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From Open Access to Open Science: The Path From Scientific Reality to Open Scientific Communication

Christian Heise[1] and Joshua M. Pearce[2,3]

Abstract

Although opening up of research is considered an appropriate and trend-setting model for future scientific communication, it can still be difficult to put open science into practice. How open and transparent can a scientific work be? This article investigates the potential to make all information and the whole work process of a qualification project such as a doctoral thesis comprehensively and freely accessible on the internet with an open free license both in the final form and completely traceable in development. The answer to the initial question, the self-experiment and the associated demand for openness, posed several challenges for a doctoral student, the institution, and the examination regulations, which are still based on the publication of an individually written and completed work that cannot be viewed by the public during the creation process. In the case of data and other documents, publication is usually not planned even after completion. This state of affairs in the use of open science in the humanities will be compared with open science best practices in the physical sciences. The reasons and influencing factors for open developments in science and research are presented, empirically and experimentally tested in the development of the first completely open humanities-based PhD thesis. The results of this two-part study show that it is possible to publish everything related to the doctoral study, qualification, and research process as soon as possible, as comprehensively as possible, and under an open license.

Keywords

communication studies, communication, social sciences, academics, education, science communication, human communication, new media, communication technologies, mass communication, cultural communication, media and society, information technology, information science, libraries, science, knowledge, technology, sociology

Introduction

The current level of knowledge regarding unrestricted and open communications is an important prerequisite for scientific research (Gibbons, 1994). Openness and transparency are also described as essential components of an ethic of science (M. A. Peters, 2014; Resnik, 2005) and form the basis for the social mandate of the science system (Hanekop, 2014) to produce and disseminate new verifiable knowledge (Graefen & Thielmann, 2007; Luhmann, 1998). This article investigates the effects of digitization and the demands for open scientific communication from universities, scientific institutions, and individual scientists.

Imbalances in the current scientific publication system (Joseph, 2006), shortcomings in the scientific incentive systems (Osterloh & Frey, 2008), increased publication pressure, the financial and ideological plight of libraries (R. D. Russell, 2008; Sietmann, 2007), challenges in safeguarding the freedom and independence of science and research (Götting, 2015), lack of transparency, increase in scientific scandals (Brembs, 2015), and the increasing economization (Bauer, 2006) and bureaucratization (Ginsberg, 2011) of university operations lead to the question of whether the scientific communication system could ever do full justice to the theoretical task of science (Schekman, 2013). However, the internet is rapidly changing the way the results of academic research are communicated within communities and with the wider public (Baum & Coen, 2019). Through increased distribution and the use of the internet as a channel for scientific communication, research activities and the exchange of information are more likely to be “disseminated as immediately, broadly and effectively as possible” (Suber, 2003a). In addition, there has been a marked historical surge in the growth of open access publications among academics from all disciplines although

[1]Leuphana University Lüneburg, Germany
[2]Michigan Technological University, Houghton, USA
[3]Aalto University, Espoo, Finland

Corresponding Author:
Christian Heise, Leuphana University of Lüneburg, Centre for Digital Cultures, Am Sande 5, Lüneburg 21335, Germany.
Email: christian.heise@leuphana.de

some disciplines are more aggressive (e.g., biomed) than others (e.g., chemistry; Piwowar et al., 2018). These expectations include the request for "unlimited access to the entire scientific journal literature" (Budapest Open Access Initiative [BOAI], 2002) for more transparency in the scientific knowledge process (European Commission, 2015), for possibilities to increase the efficiency and effectiveness of science (Partha & David, 1994), for the use of open source software (Von Krogh & Spaeth, 2007) and hardware (Pearce, 2012a) in science, and "for the old restrictions to be gradually removed" (BOAI, 2002). This is based on the assumption that the consequences of technological developments would "inevitably lead to considerable changes in the nature of scientific publishing and initiate a change in the existing systems of scientific quality assurance" (Berliner Erklärung, 2003).

There has been, and still is, a great interest in open communication and support for free access to scientific information; yet, the history of media and technology has shown that introducing a new medium with a wider reach repeatedly leads to irritations (Näder, 2010), which could lead to irrelevance or disuse (Hagner, 2015). Thus, in the first experiments with the internet, the obstacles to a change in the system to make scientific communication available to everyone are greater than originally assumed (Björk, 2004). Despite the increasing digitalization of scientific communication systems and processes as well as the rise of open source development in both the methods and the sharing of scientific results, there are extensive barriers regarding access to scientific information and to the possibilities of (re) using this information. Even about 25 years after the first electronic procedures for the open exchange of scientific publications (Albert, 2006) and 350 years after the publication of the first scientific journal (Moxham, 2015), the "old" system remains largely stable (Brembs, 2015; Hanekop, 2014; Warnke, 2012). A change in the tradition of scientific practice in the sense of a "scientific revolution" (Kuhn, 2012) has not (yet) occurred. However, if we consider the exponential rise of open source technologies' use in the sciences as denoted by references in the literature (Pearce, 2018b) as well as the proliferation of open access repositories and freely accessible digital articles (Pinfield et al., 2014), there is clearly a threat to the historical proprietary science and publishing paradigm. The reasons and influencing factors for these developments in science and research are presented below in two parts: first, empirically, ethnographically, and experimentally tested in documenting the development of the first completely open humanities-based PhD thesis; second, based on the outcome of the first part, to review discuss and summarize the ongoing debate about open access and open science.

Background

There are many reasons for wanting substantial changes in the way academic publishing works. As part of the changes, scientists, the entire university system, and other educational institutions and academic libraries are facing significant challenges (Beverungen et al., 2014; Guédon, 2004; Osterloh & Frey, 2008). Scientific communication has only changed marginally over centuries and, within the scientific area, it offers a certain degree of openness, but externally, it is closed (Kelty, 2004). In the context of these developments, universities run the risk of losing (more) significance as places of knowledge production and evaluation. Since the privatization of processing, storage, and transfer of knowledge during the second half of the 20th century, most universities stopped publishing books of their own (Joseph, 2006; Kittler, 2004). Furthermore, the current scientific economic system demands largely public financing of knowledge production and, at the same time, expects the private sector to acquire and use the knowledge produced (Suber, 2003b; Weingart, 2001). This perception results in the accusation that publishers—worth mentioning that there is incredible heterogeneity among those—are just monetizing publicly and tax-funded research, using free scholarly labor for peer review, and then selling the publications back to scholars and academia to increase their profits (Beverungen et al., 2012; Tennant et al., 2019). In addition to the paid distribution of scientific information, these publishers enable authors to gain recognition from the scientific community and reputation in the scientific system by sharing their efforts in return for a recourse to informally constituted reputations (Bernius et al., 2009; Luhmann, 1970). In the context of change, it is especially challenging for scientists and their institutions to continue with the freedom of science and research with the highly unrestricted dissemination of scientific findings (Berlin-Brandenburgische Akademie der Wissenschaften, 2015; Buss & Wittke, 2001; Hagner, 2015) and the demand for better (self-)control and performance processes (Adler & Harzing, 2009; Gibbons, 1994). However, in part, due to pressure from scientific funders, most private commercial scientific publishers offer some form of open access option or allow preprint publication of the "author's version" of their work. This creates back channels to scientific information, which have even begun to dominate the discourse in some fields as well as drive citations for authors (e.g., astronomy and physics use of arXiv; Henneken et al., 2006). This is not overly surprising as discourse through open access repositories is more rapid than using conventional channels and through preprints as they are available before rather slow traditional processes. In addition, open source approaches in innovation of a wide range of technologies is well established as superior to closed techniques (Deek & McHugh, 2007; DiBona & Ockman, 1999; Lakhani & Von Hippel, 2003; Raymond, 1999). This is most obvious with free and open source software (FOSS) as the quality of code is superior (Söderberg, 2015) and it improves research quality and scientific outputs (Goble, 2014). But free and open source hardware use for scientific tools are cost effective as well as technically superior (Goble, 2014) because it enables more control (by the scientists) and bespoke novel experiments (Baden et al., 2015; Coakley & Hurt, 2016; Chagas, 2018; Pearce, 2013).

Interests of private sector use of scientific findings, however, and the original task of science to produce and disseminate new, verifiable knowledge have diverged and led to a scientific publication and communication crisis. It is characterized by growing cost pressure, price increases (Lewis, 2011), publication (Beverungen et al., 2012; Brembs, 2013; Egger et al., 1997; Fanelli, 2012) and report bias (Chan, 2008; Dickersin & Chalmers, 2011), Cargo Cult Science (Feynman, 1974), potential market dysfunction (Tennant & Brembs, 2018), reproducibility and integrity issues (Fanelli, 2018), and access restrictions (Hess & Rauscher, 2006; Offhaus, 2012). Worse, legislation meant to enable scientific findings to reach the general public through the business sector such as the Bayh-Dole Act in the United States (Mowery et al., 2001) is actively undermining scientific advancement because of intellectual policy restrictions (Pearce, 2012c). The current system of both copyright and patenting of building block science (Boldrin & Levine, 2008; Lemley, 2005) runs against the efforts of science, which is essentially about knowledge and the unrestricted provision of this knowledge (Hanekop & Wittke, 2006). In addition, scientists feared that publication pressure and the pressure to conduct more application-oriented research would cause incorrect research results being published (Ioannidis, 2005). The traditional culture promotes a closed scientific communication system, which makes access to knowledge more difficult and impairs the emergence of new knowledge (Feyerabend, 1986; Luhmann, 1998; Willinsky, 2006), leading to an increasingly untenable state of scientific communication in some fields (Schekman, 2013).

Although scientists publish their work open access, share their discoveries, code, and technologies under public domain or libre licenses, they still do not represent the dominant mode of scientific discourse and the system of scientific communication is still "largely stable" (Hanekop, 2014, p. 2). When looking for reasons why the open model is not being universally adopted by the scientific community, it becomes clear that, above all, ignorance of economic developments, legal concerns, and the established scientific reputation system are the scientific community's central extrinsic motivating factors for the support of the antiquated system (Herb, 2015). Another reason is the majority of science is written by scientists with access to the literature and are largely exempt from dealing with the financial aspects of scientific communication (Hanekop & Wittke, 2006; Sietmann, 2007). In addition, scientists are discouraged from questioning the prevailing paradigms of scientific practice (Loeb, 2013; Siegfried, 2013). Nevertheless, the perceptible negative effects of the historical publishing paradigm along with a highly visible alternative in the open source model are contributing to the growing support in the scientific community for a change in the system (Research Information Network, 2010).

In addition to the demands articulated for the opening of this closed form of communication in science and research, science is in the midst of a "radical change" (Poynder, 2011), thanks to new possibilities offered by digitalization and globalization. This change does not only offer an opportunity to solve the challenges in the current scientific communication system but also enables a comprehensive "acceleration of the knowledge turnover" (Giesecke, 1991, p. 540), which potentially leads to innovations for more openness in scientific communication. This makes the private and public research sectors more efficient (Chesbrough et al., 2006) and would accelerate the progress of society (Chesbrough, 2003), besides general assumptions of the potential positive impacts of open access on society, the economy, and academia (Tennant et al., 2016).

Despite extensive literature on these topics, only a few studies and experiments have been conducted to open up scientific communication. For example, several experiments have been run to embrace the use of open source methodologies in research for applied sustainability using open access and open-edit internet technologies both for real-time research tools and as a means of disseminating findings to the broadest possible audience (Pearce, 2012b). These types of technical experiments occurred in the engineering disciplines, but this also applies to the humanities (Heise, 2018; Näder, 2010) and results in the necessity to examine developments in the wide field of opening scientific communication.

Method

In the context of the previous section are the differences between pure access to published knowledge (open access) and complete access to the entire scientific knowledge process (open science), which includes access to open data, open methodologies, as well as FOSS and libre hardware.

Here, scientific communication in its historical context is reviewed disclosing arguments for and against opening scientific communication. A survey of scientific actors was conducted, as well as exploring scientific and interdisciplinary debates on the opening of science and research in German-speaking countries and catalysts and obstacles to open scientific communication (see Supplementary Material for a representative sample survey).

The participants in the survey were primarily German-speaking scientists from various disciplines or employees of the scientific company from German-speaking countries. They were interviewed online between August 18, 2014, and January 18, 2015. Although librarians (1% of respondents) and students (4% of respondents) were not addressed directly, they were still welcome to take part in the survey. In the course of the survey, a total of 4,002 researchers were contacted by email. The selection of the respective subject disciplines is based on the current list of the subject systematics of the Deutsche Forschungsgemeinschaft (2014). Because the survey was designed to be interdisciplinary to evaluate the differences between the disciplines, representatives from all listed disciplines were asked to participate. On a random basis, 150 researchers per subject were contacted by email from the institute's websites in German-speaking countries and asked to take part in the survey. One thousand seven hundred sixty-eight of the respondents took part in the survey and started the questionnaire, 1,467 participants answered at least one question and thus took part in the survey. Three hundred one respondents dropped out before fully answering the first question group. The response rate of the selected persons who answered the questionnaire was thus 37%. Of the 1,768 participants who started the survey, 1,112 completed the online questionnaire (63%) and gave informed consent to participate in this study for the purpose of publication (see Supplementary Material for the online questionnaire). The remaining 656 persons (37%) stopped the online questionnaire before answering all the questions. After completion of the survey, the anonymized data sets were published on the Datorium data repository of the GESIS—Leibniz Institute for Social Sciences (Heise, 2015b). The research data were reviewed by GESIS before publication. A further publication of the data took place on the data repository Zenodo (Heise, 2015c). To ensure the representativeness of the study, the responses to the survey were evaluated on the basis of existing information on professional classification, occupational status, and age, and compared with comparable studies such as the Science 2.0 Survey 2014 (Pscheida et al., 2015) and the survey "Neue Formen des Wissenschaftlichen Publizierens" (in English, New Forms of Scientific Publishing) by the SOFI Göttingen, as well as the data on personnel at universities of the German Federal Statistical Office (Destatis, 2014). The sample can be classified on the basis of these data on the basic population. Various distortions can only be assumed because the people contacted were only contacted online. However, because the survey could be filled out publicly and anonymously online without access restrictions, it was possible for any interested person to participate. In addition, the results of the survey can be considered representative insofar as they are based on a very large sample ($n = 1{,}112$).

Based on theoretical debates and empirical data, all theoretical assumptions were compared with the practical conditions of everyday scientific life. In addition, experiences and opinions of the scientists were compared with the experiences of a self-experiment of writing a doctoral thesis openly. The openly developed humanities-based thesis was made available at any time of the writing from 2013 to 2017 freely (zero cost)—for every person and at any time, including all data-connected creation processes, under an open and free license (Creative Commons BY-SA License) at http://offene-doktorarbeit.de. It was written by Heise, a student working on the concept of "openness" as a research assistant at the Hybrid Publishing Lab of Leuphana University (Lüneburg, Germany) and who was a also member of the board of the Open Knowledge Foundation Germany. The documentation of experiences with this procedure shows which hurdles, limits, and efforts arise through an open and formal communication for scientists. In 2018, the thesis was also published as an open access book (Heise, 2018).

Using this, data developments in the field of opening scientific communication were examined from the perspective of the humanities and cultural studies and compared with the previous findings on opening scientific communication.

Results and Discussion

In the evaluation of the survey from 2015, it was possible to demonstrate a widespread understanding of open access, support for open science, and a major interest in research data from others. Yet, there is still the question of how important the criterion of "free access to the full text" is for the surveyed scientists' own publications. Half of the respondents (50%) consider this to be "less important" or "not important," the same amount, 45%, considered it to be important or very important (5% of the 1,112 respondents abstained from answering the question). This shows a discrepancy between the scientists' understanding of open access, the support for open science, and their actual practice of open communication.

Further criteria for the scientific publication of papers or books from the respondents' perspective are as follows:

- Seventy-eight percent of the survey participants consider international dissemination to be "important" or "very important" for their own publications, whereas 19% consider it to be "less important" or "unimportant."
- The peer-review process is considered an important criterion by 75% of respondents, whereas only 19% disagree.
- Seventy-five percent of respondents consider the transparency of the review process to be important, whereas 18% consider this criterion to be "less important" or "unimportant."
- Seventy-one percent of the scientists surveyed consider it important that their own publications can be found easily on the internet, whereas 25% consider this to be "less" or "unimportant."
- The rapid publication of their own work is important for 68%; for 29%, this criterion is not particularly important.
- Rankings such as the impact factor of a scientific journal were rated as "important" by 58% of respondents and as "less important" or "unimportant" by 35%.
- For the majority of respondents, the reputation of the editors was "rather unimportant" or "unimportant" (48%). In contrast, 47% considered this criterion to be "very important" or "important."

Another question in the questionnaire concerned the respondents' assessments of whether their own publications in journals or books were potentially accessible to readers. Here, 32% of respondents answered the question with the option "yes, well accessible"; 47% answered with "partially"; 9% chose the option "no, not so easily accessible"; and 2% said "no, very poorly accessible." About 10% of respondents did not know how to answer the question with these options.

When asked whether the respondents themselves had published essays, texts, or books that had been made freely accessible by the publisher, 140 participants (13%) answered "yes, one paper" and 23% answered "yes, several papers." At the time of the survey, 54% or 605 of the respondents had not yet published any articles, texts, or books that had been made freely accessible. A fifth of those who had not yet published via open access at a publishing house stated that they were planning to do so, whereas 10% of respondents did not answer the question.

Next, 397 (36%) of the 1,112 respondents who stated that they had already freely published content were asked to state how many articles, texts, or books they had freely published so far:

- Books: 63 respondents (16%) answered this optional question—26 of them stated that they had not yet published a book that had been made freely accessible; excluding the respondents who stated that they had not published any books, 37 respondents had published two books each, which had been made freely accessible by the publishing house.
- Texts: 192 of the 397 respondents (48%) stated that they had published at least one text. On average, the respondents had each published three "freely accessible" texts.
- Data: 3% (10 people) stated that they had freely published at least one data set.

About a third of the respondents (31%) estimated the effort required to make their own publications freely available online to be low; yet, 255 (28%) of them rated the effort required to make their publications freely available online as "medium" or "high," and 23% were unsure and chose "so-so," whereas 19% did not know how to estimate the effort.

Although the majority of respondents rated the effort required for the free publication of papers as "not high," the evaluation of the question regarding the estimated effort required for the publication of research data online showed something different. For this, 55% of the respondents estimated the effort required to publish research data to be "high." The smallest group of respondents (10%) assumed that the effort would be "small," 15% estimated the effort to be "so-so," and 20% did not know how to answer the question.

Open Scientific Communication and Everyday Scientific Life

The results of the survey show a lot of support and great interest in open scientific communication. In everyday scientific life, however, this interest and the acceptance of digital and open methods of communication have not yet led to a fundamental change in publication behavior of the majority of those surveyed. The theoretical and nonmaterial interest giving access to the public sphere is thus countered by a practical lack of interest in dealing with the topic in everyday life. One reason is that the demands for open scientific communication develop from a technical point of view. The first open publication projects and developments in open access took place in the science, technology, engineering, and mathematics (STEM) subjects that included medicine, which were severely affected by a journal crisis earlier than other subjects. Yet, the explanations and efforts resulting from this development led to considerable reservations regarding the usefulness and feasibility of opening scientific communication, which in turn led to a lack of interest, incentives, or polarization among representatives of these disciplines (Hagner, 2015; Näder, 2010; Scheliga & Friesike, 2014). This polarization (particularly in the humanities) continues to represent a major challenge for the establishment and dissemination of concepts for open scientific communication. At present, it is still difficult to imagine an effective and broadly adopted interdisciplinary platform for open scientific communication and joint action by the scientific community. However, there are many field-specific platforms that are functioning effectively to further the goals of open science (e.g., openwetware.org for sharing information for researchers in biology and biological engineering).

Another reason for the lack of practical implementation of open scientific communication in everyday scientific life, despite a theoretical interest, is incomplete knowledge about the economic aspects of the scientific information supply. In the literature examined, this discrepancy is justified by the situation of scientists who have little or no direct incentive to actively deal with the publication system (Scheliga & Friesike, 2014) and possible changes because they do not have to bear the costs of publication (Sietmann, 2007), or its financial aspects (Herb, 2010). In addition to the limited financial and timely resources to deal with the extensive aspects of information provision, there are still legal uncertainties and concerns of being "scooped" by labs with more or better resources to complete an experiment earlier that prevent scientists from opening up their communication.

Christopher Kelty identifies two aspects for the everyday disinterest when it comes to an open scientific communication system and everyday life: The discussion of openness is extraordinarily complex and rather boring (Kelty, 2014). In addition, the comprehensive examination of the scientific publication market would "put practices at stake that seem to lend meaning and legitimacy to the actions of many humanities scholars" (Hirschi & Spoerhase, 2015, p. 6). Therefore, they would rather not be questioned.

The survey results (Heise, 2015b) underline these fears and suggest that the majority of scientists may not play a prominent role in shaping the transformation of communication in the near future, and similar to results found elsewhere, the status quo will be preserved despite the possibilities for change (Nosek et al., 2015; Scheliga & Friesike, 2014). This fear is also relevant in the tension between science and politics, where scientists attempt to act as strategists in the political struggle for credibility for scientific work (Latour & Woolgar, 2013). At present, however, they do not sufficiently fulfill this role.

Open scientific communication is associated with many efforts for the academic community, but can be regarded as "perhaps the most precious gift of the internet to the knowledge society" if it is not guided exclusively by the "economic interests of information capitalism" (Hagner, 2015, p. 65). The focus is instead on the task of fulfilling the overall social mission of the science system. Each author decides whether and how research results will be disseminated and accessible. Yet, the fulfillment of academic expectations for the publication of findings—including internal rules using the given intellectual framework and the claim to get along with colleagues—makes it very easy to limit social idealism and the majority's commitment to openness (Hagner, 2015), to the academic syllabus and not to participate in (activist) processes of change (Flood et al., 2013), and even if many researchers support the idea of open science in theory, "the individual researcher is confronted with various difficulties when putting open science into practice" (Scheliga & Friesike, 2014). This discrepancy between the scientists' commitment to open scientific communication and their actual practice of open communication and working methods was confirmed by the results of a survey of the doctoral study (Heise, 2018).

Challenges in the Existing System of Scientific Communication

For decades, the knowledge within the framework of scientific communication and the effectiveness and expediency of this scientific communication system have been the subject of debate in the scientific community (Simon et al., 2010), in which it is repeatedly questioned and described as being of limited suitability (Brembs, 2013; Havemann, 2002; Hicks & Katz, 1996; Hornbostel, 1997; Warnke, 2012). The challenges in the existing system of formal scientific communication relate primarily to nine aspects:

1. performance evaluation of scientific work,
2. speed in the communication process,
3. respect for the freedom of science and research,
4. efficiency,
5. defect resistance and quality assurance,
6. dissemination and accessibility,
7. digitization,
8. possibilities of verifiability of knowledge/scientific quality, and
9. prevention of misuse and scientific misconduct.

In the eyes of the scientists surveyed, the acceleration of the dissemination of knowledge (supported by 64%) and the open availability of already funded research for all (supported by 55%) are hindered by the lack of established reputation criteria for the evaluation of open science (43%), the danger of misinterpretation, and the danger of misinformation (40%), as well as increased time expenditure for the provision of scientific publications and/or research data (34%). The majority of the 1,112 respondents stated that legal concerns (39%) and ignorance regarding permissions (29%) prevent them from making scientific content publicly available without financial, legal, or technical barriers.

In the evaluation of the data, it became clear that the obstacles had a larger distribution than the catalysts and that the dissemination of open scientific communication methods correlates not insignificantly with the field of study of the respective authors—for example, whereas in life sciences, 53% of the respondents said they have published essays, texts, or books that were made freely accessible by the publisher, in engineering and the humanities, just around one-third respondents claimed to have done the same (Heise, 2018). The results of the survey demonstrate the discrepancy repeatedly described in the literature between interest in and understanding of openness and the open communication and working methods actually practiced (Bartling & Friesike, 2014; Fecher et al., 2015; Hagner, 2015; Yiotis, 2005).

Many research-funding organizations still follow classic publication procedures and digital research infrastructure progress is slow, as is support for software development programs (Hey & Payne, 2015). However, there are also examples that highlight how far some parts of open science have come. For example, consider that the National Institutes of Health (NIH; the largest science funder in the United States) now demands that all research they fund

> Submit or have submitted for them to the National Library of Medicine's PubMed Central an electronic version of their final, peer-reviewed manuscripts upon acceptance for publication, to be made publicly available no later than 12 months after the official date of publication. (NIH, 2018)

This type of policy is also seen in other major science funders such as those in India (Chawla, 2014), Portugal (Carvalho et al., 2017), Denmark, and others in Europe (DTU Bibliotek, 2018). This is still not immediate or universal, so it hampers the necessary processes of change in the context of the digitization of everyday scientific life and promotes the inertia to support the current scientific communication system. However, funding agencies in scientific practice brought about by new media technologies assume their responsibility by providing the additional resources needed to create the structural foundations associated with the opening of science and research (Mennes et al., 2013; Patlak, 2010). To drive these efforts forward, funding agencies as "influential actors in the complex and changing market for scientific publications" (Wein, 2010, p. 287) could decide whether to promote the implementation of data sharing through targeted incentives (Mennes et al., 2013). To date, this collaborative use of scientific data has only been very shallow, and up to 86% of published data still remain unused or unquoted, although there is a slight upward trend (I. Peters et al., 2015). It should, however, be noted that many scientific studies display the data directly in the manuscripts themselves and are not necessarily amenable to external use or have any need to be provided in another form.

Open Writing Findings in the Self-Experiment and Beyond

To identify further connected pathways toward Open Science, Heise decided to publish everything related to his doctoral study and research process as soon as possible, as comprehensively as possible, and under an open license. Heise (2012) submitted this research project in November 2012. At the start, it was unclear whether it would be possible to write the whole PhD as openly as possible. To counter this legal uncertainty, a letter was written to the doctoral commission explaining the intention, asking about the conditions for this kind of open thesis preparation, and explaining a possible reason for the compatibility with the doctoral regulations. After almost 1 year of legal examination, the university's doctoral commission and legal department approved the open process for the thesis (Heise, 2013). However, this was only an opinion of the majority of the commission, because the final acceptance or rejection of a dissertation does not take place until it has been submitted. It could, therefore, not be ruled out that the commission would still reject the thesis when it was submitted. In 2013, the PhD commission of Leuphana University in Germany confirmed this option. Since then, the writing was conducted openly via http://live.offene-doktorarbeit.de, all data were shared immediately and the final thesis was handed in for assessment in June 2016. Disputation took place in February 2017, and in January 2018, the thesis was published as a peer-reviewed book (Heise, 2018) by the publisher Meson Press.

So, in addition to the theoretical obstacles to establishing open science, there are practical aspects that hinder the most comprehensive and freely available publication of information within the framework of scientific knowledge processes. By 2015, the platforms and applications available were not yet mature enough to enable open science to be practiced in everyday life without a great deal of extra effort (Heise, 2018). Today, this has changed as is summarized in the following section. It must be borne in mind that, despite increasing digitization, scientific work has been designed for decades for closed publication and the nonpublic publication process and is exposed to the pressure of the market as the dominant form of governance of science.

As described, the thesis was based on the requirement that the most comprehensive access possible to the entire scientific knowledge process, including all information generated during the preparation, evaluation, and communication of the scientific findings and that contributed to the reproducibility of the results, should be available at all times. This does not mean, however, that every protocol or approach has been published. This was only the open communication of all activities within the framework of the doctorate, which contributed to the traceability of the scientific quality and findings as well as the cognitive process. One finding of the open production experiment is that although the open scientific knowledge process is possible in principle according to the demands of open science and the open definition, the possibilities for the production of open scientific qualification papers were insufficient.

If one contrasts the usual scientific working method with the open creation process of Heise's dissertation, the work on a local computer (even when using internet-based services) in a closed environment must still be evaluated as much less complicated than the public writing of a thesis. On one hand, this has to do with the established structural, technical, and legal environments of scientific work, which are predominantly incompatible with the open presentation and dissemination of content. On the other hand, the lack of possibilities and functions for open working methods as well as the resulting limitations in usability and processes must be compensated for by more effort and manual work on the part of the researchers.

It seems almost understandable that only a minority use open web platforms for scientific communication (Perkel, 2014). The majority of the scientists surveyed in the context of this work fear an additional effort when starting research data analysis, although the data are already available in digital form due to the increased use of computer-aided scientific procedures. In addition, the results of the self-experiment show that, at the time, it would have been difficult, if not impossible, to disclose the entire knowledge process during the preparation of the paper without prior programming knowledge. Thus, during the preparation of the work, special software had to be programmed to meet the requirement of permanent and comprehensive availability of the work as well as the generated data (Heise, 2015a). Today, the Open Science Framework (OSF) has provided this service for free for all scientists. Missing standards and technical hurdles still pose great challenges in the evaluation, creation, and presentation of scientific content. In addition, the specific requirements for opening up the scientific knowledge process as comprehensively as possible cannot yet be met by current solutions. However, the necessary (further) development of the platforms will only take place if the demand for such solutions increases. Here, too, the scientific community is called upon to generate this demand (e.g., through experiments with open scientific communication) and to play an active and creative role in the development of such solutions.

In the future, this expertise will not only be important for the open creation of a scientist's own work. It is also important because, in contrast to paper as a carrier and storage medium, scientific knowledge is increasingly being stored digitally. However, the transmission of knowledge in scientific communication can only be understood by the actors involved if technical knowledge can be used and if the transmission channels and formats are transparent and open (Davis, 2011). The scientific community must not avoid this confrontation with technological tools and digital change, but must understand their logic. Johannes Näder quotes the French philosopher Régis Debray who said that a discourse on ends and values that is not based on a precise state of the available means is an empty discourse. But a discourse on innovation that does not examine it closely in the light of memory is a dangerous discourse (Debray, 2003; Näder, 2010).

In this discourse lies a source of revolutionary self-understanding that constitutes at least parts of the open movement. This has consequences for the entire scientific system as in our digital age, communicable knowledge no longer consists of printed words, but of code and data. Consequently, anyone who wants to read, understand, interpret, or change the raw form of knowledge—all basic prerequisites for the creation of scientific (qualification) papers—one must be able to read, understand, and write this code. The advantages of digital sharing and dissemination of knowledge have been fulfilled primarily by those who have the necessary know-how for migration. The increasing degree of digitization in the daily work of scientists leads to the necessity to deal with all produced data and to seek an experimental research approach. The transfer and modification of analog working methods, storage media, working media, and tools into digital formats for the acquisition of knowledge are inevitable. A balanced consideration of these developments has so far been given little consideration in the training of young scientists.

Recommendations of Writing an Open Scientific Paper

The experiment of openly writing a scientific PhD thesis in the humanities has made it clear that the demand for opening up the entire scientific knowledge process and the associated open scientific communication could still not be met without considerable additional effort. In other disciplines, the challenge is far less substantial. For example, in the science and engineering disciplines, it is now common to write a "manuscript-based thesis," where a PhD or master's thesis is actually a collection of published peer-reviewed single papers (manuscripts). Each of these manuscripts can be written in an open way, a preprint can be uploaded to an appropriate existing repository and then collected in the final thesis.

Best practices based on the experience of Pearce (2018a) for doing this in the STEM fields will be outlined here and then compared with the steps necessary in the humanities below. The best practices for creating fully open science follow 10 steps.

1. Attempt to as much as possible only to use open source tools in the writing of the manuscript including both hardware and software (e.g., these lines were typed on computer running a free version of Linux in Libre Office).
2. Complete a literature review on the research topic openly on a wiki using free and open source search tools detailed in Pearce (2018a).
3. Publish the methodology used for the study openly (Pearce, 2012b) in an appropriate venue for your field using an appropriate license (e.g., CC-BY-SA).
4. If software is necessary to perform any task for the study, use FOSS, and if changes are made to it or if new software is developed, publish in an open source repository (e.g., allura.apache.org) using an appropriate license (e.g., GNU GPL v3).
5. If hardware is necessary to perform a task for the study, use free and open source hardware, the design of which is described in detail by Oberloier and Pearce (2018), and using an appropriate license (e.g., CERN Open Hardware License).
6. If data are collected, publish it openly in an open data repository (e.g., the OSF located at osf.io).
7. If the nature of the study is amenable to it, the entire writing of the manuscript can take place openly in the osf.io hosted by the Center for Open Science. The OSF has (a) structured projects that enable managing of files, data, code, and protocols in one centralized location, and easily build custom organization for your project; (b) controlled access, that is, allows users to control which parts of a project are public or private (e.g., personal data), making it easy to collaborate and share with the community or just the internal team; (c) enhanced workflow that automates version control, provides persistent identifiers for projects and materials, preregister your research, generate preprints, and connect your favorite third-party services directly to OSF; and (d) ensures a dependable repository as OSF's Preservation Fund preserves and maintains read access to any hosted data on OSF for 50+ years. It is free to use (i.e., no economic cost).

8. Publish the preprint of the completed manuscript in an open access repository (e.g., arxiv.org, hal.archives-ouvertes.fr, preprints.org, or osf.io/preprints).
9. Ideally send to an open access journal for peer review and publication.
10. After publication, post the results, links to open access version of the manuscript and any useful artifacts (e.g., CAD designs) in an appropriate venue (e.g., appropedia.org for sustainable development-related research).

Ten recommendations resulted from the experience of writing a PhD in the humanities in an open format and should be considered when writing in non-STEM fields:

1. Before the author decides to write openly and publish the current status of the work in a timely or simultaneous manner, it should be clarified with the university whether this method of continuous publication is compatible with its guidelines or the requirements of the respective final publication channel. If there are any uncertainties, written permission should be requested. This applies in particular to scientific qualifications.
2. Authors who opt for direct publication on the internet should familiarize themselves with the technical basics in advance. In the past, a basic understanding of source code and software is a great advantage, if not a prerequisite. However, now, systems such as the OSF make this type of operation far less technically challenging.
3. The conscientious selection of the software for the text production and data processing plays an important role for the project. Authors should choose a solution from the outset that makes it easy for them to write the text and publish it promptly on the internet. In addition, the software used should also allow stable handling of large and complex text and data volumes if necessary for the thesis.
4. It is advisable to allow some extra time for a timely publication, documentation, and anonymization of the data collected. Prior to research data publication, a platform that carries out a review to ensure a high-quality standard should be selected to check all the research data. This way, the necessary anonymity will be maintained and the data are sustainably available and searchable.
5. Expectations of scope and benefits of the open writing process should not be too high. If you want to use open writing to get additional feedback or ideas while writing, you should not rely on that just because the work is visible for anyone. Because this is a new approach to scientific work, there is no guarantee, but a considerable range can be generated through this type of continuous publication.
6. The documentation of the project and the related activities are important and should also be included in the planning. The comprehensive documentation allows for a better presentation of the research project and the reasons behind it. In addition, interesting information (e.g., timetable and schedule) can be communicated continuously, users can be more involved in the creation process, and the knowledge process as a whole can be made more transparent and open. However, this also requires an additional effort compared with the closed production of scientific papers.
7. It is essential to use an open license to meet the requirements of openness and transparency, so others can use and reuse the content and data.
8. When producing, collecting, and presenting the work, authors need to consider that all texts, data, and information will be published online. Open scientific papers, therefore, require a great deal of care and discipline.
9. The social environment of the author should be made aware of the documentation, as this may create positive pressure within the timetable. This motivates and increases work morale.
10. It is advisable to point out that the paper is unfinished and still in progress at all prominent spots. Possible limitations of the functional diversity (e.g., no commentary function) should be communicated clearly and openly with regard to the independence of the production of the paper.

Opportunities and Challenges for the Scientific Community

An open scientific communication and digital change will have consequences for disseminating, producing, and storing scientific information (Gould, 2009). This situation can be a unique opportunity for the redesign of scientific communication, taking into account the challenges of the current system (Näder, 2010). Openness in science and research addresses the core of the production of knowledge and consequently affects not only science but also society as a whole (Mussell, 2013).

Science and research are closely linked to the norms of rapid dissemination of research results, a knowledge-sharing environment, coauthorship, and cumulative learning and innovation (Partha & David, 1994). Consequently, unrestricted and open scientific communication seems theoretically indispensable for the science system. In scientific reality, however, scientific work is largely based on a system closed by society and is still based on the assumption that "what is not printed has little chance of influencing the development of the discipline" (Luhmann, 1997, p. 606). Worse, the majority of scientists do not have access to the majority of literature because of the paywall in place of even that science, which is captured in print. The scientific communication system has remained constant so far: Communication formats such as monographs and journals still retain their high status, and the increasing use of digital tools has not yet led to any structural change in science. Questions remain unanswered as to what extent an open scientific knowledge process represents a desirable step, which side effects would arise from an open knowledge production, and whether the postulated changes are a scientific revolution or minor adaptations to the existing paradigms of science. Current developments are the precursors of a comprehensive media change that opens up new opportunities, including new challenges, for science. These developments offer new possibilities for the active publication of supplements and (raw) data, support researchers to share data that may prove a thesis false (and negative data), make withdrawn articles visible, and open up the scientific knowledge process. This way, effective mechanisms for prosecuting scientific misconduct can be installed and the existing mechanisms for self-correction can be strengthened. New models of science communication must also address which new aspects of scientific reputation are gaining relevance, and how networked computers and algorithms are being used for the increased availability of information as a result of overcoming the forced data reduction of analog media.

As shown in this two-part study, the obstacles are not only exclusively technical or financial but also social (Nosek et al., 2015). A legal clarification for the secondary use of content must remain an important catalyst for further development. If scientific communication continues to be pursued primarily through external and politically motivated measures, it can be assumed that commercial, research, and special interests that continue the economic exploitation of scientific content will have negative consequences for the truth and independence of science. In this context, major scientific publishers have been influencing the research policy agenda for decades, trying to assert their economic interests within the framework of change (Elsevier, 2012; Hirschi & Spoerhase, 2015). The scientific community must shape the inevitable change in the context of digitization by questioning the existing criteria for scientific work, experimenting with new means of communication, promoting catalysts for opening, and removing obstacles. If publishers are already demanding in this process that "authors should be free to choose where they would like to publish in a healthy, undistorted free market" (International Association of STM Publishers, 2007), the scientific community must be asked whether they or publishers should take over the design of the scientific communication system and whether they have made sufficient and self-determined use of freedom of publication in the past with the aim of disseminating knowledge as widely as possible.

Outlook and Starting Points for Further Research Efforts

The transformation from the Gutenberg Galaxy (McLuhan, 1962) to the Turing Galaxy (Rötzer, 2002) scientific communication system requires a redesign of the framework conditions for scientific communication and a redefinition of the roles of all participants in this system. The new forms in the presentation of scientific information, as exercised above, should be understood and used as an opportunity for active improvement, design, and modification of scientific communication. This redesign only works if the participants take on their role as active designers while preserving the freedoms of the scientific system. Important areas for any future evaluations are data protection and the misuse of research. Balancing and negotiating the protection of privacy against the immense value of open data use are important challenges for the future. A debate should not only take into account the effects and consequences but also carefully point out the advantages. There is also a need for a joint negotiation process between the scientific community, politics, and society.

Another starting point for research efforts results from the changeover of the publication system from the sale of content to a reimbursement of the costs for the publication of scientific findings by the public sector. As part of the transformation of publishers' business models toward the free availability of published scientific content for society, an investigation into how reimbursement of article processing charges (APCs; or fees charged to authors to publish) can be prevented without leading to false developments and false incentives that fuel a commercial open access market, which could lead to an unjustified increase in APCs and to a further concentration in the publication market. The questions are closely linked to the publication decisions of scientific authors and to the acquisition of symbolic scientific capital.

The possible competition between scientific and media communication as a result of open scientific communication is another approach to research. It must be questioned whether, and to what extent, the true monopoly of science could be negatively influenced by the monopoly of the media within the scope of open access to science and knowledge (Weingart, 2005). The challenges must be confronted offensively with possibilities and opportunities, and the latest developments in the field of citizen science (similar to citizen journalism) must also be taken into account.

There are even more questions with regard to the possible control, monitoring, and quantification of individual scientific activities within the framework of open science or the (self-) control of science. As a result of the open preparation, each step of a scientific project can be comprehensively documented with a time stamp and meta-information, and thus made comprehensible. This information can be used to monitor the work processes of individual scientists and to influence the creation process. As a result of this open creation process, it can be assumed that these new control and monitoring possibilities of scientific work can also represent a challenge for the freedom and data protection of scientists as well as their activities.

Conclusion

For the most part, the fully open PhD thesis was in the middle of the conflicting demands of opening scientific communication, technological developments, and their social consequences, as well as the increasing digitalization of scientific work. Despite the sometimes heated debates in the literature and the debates inside and outside the scientific community, there is still a lack of a concrete negotiation as to how these developments can be shaped from the scientific community's point of view. Regarding the effects they will and should have on science, one result is that there is a lack of incentive systems for a sustainable debate on the topics of open access and open science. The results of this study showed that although the majority of scientists support open science, a minority actually fully participate in it. Although the trends toward open science are increasing, strategies need to be found to stimulate the necessary negotiation within the scientific community and a new willingness to experiment with scientific communication to shape the future criteria of science.

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ORCID iD

Christian Heise https://orcid.org/0000-0001-8071-860X

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