) preferred double-blind peer review, while the more senior editors did not show a preference between the single-blind and double-blind models (Moylan et al. 2014).

Active participation of the relevant scientific community is essential for OPR to be effective. The reluctance associated with reviewer name disclosure might become an issue for OPR, shrinking the pool of willing reviewers (Baggs et al.

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[8] https://www.elsevier.com/about/press-releases/research-and-journals/peer-review-survey-2009-preliminary-findings.

2008; van Rooyen et al. 2010). It is important to understand the underlying issues related to reluctance of reviewers to disclose their identity. Unlike in the closed review system, OPR does not give protection to reviewers providing honest and critical assessment of manuscripts. Therefore, some (especially junior) researchers may be reluctant to participate (Mulligan et al. 2013) to avoid reviewing the work of senior and more established researchers out of fear of intimidation, acrimony, and possible public humiliation (Khan 2010; Ford 2015). Journals have adopted different ways to lessen this effect; for example, in *Frontiers in Neuroscience*, the reviewers of rejected papers maintain their anonymity.[9] However, reviewer anonymity is handled by various ways by different journals. Some journals (e.g., *BMJ*) reveal reviewer identities to authors but do not publish them. *PeerJ* is a journal that uses closed single-blind peer review, but also provides an optional OPR system for reviewers and authors. Reviewers are given the option of providing their names to the authors along with the review, and if the article is accepted, the signed review will be published with the article. Authors are also given the option to reproduce the complete (unedited) peer review history alongside the final publication of their article. In some cases, where reviewers' names are published, full review reports as well as interactions with authors are published (e.g., some BMC journals[10]); others publish reviewer reports but maintain reviewer anonymity (e.g., *American Journal of Bioethics*, *EMBO Journal*).

Despite concerns and challenges, OPR continues to be implemented by some journals where reviewers' names are published, full review reports as well as interactions with authors are published (e.g., the BMC series, *Biology Direct*—an author-driven OPR journal), or reviewer reports are published but reviewer anonymity is maintained (e.g., *American Journal of Bioethics*, *EMBO Journal*, *Hydrology and Earth Systems*[11]). These examples are indications that open review will be a feature in scientific scholarly communication in the future. OPR, variations of OPR, and open public discussions in combination with traditional closed peer review are being experimented or implemented by several journals. Keeping up with the many variations and experimentations of this evolving OPR system is going to be challenging for all parties involved in scholarly peer reviewing. Some of the forms of OPR adopted by journals will be discussed in the next section.

Systems with Post-Publication Review and Forms of Interactive Review

The emergence of different forms of interactive and post-publication review is an important development in open review. In the post-publication review system,

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[9] Review guidelines, *Frontiers in Neuroscience* http://journal.frontiersin.org/journal/synaptic-neuroscience#review-guidelines.

[10] Editorial policies - BioMed Central http://www.biomedcentral.com/getpublished/editorial-policies#peer+review.

[11] Hydrology and Earth System Sciences Interactive Public Peer Review http://www.hydrology-and-earth-system-sciences.net/peer_review/interactive_review_process.html.

journals use a two-stage publication process—public peer review and interactive discussion—with the intent to facilitate publishing high-quality scientific work through rapid and thorough scientific examination. These new review systems present reviewers with new challenges but also offer new opportunities (Walters and Bajorath 2015).

The interactive OA journal *Atmospheric Chemistry and Physics* and sister journals published by the European Geosciences Union successfully experimented with the OPR system, which was described as efficiently combining the advantages of OA with the strengths of traditional scientific publishing and peer review (Pöschl and Koop 2008). Manuscripts prescreened by the editorial board (a process referred to as "access review") are immediately posted on the journal's website as "discussion papers," allowing interactive public discussion for a period of eight weeks. During this period, designated reviewers and members of the scientific community can post their comments and authors can post their responses/rebuttals. While reviewers can either sign their comments or opt to be anonymous, comments by other scientists need to be signed, and all these discussions are published alongside the discussion paper and permanently archived to secure the authors' publication precedence. During the next phase, peer reviewing and manuscript revisions take place through a method similar to the traditional peer reviewing system, and, if accepted, manuscripts are published in the journal. Reflecting the success of this system, four years after launching, ACS reached and has continued to have the highest journal impact factor in the field of "Meteorology and Atmospheric Sciences" as well as one of the highest in "Environmental Sciences" and "Geosciences, Multidisciplinary." The Chemical Information Science (CIS) journals also use post-publication review. First, submitted manuscripts are processed by the *F1000Research* editorial staff and then passed on to the CIS channel editorial board to evaluate them based on scientific quality (prereview). Manuscripts with a positive prereview consensus or ones with controversial opinions are published on the CIS channel and subjected to OPR. In addition to reviewers suggested by editors, authors are also given the opportunity to suggest reviewers, and the post-publication review process starts after authors agree with the final reviewer lineup.

Systems with Pre- and Post-Publication Review Features

In 2001, Copernicus Publications[12] initiated the "Interactive Public Peer Review," a two-stage publication process with individual journals having a fully peer-reviewed journal and an access-reviewed discussion forum. *Frontiers in Synaptic Neuroscience*[13] is an example of a journal with a tiered publication system; scientifically important original research papers (tier 1) are subjected to pre-publication review. Following publication, impact metric data are collected and

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[12] Copernicus Publications http://publications.copernicus.org/services/public_peer_review.html.

[13] Copernicus Publications - Interactive Public Peer Review http://home.frontiersin.org/about/impact-and-tiering.

authors of high-impact papers are invited to write a "Focused Review" (tier 2), placing original discoveries into a wider social context for a broader audience. These articles also go through pre-publication peer review. *PeerJ* uses an interesting system to encourage research publications and comments on research: interaction is rewarded with points, as in many multiplayer online games. A potential limitation is that these points do not reflect quality of the contribution. The effectiveness of this kind of system in improving community involvement and resulting in productive scientific discussion remains to be seen. Some journals (e.g., *PLOS ONE*) facilitate post-publication public discussions but do not consider them as part of the review process.

6.6.3 "Nonselective" Review

Nonselective (impact-neutral) review is another peer reviewing trend. *PLOS ONE*, the first multidisciplinary OA journal, introduced this system in 2006, followed by Frontiers in 2007 (Walker and Rocha da Silva 2014). *PLOS ONE* uses a peer review process to assess the technical soundness of papers but argues that judgments about their importance are made by the readership. Frontiers identifies the "review" as a formal process to assure the high scientific quality of papers while the "evaluation" is a community effort that gradually establishes the importance and interpretation of results. Frontiers uses a standardized questionnaire that reviewers use to prepare their reports. In these journals, rejection of papers is based on technical or objective errors, but not on the lack of scientific importance or novelty, or because they challenge mainstream opinion; this approach reduces attempts to limit manuscript acceptance. However, the openness of the peer review process of Frontiers has been questioned because reviewer names are revealed but peer review reports are kept confidential (Schneider 2016). Other OA journals are implementing similar or somewhat similar systems to nonselective review; examples include *BiologyDirect*,[14] *F1000Research*,[15] *GigaScience*,[16] the *Journal of Negative Results in Biomedicine*,[17] *Open BMJ*,[18] *PeerJ*,[19] and *ScienceOpenResearch.*[20] Journals adopting nonselective review practices are impacting scientific journal publishing in a major way. Walker and Rocha da Silva (2014) estimated that major journal series adopting nonselective review published more than 90,000 papers in 2014, and observed that all of these journals are in biomedical sciences (Walker and Rocha da Silva 2014).

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[14] Biology Direct http://www.biologydirect.com/.

[15] F1000 Research http://f1000research.com.

[16] GigaScience http://www.gigasciencejournal.com

[17] Journal of Negative Results in Biomedicine http://www.jnrbm.com/.

[18] BMJOpen http://bmjopen.bmj.com/.

[19] PeerJ http://peerj.com/.

[20] ScienceOpen https://www.scienceopen.com.

6.6.4 *Immediate Publication with no Formal Review*

There is another emerging trend, especially in some disciplines, of authors publishing their work on preprint servers and bypassing the traditional peer review process. The best example of such a preprint server is arXiv,[21] which was created in 1991 with the objective of sharing preprints among a group of physicists, but its disciplinary scope has expanded to include mathematics, computer science, and quantitative biology, and its preprint volume has grown from 304 in 1991 to nearly 1.2 million preprints as of October 2016. Authors post preliminary versions of papers to arXiv for community discussion and criticism before submitting to journals for formal publishing; if the manuscripts are submitted and accepted by traditional journals after peer review, authors can post the updated versions, and a version history of the article is maintained. Today, arXiv also serves as a primary channel for authors to publish their papers (Walker and Rocha da Silva 2014). Although this system works for some subject disciplines (e.g., physics, mathematics), for others such as biomedical fields, sharing manuscripts that have not been checked may not be sensible and may even be dangerous.

6.7 Manipulation of the Peer Review Process

Manipulation of the peer review process by some researchers has led to retraction of their articles. In 2012, 28 papers were retracted by several Informa journals following the revelation that Hyung-In Moon, a medicinal plant researcher, created fake email accounts to allow himself to review his own papers. Journals retracted more than 110 papers in at least six instances within the next two years according to Ferguson et al. (2014) when scamming of the peer review process was uncovered, proving that these are not rare or isolated incidents (Ferguson et al. 2014). A 14-month investigation by SAGE revealed that a researcher, Chen-Yuan Chen, was involved in a peer review and citation ring consisting of fake scientists and real scientists' names with the intention of tampering with the peer review process to get his papers published, and at least one incident was discovered in which he had reviewed his own paper. This revelation led to retraction of 60 papers; according to SAGE, all retracted papers had at least one author or reviewer associated with the ring, and possibly other researchers were involved as well (Fountain 2014). When an internal investigation in 2015 revealed fabricated review reports, Springer retracted 64 articles from 10 of their journals.[22] A few months before that, BioMed Central (also owned by Springer) retracted 43 articles for the same reason. In these instances,

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[21] ArXiv http://arxiv.org.

[22] Retraction of articles from Springer journals. London: Springer, August 18, 2015 (http://www.springer.com/gp/about-springer/media/statements/retraction-of-articles-from-springer-journals/735218).

it is evident that researchers had exploited vulnerabilities of the computer systems publishers use to automate peer review as a means to trick editors into accepting their manuscripts by doing their own reviews. It is to be expected that more automation would make systems more vulnerable to gaming; an incident in which an editor's account was hacked and used to assign papers to fake reviewers, leading to the retraction of 11 articles by *Optics & Laser Technology*, drew attention to this concern (Ferguson et al. 2014). As automation is inevitable in journal publishing, all necessary precautions need to be taken by editors and publishers to secure their systems to prevent these incidents. Use of author-nominated reviewers, a practice now increasingly used by journals, is the other common factor in the incidents that led to many of the retractions mentioned here. Because identifying experts is becoming more challenging as scientific fields are becoming more specialized, asking authors to nominate reviewers for their papers may reduce the burden on editors. Nevertheless, the need for checking the identities and credentials of author-nominated reviewers before assigning papers is clearly evident. There are systems in place today that can be used to identify researchers. For example, Open Researcher and Contributor ID (ORCID) identifiers, which are unique numbers assigned to individual researchers, are designed to track researchers through all of their publications, even if they move between institutions. Moreover, as authors and reviewers are becoming increasingly multinational, it is becoming more difficult for journal editors to check the suitability of author-nominated reviewers. Regarding the issue of inappropriate manipulation of the peer review process, the Committee on Publication Ethics (COPE) issued a report[23] in January 2015 uncovering the existence of rogue third-party agencies offering services to authors involved in scamming the peer review system. These agencies are selling services ranging from fabricated contact information for peer reviewers and peer reviews to authorship of prewritten manuscripts. Amidst all these developments, there was another revelation through the investigation of their peer reviewing records in 2013–2014 by Hindawi. Although Hindawi does not use author-nominated reviewers but instead uses reviewers nominated by the guest editors of special issues, they found that three guest editors were involved in fraud by accepting 32 papers based on reviews submitted by fake reviewers.[24] These retractions and revelations unquestionably put the responsibility on journals, especially ones using the practice of author-nominated reviewers. To correct deficiencies, these journals must critically assess their reviewer selections to prevent article retractions and to uphold the trustworthiness of peer review.

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[23] COPE statement on inappropriate manipulation of peer review processes (http://publicationethics.org/news/cope-statement-inappropriate-manipulation-peer-review-processes).

[24] Hindawi concludes an in-depth investigation into peer review fraud, July 2015 (http://www.hindawi.com/statement/).

6.8 Should the Current System of Peer Review Be Continued?

Scientific fraud and misconduct are often highly publicized, such as in the case of well-known physicist, Jan Hendrik Schön, who conducted research on organic electronics, superconductivity, and nanotechnology at Bell Laboratories (Steen 2010), and was later held responsible for fabricating or falsifying data in 16 cases. Ultimately 17 articles were retracted (Service 2002).

When fraudulent science is published in the health sciences the public health consequences can be dire. One such incident is the article by Andrew Wakefield which proposed a connection between the measles, mumps, and rubella (MMR) vaccine and autism in children, published in the *Lancet*[25] in 1998. The association between the vaccine and autism suggested by the article caused many parents to refuse or delay vaccinating their children. Although measles was considered eliminated in the United States in 2000, in 2014, 667 cases were reported in the US (CDC 2016). In 1963, before a vaccine was available for Measles, three to four million cases were reported yearly, resulting in hundreds of deaths. Despite concerns raised by the scientific community surrounding the Wakefield study, it took 12 years for the article to be retracted by *Lancet*.

Another highly publicized case involved the retractions of 88 articles by Dr. Joachim Boldt, a German anesthesiologist who published on clinical trials examining intravenous colloid use as intravascular volume replacement therapy in surgical patients. The initial retractions were based on lack of ethics committee approval. This in itself does not indicate fraud, but further investigation did uncover data fraud and missing study documents on patients (Wiedermann 2016). This case will continue to be investigated for many years, but a recent systematic review has indicated the possibility of increased risk of bleeding, anaphylactic shock, and heart failure associated with the use of synthetic colloids (Hartog et al. 2011).

Article retractions based on fraud are frequently reported, indicating widespread scientific misconduct, although many retractions appear to be due to honest error and have not been linked to misconduct (Nath et al. 2006; Steen 2010). However, a larger retraction study found the opposite to be true; Fang et al. (2012) reported that 67.4% were retracted due to fraud or suspected fraud, duplicate publication, and plagiarism. Only 21.3% were attributable to error (Fang et al. 2012). Although the rates for retractions increase each year, the numbers are still very small relative to the number of articles published (Grieneisen and Zhang 2012).

The opinion that peer review is ineffective at uncovering scientific misconduct or fraud is commonly held, but to be fair peer review's purpose was never one of fraud detection. Peer reviewers' task is to evaluate research with the purpose of advancing

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[25] .Wakefield, A. J., Murch, S. H., Anthony, A., Linnell, J., Casson, D. M., Malik, M., ... & Valentine, A. (1998). Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive developmental disorder in children. *The Lancet*, *351*(9103), 637–641. (RETRACTED:See *The Lancet 375*(9713) p.445)

science. Evidence indicates that the peer review process has difficulty detecting honest errors—irreproducible data, faulty calculations or logic, or accidental contamination—as well. Reflecting these challenges, even highly revered journals accept articles that in hindsight should not have been published. For example, in two years Schön published repeatedly in two prestigious journals—nine articles in *Science* and seven articles in *Nature* which were eventually retracted (Service 2002). Peer reviewers do not normally have time to examine data sets related to manuscript submissions and this case was no exception. Often peer reviewers do not even have access to the data. Also, the numbers indicate how rare fraud actually is, so reviewers are not in the habit of looking for it or are they expecting to find it. In addition, even if reviewers were looking for signs of fraud, those who commit fraud are careful not to include anything that would attract a peer reviewer's attention (Stroebe et al. 2012).

Despite criticisms highlighting ineffectiveness in detecting scientific misconduct or fraud and other shortcomings, peer review is still accepted as the mechanism to maintain the standard and trustworthiness of recorded knowledge that is being made available at an unprecedented rate. In addition to scientific research, there are many instances in which advisory panel judgments, legal decisions, and government policies depend on peer-reviewed scientific literature. Although instances of scientific fraud are more frequently becoming known to the general public through the media, the peer reviewing process still gives the public the assurance that research findings have been validated before they are published (Grivell 2006). A survey of a large group of mostly senior authors, reviewers, and editors of leading journals representing diverse geographic regions and by fields of research, conducted by Ware (2008), revealed wide support for peer reviewing: researchers overwhelmingly (93%) believe that peer review is necessary and a clear majority (85%) believe that peer review benefits scientific communication. Most respondents (90%) said that peer review improves the quality of the published paper, and 89% of authors said that peer review had improved their last published paper in terms of correcting scientific errors (Ware 2008). Moylan et al.(2014) reported a survey of editorial board members showing that these members, regardless of their potential role as "author," "reviewer," or "editor," prefer the existing system of peer review (Moylan et al. 2014), and according to some scholars it still continues to "serve science well" (Alberts et al. 2008) in spite of its deficiencies. Both empirical and anecdotal evidence suggest that the consensus of the scientific community is not to abandon peer review but to improve it (Smith 2006). Some envision that an ideal scholarly publication assessment system can evolve from the existing system without revolutionary changes (Kriegeskorte et al. 2012).

How to improve the current peer review system is a topic that has been vigorously debated. Although peer review has become an important mechanism for assessing the quality of science, it is not well understood in scientific terms, and attempts to improve the quality of the system are based on trial and error rather than on experimental investigation (Squazzoni and Gandelli 2012). To ensure its credibility and sustainability, scientific examination of the peer review system covering all aspects is essential. Although there have been a few studies conducted to measure the quality and effectiveness of the peer review system, there is relatively little empirical evidence available in spite of the importance of this subject. The peer review system involves the interaction of several players (authors, journal editors, publishers, and the scientific community) and is influenced by professional, social, cultural, and economical factors. Therefore, sociological investigations of the peer review system that integrate behavioral sciences, psychology, and economics could provide critical understanding, and could also develop strategies to improve it (Squazzoni 2010). As suggested by Kriegeskorte et al. (2012), scientists must be involved in designing the scientific publication evaluation process rather than leaving it solely to publishing companies (Kriegeskorte et al. 2012).

6.9 The Peer Review System Is Under Stress

There is no question that the peer review system is under stress, raising serious questions about its sustainability. Bjork et al. (2009) estimated that nearly 1.3 million peer-reviewed scientific articles were published worldwide in 2006 (Bjork et al. 2009). Jinha (2011) estimated that the total number of scholarly articles published since the inception of the first journal in the year 1665 reached the 50 million mark in 2009 (Jinha 2010). Each of these individual manuscripts has been reviewed by at least one reviewer, sometime by two or even three, and many have undergone several rounds of review before being published. Moreover, with an average manuscript rejection rate of 20–50% (even higher in some leading journals) (Bjork et al. 2009), there is a considerable number of rejected manuscripts at any given time that will be resubmitted to different journals and consume additional rounds of peer reviewing time. All these reflect the enormity of the undertaking of the peer review system, which is further stretched by the ever-increasing number of OA journals. On top of that, the unethical practices used by some authors waste the time and energy of peer reviewers and editors. Spielmans et al. (2009) provided empirical evidence of a practice used by some researchers to increase the number of articles from the same set of data and criticized these as redundant publications that do not add much to scientific understanding, calling them "salami publications"[26] (Spielmans et al. 2009).

6.10 Burden on Peer Reviewers

Peer reviewers play one of the most significant roles in maintaining the excellence of high standards of the scientific knowledge base, which is a heavy burden carried out by scientists that benefits both the scientific community and the public with no

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[26] A practice used by researchers to increase the number of articles publishing multiple papers using very similar pieces of a single dataset. The drug industry also uses this tactic to increase publications with positive findings on their products.

direct financial compensation. These services are rendered based on the principle that scholars who author and publish their own work should be freely available to review the work of other authors, and to carry out this responsibility with high standards of ethics and professionalism. This practice has become a norm among scholars who fulfill this obligation by providing timely and impartial quality assessment of manuscripts to the best of their expert knowledge following the policies of the publishing journal and with the ultimate goal of improving and maintaining the integrity of the knowledge base of their specific discipline.

This task has become even more challenging as scientific research has become more interdisciplinary and highly sophisticated as articles are submitted with increasingly large amounts of supplementary material. In addition to keeping up with advances in their own subject discipline and related disciplines, reviewers need to be knowledgeable about underlying social issues related to their discipline. Reviewers might be asked to judge not only the scientific quality and technical correctness of manuscripts, but also to consider other aspects such as the potential to open up new research areas, challenge existing knowledge, or even impact society. Reviewers also need to be vigilant about scientific fraud, unethical publication practices, and potential conflict of interests of authors, further increasing their burden.

6.11 Ways to Improve the Peer Review System

As described above, peer reviewing is a voluntary service provided by researchers and scientists. Offering credit for their time and expertise is being discussed (and some journals have already begun to do this) to encourage more participation and attract better reviewers. There are proposals to use metric systems to quantify scientists' contributions as reviewers (Cantor and Gero 2015).

As the increasing number of manuscripts submitted for publication worldwide continues to overburden the available reviewers, journal editorial staff take precautions to reduce the reviewer's workload by screening manuscripts prior to sending them out for review. However, in instances when many journals have to rely on a limited pool of reviewers, the pressure on them is unavoidable. In order to alleviate this, sharing of reviewers is a strategy that has been used by some groups of journals (e.g., *BioMed Central*, the *British Medical Journal*, the *Nature Publishing Group*), and other independent journals in some subject disciplines have also experimented with this practice. For example, the Neuroscience Peer Reviewer Consortium[27] was created in 2008 with journals agreeing to share reviewers (Pulverer 2010).

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[27] Neuroscience Peer Reviewer Consortium http://nprc.incf.org/.

6.11.1 Training Peer Reviewers

As reviewers seldom receive formal training on peer reviewing, they are expected to learn the needed skills on the job. Freda et al. (2009) revealed that 65% of the participants in their international survey of nursing journal reviewers would like to have formal training, but only about 30% have received it (Freda et al. 2009). The idea of offering training to reviewers to improve the effectiveness of peer reviewing has received mixed reactions because empirical evidence shows that reviewer training has no significant effect on improving the quality of reviews (Schroter et al. 2004; Callaham and Tercier 2007). Although some journals use their own tutorials to educate new reviewers about issues related to peer reviewing, the depth of coverage on important aspects in these tutorials may not be adequate (Souder 2011). DeVries et al. (2009) suggest starting early on by training and mentoring graduate students to become good reviewers (DeVries et al. 2009).

6.11.2 Ethical Standards for Authors, Reviewers, and Editors

The unethical behavior of some participants involved in peer review that affects the credibility of the whole system is being widely discussed. To restore the trustworthiness of the peer review system, there is a need for scientific journals to adopt standardized ethical guidelines for all stakeholders—authors, reviewers, and editors. Traditionally, editors of peer-reviewed journals use their scientific expertise to prescreen manuscripts to identify ones that qualify to go through review process, identify peer reviewers, and make final publication decisions based on review reports. Thus, editors play a key role in the peer review system, which impacts the quality of the scholarly output. The editor's role becomes more important than the judgment of reviewers in high-impact journals because there are more manuscript submissions than these journals can accept, so the editors decide[28] which ones to send for peer reviewing (Lawrence 2003). Wellington and Nixon (2005) described the changing roles of editors of academic journals (i.e., filter, gatekeeper, mediator, guardian, facilitator), reminding us that they might even have a role in changing the direction of scientific progress (Wellington and Nixon 2005). Therefore, considering the critical role that journal editors play in the peer review system, it is unquestionably important to set ethical guidelines for them. Nonetheless, although many scientific journals have established ethical requirements for authors, many do not have similar standards for journal editors and reviewers. Positive developments

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[28] "About 80% of submitted manuscripts are rejected during this initial screening stage, usually within one week to 10 days." http://www.sciencemag.org/site/feature/contribinfo/faq/ (accessed on October 18, 2016); "Nature has space to publish only 8% or so of the 200 papers submitted each week" http://www.nature.com/nature/authors/get_published/ (accessed on October 18, 2016).

in this direction include the "Code of Conduct and Best Practice Guidelines for Journal Editors" developed by COPE[29] for its members, although they are not bound to follow them, and the "Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals"[30] developed by the International Committee of Medical Journal Editors. Declaration of potential COI by editors and reviewers can be considered as a major step toward ensuring the trust of all participants in the peer review system as well as consumers of scientific knowledge. Resnik and Elmore (2016) discussed steps editors should take during different stages of the process to uphold the integrity of the peer review system (Resnik and Elmore 2016).

6.12 Concluding Remarks

Peer review of manuscripts is considered a critically important aspect of maintaining the quality and trustworthiness of scientific information and knowledge. The practice of peer review, widely adopted by scholarly journals but challenged by the emerging specialization within disciplines and the increasing number of manuscripts submitted to journals, is a topic of great interest and the center of extensive academic discussion. While the peer review system is being heavily criticized for its deficiencies, no alternative system has yet been proposed. There are no signs of abandoning the peer review system, and debates and discussions are continuing on how to improve it. Despite its importance to the research community, peer review itself was not researched until the late 1980s; since the International Peer Review Congress in 1989, the number of original research articles on the subject of peer review has increased and now represents a sizable knowledge base, according to some authors (Ware 2011, p. 24). However, it is an open question whether a subject of this significance is being sufficiently studied, providing enough empirical evidence on various aspects of the peer review system to guide and support needed improvements.

The closed and secretive nature of the conventional peer review system has been criticized as contradicting the ideals of openness expected in science. The double-blind system has been promoted by some to reduce the bias associated with the single-blind system, while opposing arguments highlight the difficulty of achieving complete anonymity of authors and criticize the increased secrecy of a double-blind process. Voices for opening up the peer review system are heard loudly, and many stakeholders of scientific progress probably (some with reservations) agree with the concept, although it has practical and subjective dimensions that are difficult to overcome. The increased use of information technologies

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[29] Code of Conduct and Best Practice Guidelines for Journal Editors http://publicationethics.org/files/Code%20of%20Conduct_2.pdf.

[30] Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly work in Medical Journals http://www.icmje.org/icmje-recommendations.pdf.

enables journals to experiment with various features of OPR, combining them with features of the conventional system with encouraging success. Open review is an evolving trend that will be part of scholarly communication in the future; therefore, thorough intellectual examination of its successes, failures, discipline-specific issues, and aspects of social acceptance is needed to make it an effective, efficient, and impartial system that meets expectations of advocates of open evaluation.

Peer review of manuscripts is a collaborative process in which authors, reviewers, and editors work together in recording scientific knowledge efficiently and correctly. Like any human activity, peer review suffers from imperfections, but can be improved through the collective wisdom of not just participants but all stakeholders, to achieve the ultimate objective of publishing high-quality scientific information that expands human knowledge and promotes scientific progress.

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Chapter 7
Measuring the Impact of Scientific Research

Abstract The body of scientific knowledge grows with incremental additions. Assessing the scientific quality and the impact of these contributions is necessary because future scientific research is based on previous knowledge. As the key literature consulted and influenced their work should be cited when researchers publish findings, measures based on citations metrics became the most widely accepted impact assessment tools, and citation analysis is considered an objective means to evaluate scholarly publications. Historical developments, strengths, and limitations in citation-based assessment tools, use of impact factor in measuring the scientific quality of scholarly journals, and use, misuse, and manipulation of the journal impact factor are examined in this chapter. The discussion also includes citation indexes and related issues, and other journal ranking systems. Assessing the performance of individual scientists using citation metrics, the *Hirsch* index, and many variations proposed to correct its deficiencies are discussed. Although citation metrics can be considered the best tools yet implemented to assess the quality and influence of scientific research, the importance of understanding their strengths, limitations, and implications when using them is stressed.

Keywords Scientific scholarly impact · Citation analysis · Bibliometrics · Journal impact factor · *Hirsch* index · Self citation

7.1 Introduction

Although the body of scientific knowledge is constantly expanding, most often the growth is incremental until interrupted by major revolutionary additions. Some discoveries are so radical as to change the direction of research in a scientific field as new theories are developed, questions are raised, and then efforts are initiated to address them. All of this drives the progress of science, and the body of knowledge keeps growing. As Isaac Newton humbly expressed in his letter to Robert Hooke in 1675, "If I have seen further it is by standing on the shoulders of Giants," an acknowledgment that even the best researchers are raised up by the work of others

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and are thus able to “see further.” In other words, any research project is built on the knowledge assimilated through research that preceded it. Although assessing the impact of each contribution to the body of scientific knowledge is unquestionably challenging, such assessment is necessary to ensure that future work is built on a solid foundation (King 1987). How we measure the quality and impact of scientific research is the center of a vigorous but productive debate of interest to many stakeholders. With the expansion of scientific knowledge bases, systems are being developed to maintain the trustworthiness of scientific publication. As peer evaluation has always been considered an essential part of scientific research, peer reviewing of scientific articles has evolved to be one of the widely accepted measures of assessing the quality of scientific publications. Although there are some limitations to this process, peer reviewing is continuing as a pre-publication quality control measure. Since established in the seventeenth century, formal scientific journals have evolved to be major “dissemination carriers” of research articles. Although the number has steadily increased since then, innovations in computer and information technologies accelerated the growth. During the time science was “small,” there was consensus among scientists on the quality of journals and the best ones in their specific disciplines. However, with the continuous expansion of scientific endeavors, the need for an objective means to assess the quality and performance of articles, journals, and even researcher began to surface.

7.2 Citation Data as a Tool to Measure the Impact of Scientific Scholarly Articles

The key literature consulted during the planning and execution of a research project needs to be cited when researchers publish their findings. Therefore, the number of times an article is cited is considered to reflect the influence of that article exerted on ongoing scientific research. Building on this concept, Garfield (1955) presented the idea of using citation data as a quantitative measure to evaluate the relative importance of scientific articles and journals (Garfield 1955). Garfield and Sher in the 1960s further developed this idea, discussing the use of citation analytical measures to assess the “impact” of publications (Garfield and Sher 1963). Citation analysis involves counting the number of citations to a document and assessing that count relative to those of other documents through comparison and normalization processes (Kostoff 2002); it is thus considered an objective means to evaluate scholarly publications. Garfield (1955) also proposed creating a citation index as an “association-of-ideas index” and discussed the value of a citation index that would help researchers thoroughly search for the “bibliographic descendants of antecedent papers,” as a practical and time-saving tool to comprehensively examine the literature (Garfield 1955). In 1964, the Institute for Scientific Information (ISI) began publishing the Science Citation Index (SCI), a resource showing how many times a given article is cited in other articles, which provided a way to illustrate the significance (or influence) of the work, and by 1974 it covered nearly 400,000 articles in nearly 2,500 scientific and technical journals (Garfield 1976). Over the next two decades, many organizations including universities, research organizations, and even US and European government agencies used the ISI (now Thomson Reuters) citation database for a variety of bibliometric exploratory activities (Pendlebury 2009) and dominated the citation index arena until Elsevier introduced Scopus in 2004.

The premise behind using citation metrics to measure the "impact" of scientific scholarly literature, as mentioned earlier, relies on scientists citing previous work that influenced their research. However, using such metrics will give a misleading picture, as in reality there will be deviations from this assumption. MacRoberts and MacRoberts (2010) discussing citation habits in the discipline of biogeography, argued that the influence of uncited work used in this discipline would not be reflected in citation analysis (MacRoberts and MacRoberts 2010). Similarly in any scientific discipline, researchers do not cite every article of influence, and sometimes do not even cite all of the most important ones. These tendencies, as well as the inability to account for informal scholarly interactions that influence research, are considered limitations of citation metrics. Another issue is the fact that the citation counts do not reveal the context of citation. In addition, biased citations, negative citations, and excessive author self-citations were identified as factors that distort citation analysis results. Authorship-related issues such as multiple authorship and inability to distinguish between authors with the same last name are other limitations. Failure to differentiate among types of articles (i.e., applied research vs. basic research), and variations in citation rates (e.g., discipline specificity) are also identified as main drawbacks in citation analysis.

The "Relative Citation Ratio", a new article-level and field independent metric was proposed (Hutchins et al. 2016) and a team of NIH analysts have quickly endorsed it as a promising article ranking tool (Basken 2016). Although it is too early to judge the effectiveness and adaptability of this metric, if effective it would be an alternative, replacing the unwise practice of using the journal IF to assess the quality of articles (this issue is discussed later.)

7.3 Impact Factor to Measure Quality of Journals

In 1972, Garfield suggested using the "journal impact factor," as a measure of journal quality (Garfield 1972). The impact factor (IF) of a journal is calculated by adding up the number of citations in the current year of any items published in that journal in the previous two years and dividing by the total number of articles published in the same two years.

For example, if 2016 cites to articles published in a journal in 2014–15 = A, and number of "citable items" published in that journal in 2014–15 = B.

The 2016 IF of the journal = A/B.

The question is whether the IF correctly reflects the quality of a journal. Saha et al. (2003) found a significant correlation between the IF of general medical journals and the quality as rated by researchers and practitioners (Saha et al. 2003). The Journal Citation Report, which was first published in 1976 (Bensman 2007), now includes Journal Impact Factors (JIFs) two-year impact factor, and five-year impact factor—and other usage metrics (including journal immediacy index,[1] journal cited half-life[2] of journals covered by Thomson Reuters (previously ISI) citation databases and available through the Web of Science portal for a subscription fee).

Although IF is probably the most widely used indicator to measure journal quality, the use and misuse of this indicator is a subject of great debate. Using these metrics without proper understanding might have damaged their credibility and drawn criticism, devaluing the potential of these indicators (Glänzel and Moed 2002). A good understanding of the strengths and weaknesses of IF is critical (MacRoberts and MacRoberts 1989; Garfield 1999), not only for researchers and scholars but also for other stakeholders, including scientific information consumers (e.g., practitioners, science writers, and concerned citizens), research funders, academic administrators, and policy makers. In the next section, the use and limitations of citation metrics as an objective means to evaluate scholarly journals will be discussed.

7.3.1 Strengths of Impact Factor in Measuring Journal Quality

The JIF involves a comprehensive but relatively simple calculation conducted in the same way over a long period; thus, providing a good picture of the scholarly performance of a journal over time. JIF metrics are promptly and widely available through the Journal Citation Report (JCR). In spite of some limitations (discussed later), journal rankings based on JIF data provide a reasonable global overview of the influence of scholarly journals. Wide usage of JIFs indicates their acceptance, sometimes with reservations, by participants and consumers of the scholarly communication system. Since the JIF is based on the most recent two-year period that reflects the latest performance of a journal, dramatic fluctuations are usually not observed; therefore it can be used for performance assessment purposes when other more current indicators are not available (Glänzel and Moed 2002; Pendlebury 2009). As JIF is available only for journals indexed by Web of Science, the Thomson Reuters database, it is sometimes accused of being biased against non-English-language journals, limiting their coverage in the database. In addition, there are a number of other shortcomings, limitations, and biases of the JIF which have been discussed and debated since its introduction, several of which are summarized below.

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[1] Journal Immediacy Index is defined by JCR as "the measures how frequently the average article from a journal is cited within the same year as publication."

[2] Journal cited half-life is defined by JCR as "the age of cited articles by showing the number of years back from the current year that account for 50% of the total number of citations to a journal in the current year."

7.3.2 Limitations of Impact Factor in Measuring Journal Quality

Although citation tools are often considered as objective measures, several sources of potential bias have been identified. One criticism of the use of JIF is that it does not capture the diverse factors that contribute to a journal's influence. Even though a higher IF might suggest a greater impact, it might not necessarily indicate higher quality because JIF can be raised by a few articles that are heavily cited, even if most articles in the journal do not have high citation rates (Durieux and Gevenois 2010). As JIF does not correctly reflect the quality of individual articles published in a journal, it is misleading to use this indicator to assess the quality of a specific article.

7.3.3 Ability to Manipulate Journal Impact Factor

The lack of clarity about the "citable items" (generally original research articles and review articles) counted in the denominator, and the inclusion of citations to other types of items such as letters, editorials, and meeting abstracts in the numerator (but not counted in the denominator) will inflate the IF value and is considered a serious deficiency (Chew et al. 2007). For example, journals such as *Science*, *Nature*, the *Journal of the American Medical Association* (JAMA), and *Lancet*, which include a variety of non-source items such as news and correspondence, have high IFs (Garfield 1999; Chew et al. 2007). It is well known that review articles generally have a higher chance of being cited as they summarize many original works. This is illustrated by the fact that the review journals (e.g., *Nature Reviews Immunology*, *Nature Reviews Molecular Cell Biology*, *Chemical Society Reviews*) are among the journals with the highest IFs. Because the citation rates of non-review journals might be increased when they publish more review articles, journals are sometimes accused of using the strategy of publishing more citable articles such as reviews to manipulate their IFs.

Prereleasing articles, adjusting the timing of article publication, and breaking manuscripts into "least publishable units" with more self-citations are among other tactics editors are sometimes accused of using to manipulate the IF of their journals (Mavrogenis et al. 2010). Strategies editors are supposedly using to manipulate the JIFs are being critically discussed (Kirchhof et al. 2006). The fact that journals can manipulate their IFs reduces the credibility of this metric.

Journal self-citation,[3,4] refers to the situation when an article in a given journal cites other articles published during the previous two years in the same journal. It had been reported that a journal's self-citation level can influence its IF

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[3] Not to be confused with author self-citation that will be discussed later.

[4] Available from the JCR provided as a part of the Web of Knowledge platform by Thomson Reuter.

(Hakkalamani et al. 2006; Miguel and Martí-Bonmatí 2002; PLoS Medicine 2006). McVeigh (2004) reported that the majority of high-quality science journals covered in Thomson Reuters had a journal self-citation rate of 20% or less (McVeigh 2004). Others reported journal self-citation levels ranging from 7 to 20% of an article's references (Falagas et al. 2008; Fassoulaki et al. 2000; Hakkalamani et al. 2006; Miguel and Martí-Bonmatí 2002).

Several factors may lead to high self-citation rates. For example, this would tend to occur when a particular journal provides only one of the few publication venues for a highly specific or unique topic, so highly specialized journals may have a high self-citation rate (Hakkalamani et al. 2006). When such a journal has a low total number of articles (small denominator), having only a few citations coming from other journals will lead to a high self-citation level. In a journal with low citation numbers, even a slight change in the number of self-citations can significantly change its IF (Kirchhof et al. 2006). Although self-citation of relevant articles is not considered inappropriate, excessive self-citation rates can indicate questionable practices, since there are instances of journals promoting self-citation to manipulate its IF (Krell 2010; Kurmis 2003) and even publishing their own work with high levels of self-citation (Schiermeie 2008; Mavrogenis et al. 2010).

7.3.4 Issues with Discipline-Specific Journal Impact Factor Variations

The IF of journals can significantly differ among subject disciplines because citation practices and citation density (average number of citations per article) can vary depending on the discipline. For example, the citation density is known to be much lower in mathematics than in biomedical sciences. The half-life (a measure of how long journal articles are typically cited within a particular discipline) is another important variable that must be taken into consideration; for example, the half-life of a physiology journal is going to be longer than that of a molecular biology journal (Garfield 1999). Van Eck et al. (2013) discussed the differences in citation practices among medical fields and argued that clinical intervention research may be undervalued due to the low volume of research, when compared with basic and diagnostic research (Van Eck et al. 2013). Therefore, to control for citation frequency differences, allowing meaningful comparisons of citation impacts between subject disciplines, normalization at the discipline level is needed (Garfield and Merton 1979, p. 366; Moed 2010). Waltman and van Eck (2013) compared several bibliometric indicators which use various approaches to normalize for differences in citation practices between scientific fields, with the Mean Normalization Citation System (which is based on the traditional subject field classification system).[5]

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[5] Citation impact of a publication is calculated relative to the other publications in the same subject field.

They recognized several problems with the traditional subject classification system and suggested that these can be solved by using a more accurate field classification system such as MeSH in biomedicine and PACS in physics and astronomy (Waltman and van Eck 2013). Other solutions to correct the normalization issues in differences in discipline-specific citation behaviors have been discussed (Leydesdorff and Opthof 2010).

Since the use of a single impact measure to make meaningful comparisons among journals in multidisciplinary fields is disputed, a need for subject-specific impact measures has been suggested. For example, although a two-year window can be considered a strength for fast-developing fields such as molecular biology, it is considered too short for some subject disciplines (e.g., mathematics) in which the peak citation time is reached well beyond two years (Van Leeuwen et al. 1999). These observations have led to the assertion that a two-year window favors journals with rapid citation rates (Vanclay 2009, 2012). Reacting to this criticism, Thomson Reuters is now providing JIFs with a five-year citation window; however, some researchers have reexamined this topic and concluded that JIF calculated using two-year data effectively predicts the long term citation impact of journals (van Leeuwen 2012).

7.4 Need for Other Indicators to Measure Journal Quality

In spite of the popularity and prevalent usage of the JIF, due to its limitations and vulnerability to manipulation, the need for other complementary measures has been discussed for a long time. There are new measures such as "Usage factor"—promoted by the United Kingdom Serials Group, "Y-factor"—a combination of both the IF and the weighted page rank, developed by Google (Bollen et al. 2006), "Eigenfactor", and "SCImago Journal Rank" (SJR) that have been proposed. The most prominent measures that are already becoming widely accepted will be discussed here.

7.4.1 Eigenfactor Score

The Eigenfactor score (ES) is a measure of the influence of a journal,[6] and its model is based on the notion of how researchers follow citations. It ranks journals using an iterative algorithm similar to the one Google uses to rank web sites. Comparing these two, Bergstrom et al. (2008) stated, "Eigenfactor algorithm does something

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[6] Calculations are based on article citations in the JCR from the journal over the last five years, also taking into consideration which journals contributed the citations, giving more weight to the highly cited journals.

similar, but instead of ranking websites, we rank journals, and instead of using hyperlinks, we use citations" (Bergstrom et al. 2008). As the references for articles from the same journal are removed in calculations, ESs are not influenced by journal self-citations issue.

7.4.2 SCImago Journal Rank

The SCImago Journal Rank (SJR) indicator was developed using the widely known Google PageRank algorithm to assess the quality of scientific journals in the Scopus database.[7] In this system the weight of the citation is based on the "prestige" of the citing journal, and also the relatedness of the subject fields of the citing and cited journals is taken into consideration instead of using traditional classification of scientific journals. The citation window used is three years and the self-citation percentage is restricted to prevent an artificial increase in journal rank which is considered a major improvement over JIF (González-Pereira et al. 2010). SJR is an open access resource and includes a higher number of journals and publication languages, which are considered major advantages over JCR. In particular, the SJR is assumed to provide better estimation of the scientific value for non-English language journals. On the other hand, its shortcomings include the complicated calculation methodology and considerable undervaluing of non-source items such as news and correspondence, etc., some of which may be of interest to readers (Falagas et al. 2008).

7.4.3 Comparing Eigenfactor Score, SCImago Journal Rank, and Journal Impact Factor

Comparative studies of these metrics are being carried out for journals in different subject disciplines, and findings are leading to some sort of common agreement. Although there is a growing acceptance of SJR indicators because of some of their strengths (discussed previously), some argue that its introduction did not lead to a major change: for example, Falagas et al. (2008) compared the JIF and SJR rankings of 100 journals and found that half of them were within the range of 32 ranking places (Falagas et al. 2008). Bollen et al. (2006) observed a significant correlation between the weighted PageRank and the JIF rankings; however, they also observed discrepancies when considering different subject disciplines (Bollen et al. 2006). Comparing journal rankings based on SJR and JIF indicators, González-Pereira et al. (2010) found that the two metrics are strongly correlated, although there were noticeable trends of SJR values decreasing certain JIF (3y)

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[7] SCImago Journal & Country Rank http://www.scimagojr.com/aboutus.php.

values (González-Pereira et al. 2010). A study revealed that the correlation among all three indicators—JIF, SJR, and ES—are high for journals in the nuclear medicine field and can be used interchangeably to measure the quality of these journals. However, the study investigators reported that under certain conditions, SJR and ES indicators can be more accurate measures than JIF (Ramin and Shirazi 2012). Investigations of the JIF, ES, Article Influence Score (AIS),[8] and SJR values of pediatric neurology journals revealed that the highest correlation was between the JIF and AIS and moderate correlations were observed between JIF and SJR, and between JIF and ES; however, the journal rankings of JIF, SJR, and ES showed only minor differences. Another study examined JIF, ES, and SJR of Anatomy and Morphology journals and observed a negative correlation between JIF and EF, and JIF and SJR, and none of the journals had the same ranking by each of these indicators (Cantín et al. 2015). All these findings suggest that when determining the quality of journals, other indicators in addition to JIF should be used, along with an understanding of how citation practices vary among different disciplines.

7.5 Measuring the Impact of Individual Scientists or Groups of Scientists

The assessment of individual researchers is important not only for their promotion and tenure, and career advancements, but also to be more competitive in acquiring research funding. Assessing the performance of individual researchers by other experts in the field is a widely used practice, but since it is a subjective method, it can suffer from biases inherent in human interpretation. The integration of quantitative analytical tools in assessment can ensure the objectivity of expert evaluation (Sahel 2011). Therefore, bibliometric measures are becoming increasingly popular in the performance evaluation of individual researchers. Identifying the best metrics to use and understanding the limitations of each measure is critical. The troubling trend is that funding agencies, promotion committees, and scientists often extend the use of JIF, which is designed to measure the impact of journals, as a convenient means of assessing the scientific contributions of individual scientists and institutions.

The most commonly used metrics to measure the influence of an individual scientist are: number of publications, citations per paper, number of highly cited papers, and the total number of citations. The number of times an author has been cited is considered as a good bibliometric indicator, but has several deficiencies; these include, articles being cited for reasons not related to the quality, articles

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[8] Article Influence Score measures the average influence of each article in a journal. It normalizes the values by giving the mean article in the JCR an AIS of 1.00. So, a journal with an AIS of 2.00 means that its articles are on average two times more influential than the average article in the JCR. (Bergstrom et al. 2008).

published in prestigious journals having an unfair advantage, the positive or negative impact on citations when publishing in certain countries or languages, and the type of article (for example, review articles get higher citation numbers than original research articles). Another deficiency more relevant to author assessment is issue of all authors receiving equal rating despite differences in their levels of contribution, in other words the primary contributor carries the same weight as the author playing a minor role (Sahel 2011). Although the use of citation metrics is well accepted, a survey conducted by *Nature* in 2010, designed to gauge the perception of metrics in evaluating individual scientists, revealed that 63% of respondents were not happy with the way in which some of the metrics are used (Abbott et al. 2010).

7.5.1 **Hirsch** ***Index (*****h-*****Index) and Its Variants***

In 2005, in light of the limitations of bibliometric methods for evaluating individual researchers, George Hirsch proposed an indicator, the *h*-index, which calculated both the quantity and the impact of a researcher's publications. It provided information about a researcher's productivity and the impact of his or her publications in a single number (Bornmann and Marx 2014). Hirsch defined the *h*-index as "a scientist has index *h* if *h* of his or her *Np* papers have at least *h* citations each and the other (*Np* _*h*) papers have _*h* citations each" (Hirsch 2005). Advantages of the *h*-index include ease of computing, especially through databases such as Web of Science, Scopus, and Google Scholar and ease with which one can evaluate the overall performance of a scientist's output by measuring the quantity of publications, along with their influence. The *h*-index can also measure the impact of research groups or institutions (Egghe and Rao 2008; Molinari and Molinari 2008). Banks (2006) proposed the *hb*-index as an extension to the *h*-index to determine how much work has already been done on topics and chemical compounds and to identify "hot topics" or research topics and compounds in mainstream research at any point in time (Banks 2006).

Although the *h*-index is praised for its objectivity when used to compare scientists within the same field, it has been criticized for limitations as well. Comparing scientists from different fields is one such limitation, since it does not adjust for variety in productivity and citation practices across disciplines. Imperial and Rodríguez-Navarro (2007) indicated that applied research areas are less cited than basic areas of science due to differences in citing populations, resulting in lower *h* values in applied research areas. To adjust for these differences, the authors suggest using the h_R derivative which allows for differences in publication patterns for different scientific areas, as well as for countries which may not have well-established research systems (Imperial and Rodríguez-Navarro 2007).

The tendency of the *h*-index to favor scientists with long careers, making it unsuitable for comparing scientists in different stages of their careers, is also a concern. Having recognized this problem, Hirsch (2005) proposed dividing a researcher's *h*-value by the number of years since his or her first publication, calling it the m-quotient. Others also?? have discussed ways to overcome this limitation (Burrell 2007). Another drawback of the *h*-index involves highly cited papers; once a paper is selected to the top group, its subsequent citations do not affect the *h*-index. So if a paper eventually becomes a highly cited paper, the *h*-index will not reflect the change. Egghe (2006) contends that a researcher with one highly cited paper can have an equal *h*-index to a researcher with several moderately or several highly cited publications and introduced a variant *g*-index to rectify this deficiency (Egghe 2006).

The influence of self-citations on the *h*-index can be considered as one of the most criticized aspects of it (Alonso et al. 2009). Self-citations artificially inflate the *h*-index value and this impact can be significant, especially in the case of young scientists with low *h*-index (Schreiber 2007). Several authors proposed to exclude self-citations from any citation-based index calculation (including the *h*-index) to obtain a fairer indicator (Schreiber 2007; Vinkler 2007). But as with other modifications, excluding self-citations might complicate matters.

Inability to take into account the "order of the authors"?? of published articles, which may give unfair advantage to some researchers, is considered a serious shortcoming of the *h*-index. Schreiber (2008) proposed a variant that adjusts for this called the *hm*-index which involves fractionalized counting of papers (Schreiber 2008). Egghe (2008) also addressed this problem with a similar solution to give single authors more credit than those working in big groups (Egghe 2008). Romanovsky (2012) introduced the *r*-index by revising the *h*-index to give higher recognition to leading investigators of large groups, correcting the unfair advantages collaborators might gain (Romanovsky 2012). Another updated *h*-index was introduced by Bucur et al. (2015) named Hirsch *p,t*-index that can be applied to disciplines (e.g., biomedical disciplines) where the first and last positions of the author list in an article are the most important (Bucur et al. 2015). Another deficiency of the *h*-index relates to performance changes of a scholar across his or her lifetime. Jin et al. (2007) proposed that one must include the age of the publications to evaluate performance changes. Jin's *AR*-index takes the age of the publications into account and is suggested to be used in combination with the *h*-index (Jin et al. 2007). The *AR*-index can increase or decrease over time, unlike other indices.

Interestingly, based on the findings of a meta-analysis that included 135 correlation coefficients from 32 studies, Bornmann et al. (2011) argued that there is redundancy between most of the *h*-index and its variants as they found high correlation between the *h*-index and its 37 variants (Bornmann et al. 2011).

7.6 Concluding Remarks

Measuring the impact of scientific research is a complex issue and unquestionably challenging. Although, the quality of scientific research cannot be quantified, a variety of quantitative measures are being developed to assess the influence of journal articles as proxies for scientific impact of research, many of which rely on citation data. The sheer number and variety of available bibliometric measures reflect the degree of difficulty of appropriately assessing the scientific scholarly communication landscape. It is important to understand the strengths, weaknesses, and implications involved when using assessment metrics.

As a result of the ongoing discussions about the issues and limitations of some of these measures, efforts continue in refining and improving them. Moreover, because of the complex nature of scientific research, measuring the quality using a single indicator might provide an incorrect or even a misleading assessment. Therefore, it is important to identify the best combination of indicators depending on the situation, and interpreting assessment results with a greater understanding of the strengths and limitations of metrics used.

Regardless of the confusion, criticism, and disagreements, citation metrics can be considered the best tools yet implemented to assess the quality and influence of scientific research. These measures however, focus on assessing the scientific impact of research but do not address the social benefits or broader impacts which is critically important aspect in assessing the total quality of scientific research.

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Chapter 8
Assessing the Societal Impact of Scientific Research

Abstract Peer reviewing and citation metrics are traditionally used in assessing scientific research, with the emphasis on measuring the scientific quality and impact. Consensus among stakeholders of scientific research was building toward the need for assessing the societal benefits of scientific research, in addition to scientific quality. With the recognition of these needs by different governments and research funding agencies, formulating policies and guidelines to incorporate societal impact assessment in grant funding requirements and national science policies began. The most critical and challenging aspect of measuring the societal benefits is identifying assessment tools that efficiently and effectively measure these impacts. With the computer and communication technological advances and fast evolving social networking environment, use of the alternative metrics or altmetrics in assessing the societal impact of research gained attention. In this chapter, these developments are discussed by reviewing literature on the topic. The potential of altmetrics in assessing societal benefits of scientific research, and their strengths and limitation as assessment metrics, the empirical evidence of the correlation between altmetrics and traditional citation metrics, and efforts that are needed and in progress to improve the quality and standards of altmetrics are examined.

Keywords Societal impact · Alternative metrics · Altmetrics · Citation metrics

8.1 Introduction

Well-known historical events such as Galileo Galilei's experience in the seventeenth century with his support of heliocentric theory, the Soviet government's banning of Mendelian genetics and promoting genetic theories of Trofim Lysenko in the twentieth century, and many more lesser known happenings have shaped the direction of science. Awareness of these incidents has led to voices urging for "science as an autonomous human activity" free of political and religious influence and persuasions, to be ultimately directed toward the benefit of society. For example, after investing heavily in defense-related research during World War II, US government agencies associated with scientific research were looking for new

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directions. Vannevar Bush who was a prominent scientist and the science advisor to President Franklin D. Roosevelt highlighted the value of basic scientific research and advocated for strong autonomy in science in his report, "Science, the endless frontier" submitted in 1945. However, the "Science and Public Policy" report prepared by Steelman in 1947 emphasized the need for partnerships between universities, industry, and government, and advocated federal support for research and development (R&D) to accelerate basic as well as health and medical research areas largely neglected during wartime. Steelman's report was considered as limiting the autonomy advocated by Bush but aligning science with national policies. Against this backdrop, the National Science Foundation (NSF)[1] was established in 1950 as an independent agency in the executive branch of the US government.

With a few exceptions, "science policy did not become a serious intellectual discussion" until the 1960s (Bozeman and Sarewitz 2011), and many countries invested in R&D with the assumption that increased investments would make their countries more competitive and improve the lives of the people. However, consensus was building among stakeholders toward the need for assessing the "societal benefits" of scientific research, in addition to assessing the scientific quality. Defining "societal benefits of science" is challenging as it may be interpreted differently by various sectors of the society, and these interpretations undoubtedly will evolve with time. For example, during the World War II era, national defense was the main beneficiary of scientific research in the US. Meanwhile, the emphasis on commercialization or "wealth creation" was observed in the science, technology, and innovation (STI) policy that regulates publicly funded research in the OECD (Organization for Economic Co-operation and Development) countries (Donovan 2005). However, the focus of public policies of many countries, including OECD countries, started to change with increased understanding of the value of social and environmental aspects of human development. Economic, environmental, social, and cultural factors are considered societal benefits: contributions to improving national productivity, economic growth, employment growth, and innovations are identified as economic benefits, whereas increasing biodiversity, preserving nature, or reducing waste and pollution are recognized as environmental benefits. Social benefits of research are contributions made to the social capital of a nation (e.g., stimulating new approaches to social issues, informed public debate, and improved policymaking) (Donovan 2008).

8.2 Challenges in Defining Societal Benefits

There are many questions to be answered before identifying effective strategies of societal benefit assessment of scientific research; although we do not have answers to many of these questions, it is encouraging to see that a productive discussion

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[1] National Science Foundation http://www.nsf.gov/about/history/legislation.pdf.

about this topic is continuing among many stakeholders. These stakeholders include the scientific community, policy makers who facilitate the transfer of benefits to the society, research-funding organizations (including governments) who are interested in maximizing the benefits of their investments, professionals who use the new knowledge to improve their services and product developments, and the general public. As mentioned earlier, defining "societal benefits" or "societal impact" is confusing and problematic because these concepts may mean different things to different stakeholders. Reflecting this vagueness, a variety of terms have been proposed to describe the concept of societal benefits of research, such as "societal relevance" (Holbrook and Frodeman 2011), "public values" (Bozeman and Sarewitz 2011), and "societal quality" (Van der Meulen and Rip 2000). Since there is no definitive agreement on the appropriate term, "societal impact" will be used hereafter in this discussion.

Identifying the most feasible indicators is the essential but most challenging issue in assessing the societal impact of research. As societal impacts cannot be clearly defined, setting up criteria or metrics to assess these impacts is inherently difficult. To assess the "scientific impact" of research, widely recognized and time-honored bibliometric indicators[2] are used and continually refined to fit the evolving requirements. However, there are no accepted systems developed yet to assess the societal impact, and the "societal impact assessment research field" is in its infancy.

Identifying common indicators is also difficult in many ways as societal impacts of research vary with the scientific discipline, the nature of the research project, the target group, etc. In some research fields the impact can be complex or contingent upon other factors and it is therefore a challenge to identify substantial indicators to measure these impacts. Sometimes there may be benefits that are important and readily evident, but not easily measured. In other instances, for example in basic research, it will take many years, even decades, to realize benefits, and decisions or policies made based on early impact measurements might be misleading and even detrimental. Therefore, the societal impact of basic research needs to be thoroughly studied before setting up criteria. As impacts of scientific research may not always necessarily be positive, assessment criteria should be able to distinguish between positive and negative impacts as well (Bornmann and Marx 2014).

8.3 Research Assessment Strategies of Government Agencies in Different Countries

Different countries have their own research assessment policies and continuously improve these systems in accordance with their evolving national needs and priorities to get the best returns for the public funds they invest in research.

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[2] See Chap. 6, "Measuring the impact of scientific research" (pp. 98–112).

For example in the US, the NSF revised its grant review criteria in 1967, 1974, and 1981. Since 1981, grant proposals have been reviewed based on four criteria: researcher performance competence, intrinsic merit of the research, utility or relevance of the research, and effect on the infrastructure of science and engineering. In 1997, it approved new research assessment criteria aimed at emphasizing the importance of the societal impact of NSF grant proposals. With those changes in place, peer reviewers of grant proposals were asked to consider the broader impact of the research proposals. These criteria remained largely unchanged but were further clarified in 2007. In 2010, NSF examined the effectiveness of these merit review criteria and proposed new recommendations. Two merit review criteria—intellectual merit and broader impact—remained unchanged, but the value of broader impacts of scientific research beyond advancing scientific knowledge was recognized as emphasized by the America COMPETES Reauthorization Act of 2010 and the NSF strategic plan. In the revised merit review criteria implemented in January 2013, "broader impact" was clearly defined by adding a principles component in order to clarify their functions and stated that the criterion covers "the potential to benefit society and contribute to the achievement of specific, desired societal outcomes".

Similarly, in the United Kingdom (UK) and Australia (Lewis and Ross 2011) the basis of research fund awarding shifted in the 1980s, from the traditional model toward research quality that directly provides economic or social benefits. In 1986, the Research Assessment Exercise (RAE) was introduced and was replaced by the Research Excellence Framework (REF)[3] in 2011 for assessing the quality of research conducted in higher education institutions in the UK. The impact assessment measures in REF include both quantitative metrics and expert panel reviews (Bornmann and Marx 2014). Along those same lines, the Research Quality Framework (RQF) preparation began in Australia in 2005, but was replaced by the Excellence in Research for Australia (ERA) initiative with the discussion directed toward a different direction (Bloch 2010).

8.4 Societal Impact Assessment Indicators

Traditionally, scientists focused mainly on deliberating the significance and impact of their research within their specific scientific communities. However, they now recognize the importance of discussing the broader applications of their research with government agencies for funding and other support, with other professional communities who are the consumers of scientific knowledge, with educators to help formulate science education strategies, and with the general public, the ultimate beneficiaries of their work.

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[3] The Research Excellence Framework (2011) defined the research impact as "…the social, economic, environmental and/or cultural benefit of research to end users in the wider community regionally, nationally, and/or internationally."

Although, societal benefit assessment system is at its early developmental stages, there are several methods currently being used. As each can provide useful information, it is important for us to understand their strengths and limitations. Today, funding agencies in many counties use peer reviewing to assess the potential impacts of research proposals. The Comparative Assessment of Peer Review (CARP)[4] examined the peer review process of six public science agencies (three US, two European, and one Canadian), particularly on how broader societal impact issues are integrated into their grant proposal assessments. When funding agencies use peer evaluation in measuring the scientific value of grant proposals, peer reviewers are asked to assess the potential societal impact, as well as the scientific soundness of these projects. In addition to issues associated with subjectivity of peer review assessments, there is a concern that the scientists conducting the review may lack expertise or experience in assessing some societal impacts of proposed projects which may be outside of their specific areas of expertise. However, based on the findings of their study of the peer review processes of NSF and the European Commission (EC) 7th Framework Program (FP7), Holbrook and Frodeman (2011) did not find evidence to support these concerns, and they rejected the widely reported resistance to addressing societal impacts by project proposers and reviewers (Holbrook and Frodeman 2011). Case studies are also commonly used in societal impact assessment. Although labor-intensive, this method may be the best approach considering the intricacies involved in evaluating the societal impact of some research projects (Bornmann 2012). Quantitative metrics are becoming popular in societal impact assessment. Cost effectiveness, ease of collection, transparency of collection process, objectivity, verifiability, and ability to use data in comparative and benchmarking studies are stated as strengths of quantitative metrics (Donovan 2007).

Greenhalgh et al. (2016) reviewed the strengths and limitations of some of the established and recently introduced impact assessment approaches (Greenhalgh et al. 2016). Most metrics capture direct and immediate impacts, but not the indirect and long-term impacts. At the same time, use of more robust and sophisticated measures may not be feasible or affordable. Because of the complex nature, a single indicator may not provide a complete picture of societal impacts of scientific research. Therefore, the common consensus among scholars stresses the need to use different indicators or combination of metrics depending on circumstances.

8.4.1 Alternative Metrics to Measure Societal Impact

Since no accepted system has emerged, a nontraditional system—communication technology—gained attention for identifying new metrics. Would new advances in

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[4] A four year study (2008–2012) funded by the NSF's Science of Science and Innovation Policy (SciSIP) program.

this field provide the means of measuring the societal impact of science effectively and properly?

As users began to interact on the Internet, creating content and leading user conversations, the line between producers and consumers or users of information blurred. Tim O'Reilly and Dale Dougherty coined the term "Web 2.0" as a marketing concept (O'Reilly 2007) to describe this noticeable shift. Web 2.0 eventually became to be known as the Social Web. Meanwhile, new developments in computer and information technologies impacted scholarly practices and scientific research infrastructures as well. With publication and access of scholarly literature moving exclusively into the online environment, some social web tools were predicted to become useful for assessing the "quality" of scholarly publications (Taraborelli 2008). Moreover, since the social web has a wide audience outside of science, it may offer an alternative way of assessing impact, particularly societal impact (Thelwall et al. 2013).

Recognizing these potentials, the use of "alternative metrics" to evaluate research began; Web/URL citations referred to as "webometrics" or "cybermetrics" showed early indications of a new trend (Kousha and Thelwall 2007). In 2009, the Public Library of Science (PLoS) began offering Article-Level Metrics (ALMs)[5] that include online usage, citations, and social web metrics (e.g., Tweets, Facebook interactions) for their articles. They grouped the engagement captured by these data sources as: (1) Viewed (user activity on online article access), (2) Saved (article savings in online citation managers), (3) Discussed (tweeting and blog posting), (4) Recommended (formally recommending research articles via online recommendation channels), and (5) Cited (citing articles in other scientific publications) (Lin and Fenner 2013).

These developments led to further exploration of the concept of alternative metrics not confined to just ALMs. In response to the call for a diversified metrics system, in 2010 Priem tweeted[6] the term "altmetrics",[7,8] which have become a term that encompasses a variety of web-based alternative metrics. Although it was originally described as new indicators for the analysis of academic activity based on the participation aspect of Web 2.0 (Priem and Hemminger 2010), altmetrics also include social media interaction data providing immediate feedback. These data points may include clicks, views, downloads, saves, notes, likes, tweets, shares,

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[5] A set of metrics at the article level introduced by PLoS, which include citations, usage data, and altmetrics. Although ALMs and altmetrics are sometimes used interchangeably, there are major differences; ALMs also include citation and usage data for individual articles, altmetrics can be used to research outputs other than articles (Fenner 2014).

[6] "I like the term #articlelevelmetrics but it fails to imply *diversity* of measures. Lately, I'm liking the term #altermetrics". https://twitter.com/jasonpriem/status/25844968813 (accessed on May 17, 2016).

[7] The altmetrics manifesto was published in October 2010. It is available at: http://altmetrics.org/manifesto/.

[8] "Influmetrics" (Rousseau and Ye 2013) or "social media metrics" (Haustein et al. 2015a), are other terms suggested for alternative metrics.

comments, recommends, discussions, posts, tags, trackbacks, bookmarks, etc. The different data sets can be categorized based on the data source and the target audience. For example, PLoS data source categories (viewed, saved, discussed, cited, and recommended) are mainly related to interactions of scholars while ImpactStory[9] uses the same categories for two different audiences—citations by editorials and Faculty1000 are recommendations for scholars, while press articles are recommendations for the public. These web-based tools capture and track a variety of researchers' outputs by collecting altmetrics data across a wide range of sources and altmetrics services[10] aggregate them. As some level of inconsistencies currently exists between scores provided by different service providers/vendors (Jobmann et al. 2014), greater uniformity is needed to improve the trustworthiness and the reliability of these metrics.

Because of the inherent communicative nature of science, scientists became early adopters of social web services and tools created for scholarship. These tools include social book marking (e.g., CiteULike) , social collection management (e.g., Mendeley), social recommendation (e.g., Faculty of 1000), publisher-hosted comment spaces (e.g., British Medical Journal, PLoS, BioMed Central), user-created encyclopedias (e.g., Encyclopedia of Science), Blogs (e.g., Research blogging), social networks (Nature networks, VIVOweb), and data repositories (GenBank). However, based on some research findings, the altmetrics density for publications in the social sciences and humanities is significantly higher than publications in scientific disciplines except biomedical and health sciences (Costas et al. 2015; Haustein et al. 2015a; Zahedi et al. 2014). Do these findings indicate that altmetric measures reflect the cultural and social aspects of scientific work other than the scientific quality?

8.4.2 *Strengths and Limitations of Altmetrics as Scientific Research Assessment Tools*

Although still evolving, altmetrics are gaining attention as a useful supplement to the traditional means of measuring the impact of scientific scholarly literature. There are several advantages of these metrics when compared with the traditional bibliometric system. One of the major strengths of altmetrics is said to be the speed—enhanced by social media—at which we get metrics in comparison to

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[9] ImpactStory provides metrics for individual researcher instead of article. It is a product of the impactstory.org, is a not-for-profit organization supported by the Alfred P. Sloan Foundation (Piwowar 2013) Altmetrics: value all research products. Nature 493(7431):159.

[10] In 2012, workshops and presentations devoted to altmetrics, journals initiating altmetrics data at the article level, the introduction of several altmetrics services were observed.

Example of altmetrics services are PLOS Article-Level-Metrics (http://article-level-metrics.plos.org/), Altmetric.com (www.altmetric.com/), Plum Analytics (www.plumanalytics.com/), and Impact Story (www.impactstory.org/).

traditional citations which may take years. The question is what do these instant responses reveal about the quality of the scientific research? Or do these immediate tweets and retweets represent just the superficial reactions to some interest-grabbing aspects of the work? Can the quality of scientific work be assessed instantly? Definitely not; it needs careful examination and scholarly insight which takes time. Therefore, faster is not better in measuring the quality of scientific research. However, the speed may be advantageous in initiating scholarly discussions and examinations of research findings. These discussions may attract attentions of other researchers leading to further research, or informing and educating professionals to use that knowledge in improving their professional services.

The diversity of metrics, collected using a variety of tools capturing the interactions and communications related to scientific work outside the scientific communities, is considered a strength of altmetrics. For instance, how do we learn about the influence of articles that are heavily read, saved, and even discussed, but rarely cited? The significance of the altmetric data is the insight they provide that cannot be captured by traditional bibliometric measures. As some social media platforms include information about their users (e.g., Twitter and Mendeley), it is possible to mine these data to learn about the social network audience of scholarly publications. Reflecting on their study findings, Mohammadi et al. (2015) suggested that Mendeley readership provides a measure of scientific publication impact capturing a range of activities within academic community, varying from "plain reading" or reading without subsequently citing, drafting research proposals, and some evidence of applied use outside the academic community (Mohammadi et al. 2015).

Some altmetrics services such as Altmetrics.com collect user demographic data across different social media platforms, providing researchers and institutions data (for a fee) to learn about the audience of their scholarly work. However, there are limitations in collecting reliable user information; in addition to technical issues, the demographic data gathered is entirely based on profile information users provide that may be incorrect or not up to date.

The inability to measure the impact of scholarly outputs such as datasets and software that are not published articles is considered a shortcoming of the traditional citation system and altmetrics provides a way of measuring the impact of these products (Zahedi et al. 2014). The "openness" is considered a strength of altmetric data as it is easy to collect—can be collected through Application Programing Interfaces (APIs)—and the coverage, algorithms and code used to calculate the indicators are completely transparent to users. However, there are questions about the implementation of the ideal of "openness" in developing the web-based tools by information services. Wouters and Costas (2012) argue that "transparency and consistency of data and indicators may be more important than free availability" (Wouters and Costas 2012).

Although, the value of altmetrics in capturing the interest in scientific findings outside the scientific community is unquestionable, interpreting the plethora of these diverse sets of data feeds is becoming increasingly complicated. What do the number of tweets, downloads, usage data, hyperlinks, blog posts, and trackbacks tell us? Are these numbers real and do they capture real community interactions?

Do these numbers provide a direct measure or reflect the societal impact of scientific research? Moreover, when we interpret different altmetric data, do we assign the same weight to all of them? For example, a Twitter mention, a recommendation on F1000 (now F1000 Prime),[11] and a readership count on Mendeley represent three different user engagement levels, but the ability to assign different values to different engagement levels are not yet available. Since they can be manipulated (or gamed), the trustworthiness of these metrics (at least some of them) are being increasingly scrutinized.

The liquidity of the social web causes a major challenge in adopting altmetrics as a scholarly assessment measure. Instability of platforms that generate these indicators such as the disappearance of Connotea[12] in 2013 and elimination of platform functions are uncertainties leading to skepticism regarding the relevance of these indicators in assessing scientific work in comparison to the fairly stable time-tested citation indexes (Torres et al. 2013).

Altmetrics are a heterogeneous collection of data sets due to a range of underlying reasons, caused at social media platform levels, making it difficult to find a common definition for these data and conceptualizing them. This heterogeneity and the dynamic nature of the social media interactions also affect the data quality (i.e., lack of accuracy, consistency, and replicability) (Haustein 2016). Poor data quality is a major constraint for the incorporation of these metrics in formal research assessment. Wouters and Costas (2012) expressed concerns about web-based tools delivering statistics and indicators on "incorrect data" and not providing users with data cleansing and standardization options. Out of 15 tools reviewed, they identified F1000 as the only tool that enables some level of data normalization. They stressed the need of following stricter protocols of data quality and creating reliable and valid impact assessment indicators (Wouters and Costas 2012). Even though traditional bibliometrics have long been suspected of manipulation (e.g., author/journal self-citations, and citing based on favoritism) altmetrics suffer more from accusations of dishonest practices, because of the ease with which web-based data can be manipulated. Even an amusing title which is unusual in scientific literature might increase altmetric data counts; in the case of the article published in the *PLoS Neglected Tropical Diseases* in 2013, "An In-Depth Analysis of a Piece of Shit: Distribution of Schistosoma mansoni and Hookworm Eggs in Human Stool" was the top PLoS article on Altmetric.com (Thelwall et al. 2013). Due to the very nature of the social web and lack of quality control measures in altmetric platforms, there are many openings to doctoring data and systematically generating high altmetric scores. For example, we hear about automated paper downloads and Twitter mentions generated through fake accounts, and "robot tweeting" (Darling et al. 2013).

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[11] F1000 is composed of senior scientists and leading experts in all areas of biology and medicine. They review and rate articles in their specialized areas and provide short explanations for their selections.

[12] "Connotea to discontinue service" posted by Grace Baynes on Nature.com blog, 'Of Schemes and Memes Blog' on 24th Jan, 2013.

8.4.3 Altmetrics as Discovery Tools

Because of the immediacy quality (instant access, prompt discussions, speedy sharing) and the diversity of data sources, altmetrics are used as discovery tools (Fenner 2014) and data manipulation for self-promotion and gaming issues do not affect their discovery process. There are free and commercial products; the Altmetrics PLoS Impact Explorer[13] is a free tool that uses altmetric data for PLos articles, highlighting mentions in the social media sites, newspapers and in online reference managers, while Altmetrics.com charges for their products.[14]

8.4.4 Improving Standards and Credibility of Altmetrics

To gain credibility, measures need to be taken to minimize unethical self-promotion practices and potential for gaming[15] social web indicators. The good news is defenses against these activities are already building; counter measures such as cross-calibration of data from different sources to detect suspicious data patterns are being suggested to minimize harm (Priem and Hemminger 2010). The Alternative Assessment Metrics Project's white paper discussed later, includes "Data Quality and Gaming" as one of the categories with six potential action items, including the use of persistent identifiers, normalization of source data across providers, and the creation of standardized APIs or download or exchange formats to facilitate data gathering to improve reliability of altmetrics.

Interpreting altmetrics numbers in assessing scientific research needs to be done with utmost care until these data sets are reasonably defined, characterized, codified, and standardized. Standardization is one of the stickier issues surrounding altmetrics. The National Information Standards Organization (NISO) of the United States received a two-year Sloan Foundation grant in 2013 for the Alternative Assessment Metrics Project to address issues related to altmetric data quality, and to identify best practices and standards. The final version of the White Paper[16] of Phase-I of the project was published in May 2014, and identified 25 action items under nine categories—definitions, research outputs, discovery, research evaluation, data quality and gaming, grouping and aggregation, context, stakeholders' perspectives, and adoption.

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[13] Altmetrics PLoS Impact Explorer https://www.altmetric.com/demos/plos.html.

[14] Altmetric.com https://www.altmetric.com/.

[15] "Behavior that is meant to unfairly manipulate those metrics, generally for one's benefit." NISO White paper.

[16] Alternative Metrics Initiative Phase 1 - White paper http://www.niso.org/apps/group_public/download.php/13809/Altmetrics_project_phase1_white_paper.pdf.

8.4.5 Association Between Altmetrics and Traditional Citation Metrics

Considering the scholarly article publication cycle, altmetrics reflect activities of scholars that may occur between viewing and citing articles (i.e., downloading, saving, informal discussions, etc.). Is there an association between altmetrics generated from theses interactions and the traditional impact assessment system based on citation metrics? If there is a strong relationship, altmetrics can be used as a reliable predictor of article citations. Correlation tests are the most extensively used technique to measure the strength of a linear relationship between a new metric and an established indicator. In correlation tests, a positive correlation would reflect similar "quality" of both; however, positive or negative values may result from reasons unrelated to the quality of work. Therefore, positive correlations between two metrics can be accepted only if there is no obvious sources of bias in the comparison. Considering the complexity associated with altmetrics (some of which was discussed earlier), interpreting correlation test results to make inferences can be difficult. The inconclusive findings of the studies conducted to explore whether altmetrics correlate to eventual citations reflect these challenges.

Sud and Thelwall (2014) discussed the major factors affecting the relationship between altmetric scores and citation counts of articles as well as the complexity of using correlations between these two metrics (Sud and Thelwall 2014). According to them, the most direct way to assess the relatedness of a metric to the quality of a work is to interview the creators of the raw data to find out if the quality of work is the reason for them to create data (e.g., tweeter for tweet count data). Although there are several limitations such as time involved, small sample size, and data creators providing inaccurate information, this method provides insight that may not be evident by other methods. Content analysis and pragmatic evaluation are other methods proposed for the evaluation of altmetrics (Sud and Thelwall 2014).

8.4.6 Article Readership Counts and Citation Counts

Scientists might read many articles related to their research area, but out of all these they will only cite the articles that directly influence their specific research topic. Therefore, reading and citing are related but clearly different scholarly activities. Several investigators have examined the relationship between the article readership counts and citation counts to see if this altmetric indicator (i.e., article readership counts) can be used to predict future citations. Out of all the altmetrics sources, Mendeley readership data offers the closest association with citation data to date, showing a moderate to significant correlation in most studies. In a 2011 study, Li, Thelwall, and Giustini found a statistically significant correlation between bookmarks in Mendeley and traditional citation counts from Web of Science, but the number of users of Mendeley and CitULike are still small (Li et al. 2012). Zahedi compared altmetrics (from ImpactStory) for 20,000 random articles (from Web of Science) across disciplines published between 2005 and 2011. Once again, Mendeley had the highest correlation score with citation indicators while the other altmetric sources showed very weak or negligible correlation (Zahedi et al. 2014). Mohammadi et al. (2015) reported somewhat similar findings; in their study, the highest correlations were detected between citations and Mendeley readership counts for users who have frequently authored articles (Mohammadi et al. 2015). Another study compared the F1000 post-publication peer review[17] results, i.e., F1000 article factors (FFa)[18] and Mendeley readership data with traditional citation indicators for approximately 1300 articles in Genomics and Genetics published in 2008. Both showed significant correlations with citation counts and with the associated Journal Impact Factors, but the correlations with Mendeley counts are higher than that for FFas (Li and Thelwall 2012). Another study conducted using a sample of approximately 1,600 papers published in *Nature* and *Science* in 2007 revealed significant positive correlations between the citation counts, with Mendeley counts and CiteULike counts (Li et al. 2012).

8.4.7 Science Blogging, Microblogging, and Citation Counts

Thelwall et al. (2013) found strong evidence of an association between citation counts with six altmetrics including blog mentions and tweets[19] out of 11 altmetric indicators they examined (Thelwall et al. 2013). However, when analyzed ALMs of 27,856 PLoS One articles, De Winter (2015) found only a weak association between tweets and number of citations, and concluded that "the scientific citation process acts relatively independently of the social dynamics on Twitter" (De Winter 2015).

By examining blog posts aggregated by ResearchBlogging.org, which discusses peer-reviewed articles published in 2009 and 2010, Shema et al. (2014) found that articles discussed in science blogs later received significantly higher citation counts, than articles without blog citations published in the same journal in the same year. Therefore, they proposed that "blog citation" be considered as a valid alternative metric source (Shema et al. 2014). Costas et al. (2015) found that mentions in blogs are able to identify highly cited publications with higher precision than journal citation score (JCS)[20] (Costas et al. 2015).

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[17] F1000 is a post-publication peer review system supported by a social media platform.

[18] FFa is calculated based on the rating given by all selectors for a particular article.

[19] Other metrics that showed a significant association with citation counts were Facebook wall posts, research highlights, mainstream media mentions and forum posts.

[20] The JCS of a journal is the average number of citations received by all publications in that journal within a particular year (Costas et al. 2015).

Twitter (microblogging) is becoming increasingly popular among scholars, especially those for whom sharing information is an important aspect of their professional activities. Although, posting a quick Twitter message about a scholarly work may reflect an instant reaction that does not involve much intellectual examination, closer analysis of scholars' microblogging behaviors would provide a better understanding about the nature and depth of scientific discussions happening through microblogging. Findings of research conducted to investigate the relationship between the volume of Twitter mentions and scholarly value of the discussed scientific publications provide a confusing picture. By examining the online response—downloads, Twitter mentions, and early citations—of preprint publication of approximately 4600 scientific articles submitted to the preprint database arXiv.org in the 2010–2011 period, Shuai et al. (2012) reported that the volume of Twitter mentions is statistically correlated with early citations (Shuai et al. 2012). However, Bornmann (2015) did not find a correlation between microblogging and citation counts in his meta-analysis of several correlation studies examining the association of altmetrics counts and citation counts (Bornmann 2015). Based on a study of about 18,000 publications in different disciplines, Costas et al. (2015) found only two altmetric indicators—twitter and blog mentions—were closely correlated with citation indicators. They concluded that there is a positive but moderate correlation between altmetrics and citation and/or JCS (Costas et al. 2015).

Investigators report low levels of social media interactions to articles in the scientific disciplines, compared to the citation numbers articles receive, suggesting that different factors are driving social media and citation behaviors. These findings indicate that altmetrics can be considered as complementary metrics but not as an alternative to citation metrics in assessing scientific research (Haustein 2015b).

8.5 Concluding Remarks

Scientific endeavor has always had the ultimate goal of benefitting society at its core. Growth in scientific research has surpassed available resources leading to allocation shortfalls. To help determine the worthiness of research proposals, funding agencies are now tasked with not only evaluating the scientific impact of research proposals, but their societal impact as well. Determining societal impact is challenging for a variety of reasons: it generally takes a long time to become evident and has many different intricate components to consider, and the impact of some components may be readily evident, but hard to measure. Although there are international attempts to identify the best assessment measures and implement policies to allocate public research funds to reap the maximum benefits for society, a clear consensus on how to evaluate the impact of research on society does not yet exist. Alternative metrics or "altmetrics" enhanced by the fast-expanding social networking environment are becoming increasingly used in assessing the societal impact of scientific research. Although altmetrics seem to hold a convincing potential in this regard, there are many questions to be answered and many issues to be addressed and resolved before these metrics can be effectively used in the assessment of the societal impact of scientific research. Therefore, altmetric assessment measures need to be well studied and critically evaluated in addition to improving data quality by identifying best practices and setting standards. The systematic but steadfast development of the field of "societal impact assessment research" which is relatively new compared to that of scientific impact assessment might answer questions and resolve many issues related to altmetrics. Altmetric indicators capture related but distinctly different aspects of the impact of scientific research that cannot be measured by traditional bibliometric indicators. Therefore, integrating altmetrics with bibliometrics in the scholarly research assessment toolbox would help to get a complete, or at least near-complete picture of the impact of scientific research.

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Final Thoughts

Scientific Scholarly Communication: The March Forward

Science is a distributed system in which scientists individually or collaboratively conduct research following the scientific process, exploring new theories, or reexamining existing theories. In recent years, science has become more collaborative and interdisciplinary in nature, and the somewhat closed scientific practices that once existed are evolving into a more open and inclusive system. Open and unrestricted access to scientific knowledge facilitates free exchange of ideas, faster sharing, as well as public scrutiny of research findings, which together instigate the self-correction of science and accelerate its advancement.

Scholarly communication is an integral part of the science enterprise. The formal scientific scholarly communication system that originated in the 17th century has evolved through the centuries, creating an authority structure in the form of journal publications that still remain as the preferred venues for sharing scientific research findings. Society places a great deal of trust in the authority represented by the pantheon of revered publications that form the foundation of scientific knowledge. Although the scholarly publishing structure evolved for nearly three centuries with relatively little change, the unprecedented transformation of the scientific infrastructure and culture accelerated by technological advances has challenged these traditions. Along with these changes came the demand for a strong but flexible and efficient system that can handle the unprecedented accumulation of knowledge coming at varying speeds, in diverse and complex formats, from dispersed geographical locations.

One of the most prominent revolutionary changes that has emerged over the past three decades was the "opening up" of the scientific scholarly communication system; as a result, the open access (OA) publishing movement was born. OA publishing challenges the restrictions imposed on information sharing by the continuously increasing subscription rates of scholarly journals. Although the OA concept agrees with the norms of openness in scientific inquiry, it was initially met with skepticism and even resistance in some sectors of the scientific community. However, the support for OA publishing has been steadily increasing among many

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stakeholders, and many innovative and bold experimentations have led OA publishing to become a significant part of the scientific scholarly communication system. OA publishing extends the reach of information sharing to a broader audience, allowing researchers in geographic areas outside of the established research centers to join the scientific global forum. This expansion has allowed collaborations within the worldwide scientific community, increasing the speed of progress. Nonetheless, there are many challenges to overcome. Unfortunately, trust in OA publishing has eroded under the cloud of predatory publishers who exploit the author-paid publishing model. Of course, these unethical publishers are the exceptions, and many OA journals maintain high standards that include rigorous peer review, exemplifying the practices that establish trust. The fact that the traditional subscription journals are moving toward offering a hybrid system, i.e., publishing OA articles in their subscription-based journals, highlights the increased acceptance of the OA publishing concept. There is no question that OA scholarly publishing is pushing the boundaries of journal publishing toward a more open scientific scholarly communication system.

Critical evaluation of scientific claims by other experts in the field is considered as an essential facet of the scientific process. The peer-review system evolved parallel with the formal scholarly communication to fulfill this need and has gained the trust of the scientific community and society as a way to determine the credibility of publications of research findings. However, the conventional peer-review system is drawing criticism for its deficiencies, and the scientific community agrees that it needs to be improved. The closed and secretive nature of the conventional system contradicts the norms of openness in science, and the arguments for opening up the peer-review system, making it more transparent, have gained momentum. Enabled by technological advances, the open peer-review (OPR) model is being tested with and even implemented with varying levels of success by some scholarly journals. Moreover, peer review is now evolving in many different directions as new reviewing models are created, ranging from OPR models with pre- and post-review to hybrid models of closed pre-publication review with open post-publication review, and even to publishing with no review. The traditional closed peer-review system concentrates on pre-publication review, but the post-publication evaluation of journal articles is a novel and inventive concept that has been tried by some journals. Community engagement in reviewing is probably one of the most important aspects of OPR and can be constructive, especially in some scientific fields, if used effectively. Some journals with closed peer-review traditions now allow public discussions about published articles, thus encouraging public engagement. Probably, the most intriguing aspect of all these new approaches is the freedom journals enjoy in adopting peer-review systems by combining features of different models that works best for the journals themselves and the scientific community they serve. There may be failures and glitches on the way, but OPR is surely going to be a permanent fixture in the scientific scholarly communication system.

Assessing the scientific quality and the impact of scientific research is a necessity but is unquestionably challenging. There are quantitative measures, mainly relying on citation data, that are being developed to assess the influence of journal articles as proxies for the scientific impact of the research they describe. Although there are concerns regarding the effectiveness of these metrics and implications arising from incorrectly using them, still citation metrics can be considered the best tools yet implemented to assess the influence of scientific research; however, it is important to stress that their strengths, limitations, and implications need to be well understood when using them. Use of alternative metrics systems (altmetrics), mainly based on social media interactions to assess the societal impact of scientific research, is a fascinating but logical concept. It is important to understand and correctly interpret these social interactions beyond just counting the numbers. Both the scientific community and society need to be mindful about the possibilities of selective dissemination of research and misinterpretation of findings, in addition to the potential for manipulation of interaction counts.

Traditionally, scientists have shared research data as tables, graphs, and summaries in support of their scientific claims when publishing their work. With advances in computer and communication technologies, collection, storing and archiving, dissemination, retrieving, and analyzing data are becoming easier and faster. As data are considered the foundation of science, data sharing is gaining momentum. Compared with sharing scientific information as journal articles, a system that has evolved over 350 years, sharing research data is still a relatively new experience for researchers. Although data sharing has already become a regular practice in data-driven scientific fields, it poses many challenges as it is a complex, costly, and time-consuming endeavor, especially in disciplines with small-scale research projects. The practice of making supporting research data available along with each article is being promoted, especially by research funders. The concept of formal data publication is being introduced to provide a means of rewarding researchers for their useful and well-documented research data. Following this trend, the emergence of data journals is a new development in scientific publishing.

Along with OA publishing and OPR, there is a move toward "open data," another development that embraces openness in science. The "open data" paradigm expedites scientific collaborations and leads to scientific discoveries and innovations that otherwise would not have been possible, or at least would take much longer to achieve. However, it is important to recognize that there are boundaries to opening up scientific data that need to be recognized and respected. The privacy of individual research subjects, their families, and their communities needs to be respected when sharing scientific data. Safety, national security, and economic interests are other areas that need careful attention and caution when openly sharing data. These critically important aspects highlight the need to promote not just openness but intelligent openness in scientific data sharing.

Has active public engagement and participation always being positive? Some public engagements have turned against scientists, and there have sometimes been well-organized and well-financed harassment campaigns against scientists and calls for retraction of research articles on sensitive and controversial topics. Scientific communities and society as a whole need to be aware of these practices, and journals should publicize these threats and litigations to expose these incidents.

Despite these negative incidents, opening up of the scientific scholarly communication system enabled by technological advances is moving ahead, empowering scientific innovations through the open exchange of ideas, evidence, and collaborations. As illustrated in different chapters in this book, invigorating academic discussions and conscientious deliberations of stakeholders of science have been integral to the evolution and improvement of the scientific communication system, thus promoting scientific advances that support and enrich the well-being of all human life.

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