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Open Science: One Term, Five Schools of Thought

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Abstract:

Open Science is an umbrella term that encompasses a multitude of assumptions about the future of knowledge creation and dissemination. Based on a literature review, this paper aims at structuring the overall discourse by proposing five Open Science schools of thought: The *infrastructure school* (which is concerned with the technological architecture), the *public school* (which is concerned with the accessibility of knowledge creation), the *measurement school* (which is concerned with alternative impact measurement), the *democratic school* (which is concerned with access to knowledge) and the *pragmatic school* (which is concerned with collaborative research).

Keywords: *Open Science, assessment and review, science 2.0, open access, open data, citizen science, science communication, altmetrics*

JEL Classification: *H42, H44, I28, K11, L17, Z13*

I. Introduction

'Open Science' is one of the buzzwords in the scientific community. It is accompanied by a vivid discourse that apparently just grasps any kind of change in relation to the future of knowledge creation and dissemination; a discourse whose lowest common denominator is perhaps that academic research somehow needs to open up more. The very same term however evokes quite different understandings about how science could open up, ranging from the democratic right to access knowledge (e.g. open access to publications), the demand for including the public in the research (e.g. citizen science) to the use of tools for collaboration and sharing. It appears that the 'open' in Open Science can refer to pretty much anything: The process of knowledge creation, its result, the researching individual, or the relationship between research and the rest of society.

We aim to offer an overview of the multiple directions of development of the still young discourse, its main arguments and common catchphrases. Looking thoroughly at the relevant literature on Open Science, one can indeed recognize iterative motives and patterns of argumentation that, in our opinion, form more or less distinct streams. We allowed ourselves to call these streams schools of thought.

After dutifully combing through the literature on Open Science, we identified five schools of thought. We do not claim a consistently clear-cut distinction between these schools (in fact some share certain ontological principles). We do however believe that our compilation can give a useful overview of the predominant thought patterns in the current discourse and point towards new directions in research on Open Science. In terms of a literature review, we believe that this paper identified some of the leading scholars and thinkers within the five schools.

The following table comprises the five identified schools together with their central assumptions, the involved stakeholder groups, their aims and the tools and methods to achieve and promote these aims.

TABLE 1

It has to be said that our review is not solely built on traditional scholarly publications but, due to the nature of the topic, also includes scientific blogs and newspaper articles. It is our aim in this paper to present a concise picture of the ongoing discussion rather than a complete list of peer-reviewed articles on the topic.

II. The Public School

In a nutshell, advocates of the public school argue that science needs to be accessible for a wider audience. The basic assumption herein is that the social web and Web 2.0 technologies allow and urge scientists on the one hand to open up the research process and, on the other hand, to prepare the research product for interested non-experts.

Accordingly, we recognize two sub-streams within the public school—the first is concerned with the accessibility of the research process (the production); the second with the comprehensibility of the research result (the product). Both streams involve the relation between the scientists and the public and define openness as a form of devotion to a wider audience. In the following section we will elaborate more on both streams in reference to relevant literature.

TABLE 2

A. Accessibility of Non-experts to the Research Process

It sounds like a romantic blueprint of doing science that the formerly hidden research process becomes not only visible but also accessible to the common man. Yet, coming from the stance that communication technology not only allows to document research constantly but also to include external dispersed individuals (as supposed in the pragmatic school), an obvious inference is that the formerly excluded public can now play an active role in research. A pervasive catchphrase in this relation is the so-called citizen science which, put simply, describes the participation of non-scientists and amateurs in research.

Hand refers, for instance, to Rosetta@home, a distributed-computing project in which volunteer users provide their computing power (while it is not in use) to virtually fold proteins [1]. The necessary software for this allowed users to watch how their computer tugged and twisted the protein in search of a suitable configuration. Watching this, numerous users came up with suggestions to speed up the folding process. Reacting to the unexpected user involvement, the research team applied a new interface to the program that enabled users to assist in the folding in form of an online game called Foldit. Hand states: "*By harnessing human brains for problem solving, Foldit takes BOINC's distributed-computing concept to a whole new level*" [1]. In this case, citizen science depicts a promising strategy to 'harness' volunteer workforce. One can however arguably question the actual quality of the amateur influence on the analytical part of the research. Catlin-Groves takes the same line as the Rosetta@Home project. She expects citizen science's greatest potential in the monitoring of ecology or biodiversity [2]. The specific fields possibly issue from the author's area of research (natural sciences) and the journal in which the review article was published (International Journal of Zoology). Nonetheless, in the two delineated examples, citizens can be rather considered a mass volunteer workforce instead of actual scientists with analytical or heuristic capacity.

Most citizen science projects follow indeed a certain top-down logic, in which professional scientists give impetuses, take on leading roles in the process and analysis and use amateurs not as partners but rather as free workforce. Irwin even claims, that most citizen science projects are not likely to provide amateurs with the skills and capacities to significantly affect research in meaningful ways [3]. Powell and Colin also criticize the lack of meaningful impact of non-experts in the research: "*Most participatory exercises do not engage citizens beyond an event or a few weeks/months, and they do not build citizens' participatory skills in ways that would help them engage with scientists or policy makers independently*" [4, p327].

The authors further present their own citizen science project, the Nanoscale Science & Engineering Center (NSEC), which at first also started as a onetime event. After the project was finished however, the university engaged a citizen scientist group that is in frequent dialogue with field experts. The authors do not outlay in detail the group's role in research and its influence on research policies; yet points at a perspective for a bottom-up involvement of interested amateurs and professionals. There is still a lack of research when it comes to models of active involvement of citizens in the research process beyond feeder services. Future research could therefore focus on emerging areas of citizen participation or alternative organizational models for citizen science (e.g. how much top-down organization is necessary?).

B. Comprehensibility of the Research Result

The second stream of the public school refers to the comprehensibility of science for a wider audience. Whereas citizen science concerns the public engagement in research, this sub-stream concerns the scientists' obligation to make research understandable for—a demand that Tacke, in an entry on his blog, provocatively entitled "*Come out of the ivory tower*" [5].

Cribb and Sari demand a change in the scientific writing style: "*Science is by nature complicated, making it all the more important that good science writing should be simple, clean and clear*" [6]. The authors' credo is that when the audience becomes broader and the topics more specific, then the academic dissemination of knowledge needs to adapt.

On a more applied level, numerous authors suggest specific tools for science communication. Puschmann and Weller for instance, describe the microblogging service Twitter as a suitable tool to direct users to, for example, relevant literature and as a source for alternative impact factors (as expressed in the measurement school) [7]. Grand argues that by using Web 2.0 tools and committing to public interaction, a researcher can become a public figure and honest broker of his or her information [8].

While numerous researchers already focus on the new tools and formats of science communication and the audience's expectations, there is still a need for research on the changing role of a researcher in a digital society, that is for instance the dealings with a new form of public pressure to justify the need for instant communication and the ability to format one's research for the public. A tenable question is thus also if a researcher can actually meet the challenge to, on the one hand, do research on highly complex issues and, on the other hand, prepare these in digestible bits of information. Or is there rather an emerging market for brokers and mediators of academic knowledge?

III. The Democratic School

The democratic school is concerned with the access to knowledge. The reason we refer to the discourse about free access to research products as the democratic school issues from its inherent rationale that everyone should have the same right to access knowledge, especially when its state funded. This concerns mostly research publications and scientific data, but also source materials, digital representations of pictorial and graphical materials or multimedia material.

In the following, we will discuss open access to research publications and open data.

A. Open Data

Regarding open data in science, Murray-Rust relates the meaning of the prefix 'open' to the common definition of open source software. In that understanding, the right of usage of scientific data does not demise to a journal but remains in the scientific community: "*I felt strongly that data of this sort should by right belong to the community and not to the publisher and started to draw attention to the problem"* [9, p52]. According to Murray-Rust, it is obstructive that journals claim copyright for supporting information (often research data) of an article and thereby prevent the potential re-use of data. He argues that "*(it) is important to realize that SI is almost always completely produced by the original authors and, in many cases, is a direct output from a computer. The reviewers may use the data for assessing the validity of the science in the publication but I know of no cases where an editor has required the editing of (supporting information)*" [9, p54]. The author endorses that text, data or meta-data can be re-used for whatever purpose without further explicit permission from a journal. He assumes that, other than validating research, journals have no use from claiming possession over supporting information—other researchers however do.

According to Murray-Rust's, data should not be 'free' (as in free beer), but open for re-use in studies foreseen or not foreseen by the original creator. The rationale behind open data in science is in this case researcher-centric; it is a conjuncture that fosters meaningful data mining and aggregation of data from multiple papers. Put more simply, open data allows research synergies and prevents duplication in the collection of data. In this regard, Murray-Rust does not only criticize the current journal system and the withholding of supporting information but also implies a productive potential of practicing open data. It has to be said though, that the synergy potentials that Rust describes mostly apply to natural sciences (or at least research fields in which data is more or less standardized) or at least fields in which intermediate research product (e.g. data) can be of productive use for others.

Similar to Murray-Rust, Molloy criticizes the current journal system, which works against the maximum dissemination of scientific data that underlies publications. She elaborates on the barriers inherent in the current journal system: "*Barriers include inability to access data, restrictions on usage applied by publishers or data providers, and publication of data that is difficult to reuse, for example, because it is poorly annotated or 'hidden' in unmodifiable tables like PDF documents*" [10, p1]. She suggests a handling with data that follows the ***Open Knowledge Foundation***'s definition of openness, which means that data should be available as a whole, at no more than a reasonable reproduction cost (preferably through download) and in a convenient and modifiable form.

Other than Murray-Rust and Molloy, Vision [11] and Boulton [12] first of all hold the researchers liable for practicing open data. Vision refers to a study by Campbell et al. (2002), after which only one quarter of scientists share their research data—even upon request. According to that study, the most common reason for denying requests was the amount of effort required for compliance. Vision presents disciplinary data repositories that are maintained by the data creators themselves as an appropriate solution to the problem. This way, scientists would only need to upload their data once instead of complying with requests. Although Vision emphasizes the necessity to minimize the submission burden for the author, he does not suggest concrete inducements for scientists to upload their data (for instance forms of recognition or another a material reward).

Andreoli-Versbach and Mueller-Langer (2013) examined the data availability of economic data based on a random sample of 435 researchers. According to that study, 89.14% of the researchers neither have a data and code section on their academic website nor do they indicate whether and where their data is available. Only 2.05% fully share data and code on their academic website. The current status quo, at least in economics, is in this regard to not share data or facilitate access to data and codes for empirical work. Interestingly, the study further reveals that data sharing goes hand in hand with status : "*The likelihood to share is positively associated with sharing other material, being full professor and being affiliated with a higher-ranked institution*" [13, p8]

In an empirical study about the sharing behavior among scientists, Haeussler found out that the sharing of data is indeed closely related to a form of counter-value [14, p117].

The apparent divergence regarding the impediments of open data demonstrate the need for further empirical research on that issue. Future studies could address the researcher reluctance to practice open data, the role of journals and supporting material, the design of an appropriate online data repository or meta-data structures for research data. The implied multitude of obstacles for practicing open data also illustrates that research on that issue needs to be holistic.

TABLE 3

B. Open Access to Research Publications

When it comes the open access of research publications, the argument is often less researcher-centric. Cribb and Sari make the case for the open access to scientific knowledge as a human right [6]. According to them, there is a gap between the creation and the sharing of knowledge: While scientific knowledge doubles every 5 years, the access to this knowledge remains limited—leaving parts of the world in the dark: "*As humanity progresses through the 21st century (...) many scholars point to the emergence of a disturbing trend: the world is dividing into those with ready access to knowledge and its fruit, and those without.*" [6, p3]. For them, free access to knowledge is a necessity for human development. In a study on open access in library and information science, Rufai et al. take the same line. They assume that countries "*falling in the low-income economic zones have to come on open access canvas"* [15]. In times of financial crises, open journal systems and consequently equal access to knowledge could be an appropriate solution. Also Phelps et al. regard open access to research publications as a catalyst for development. Consistently, they define open access as "*the widest possible dissemination of information*" [16, p1].

Apart from the developmental justification, Phelps et al. mention another, quite common, logic for open access to research publications: "*It is argued (...) that research funded by tax-payers should be made available to the public free of charge so that the tax-payer does not in effect pay twice for the research (...)*" [17, p1]. 'Paying twice for research' refers to the fact that citizens do not only indirectly finance government-funded research but also the subsequent acquisition of publications from public libraries. Carroll also criticizes the inefficiency of traditional, subscription-financed scientific journals in times of growth in digital technologies and networks [17]. He argues that prices should drive down in the light of the Internet—instead they have increased drastically. He further argues that the open access model would shift the balance of power in journal publishing and greatly enhances the efficiency and efficacy of scientific communication [17]. By shifting the financing away from subscriptions, the open-access model re-aligns copyright and enables broad re-use of publications while at the same time assuring authors and publishers that they receive credit for their effort (e.g. through open licensing).

TABLE 4

I. The Pragmatic School

Advocates of the pragmatic school regard Open Science as a method to make research and knowledge dissemination more efficient. It thereby considers science as a process that can be optimized by, for instance, modularizing the process of knowledge creation, opening the scientific value chain, including external knowledge and allowing collaboration through online tools. The notion of 'open' follows in this regard very much the disclosed production process known from open innovation concepts.

Tacke for instance builds upon the connection between open innovation and Open Science. Similar to open innovation, the author applies the outside-in (including external knowledge to the production process) and inside-out (spillovers from the formerly closed production process) principles to science [18]. He regards the Web 2.0 in this regard as a fertile ground for practicing collaborative research and emphasizes the 'wisdom of the crowds' as a necessity to solve today's scientific problems: "*Taking a closer look at science reveals a similar situation: problems have become more complex and often require a joint effort in order to find a solution*" [18, p37].

Tacke refers to Hunter and Leahey who examined trends in collaboration over a 70 years period [19]. They found out that between 1935 and 1940 only 11 % of the observed articles were co-authored, whereas between 2000 and 2005 almost 50 % were coauthored—a significant increase that according to Tacke issues from the increasing complexity of research problems over time; research problems that apparently can only be solved through multi-expert consideration. Indeed, Bozeman and Corley, in an empirical study on researcher collaboration, found out that some of the most frequent reasons for collaborative research are the access to expertise, the aggregation of different kinds of knowledge and productivity [20]. Apart from the assumed increasing complexity of today's research problems and the researcher's pursue of productivity, Tacke also points at the technical progress that enables and fosters collaboration in the first place. The Web 2.0 allows virtually anyone to participate in the process of knowledge creation. It is thus tenable to consider, besides striving for productivity and the increasing complexity of research process, also the emerging communication and collaboration technology as a solid reason for collaborative research.

Nielsen argues accordingly. He proceeds from the assumption that openness indicates a pivotal shift in the scientific practice in the near future—namely from closed to collaborative. By reference to numerous examples of collective intelligence, such as the Polymath Project (in which Tim Gower posted a mathematical problem on his blog that was then solved by a few experts) or the Galaxy Zoo Project (an online astronomy project which amateurs can join to assist morphological classification), he emphasizes the crucial role of online tools in this development: "*Superficially, the idea that online tools can make us collectively smarter contradicts the idea, currently fashionable in some circles, that the Internet is reducing our intelligence*" [21, p26].

Nielsen's presentation of examples for collaborative knowledge discoveries allow to conjecture the wide variety of collaborative research when it comes to scale and quality—may it be a rather-small scale expert collaboration as in the Polymath project or large-scale amateur collaboration as in the Galaxy Zoo project. Nielsen also points towards the importance of open data and promotes comprehensive scientific commons: "*We need to imagine a world where the construction of the scientific information commons has come to fruition. This is a world where all scientific knowledge has been made available online, and is expressed in a way that can be understood by computers*" [21, p111]. It becomes obvious that Nielsen's vision of Open Science is based on vesting conditions like the enhanced use of online platforms, the inclusion of non-experts in the discovery process and, not least, the willingness to share on the part of scientists; all of which show that Nielsen's notion of collective research is also bound to numerous profound changes in the scientific practice—not to mention the technological ability to understand all formats of knowledge by computers.

Haeussler addresses the sharing behaviour of researchers in an empirical study [13]. She uses arguments from social capital theory in order to explain why individuals share information even at (temporary) personal costs. One of Haeussler's results concerns the competitive value of information. She concludes: "*My study showed that factors related to social capital influence the impact of the competitive value of the requested information on a scientist's decision to share or withhold information*" [18, p117]. If academic scientists expect the inquirer to be able to return the favor, they are much more likely to share information. Haeussler's study shows that the scientist's sharing behaviour is not per se altruistic—which is often taken for granted in texts on Open Science. Instead, it is rather built on an, even non-monetary, return system. The findings raise the question how the sharing of information and thus, at least according to Nielsen and Haeussler, a basic requirement for Open Science could be expedited. It implies that a change in scientific practice comes with fundamental changes in the scientific culture (e.g. community recognition for sharing information).

Neylon and Wu elaborate more on Web 2.0 tools that facilitate and accelerate scientific discovery. According to them, tools "*whether they be social networking sites, electronic laboratory notebooks, or controlled vocabularies, must be built to help scientists do what they are already doing, not what the tool designer feels they should be doing*" [22, p543]. The authors regard the implementation of Web 2.0 tools in close relation to the existing scientific practice. Following this, scientific tools can only foster scientific discovery if they tie in with existing research practice. The most obvious target, according to the authors, is in this regard *"tools that make it easier to capture the research record so that it can be incorporated into and linked from papers"* [22, p543]. Unfortunately the authors do not further elaborate on how potential tools could be integrated in the researchers' workflows. Nonetheless, they take a new point of view when it comes to the role of Web 2.0 tools and the necessity to integrate these into an existing research practice.

Future research must focus on the structural parameters for Open Science, the incentives for scientists to share knowledge or the inclusion of software tools in the existing practice.

TABLE 5

IV. The Infrastructure School

The infrastructure school is concerned with the technical infrastructure that enables emerging research practices on the Internet. That concerns mainly software tools and applications as well as computing networks. In a nutshell, the infrastructure school regards Open Science as a technological challenge. Literature on this matter is often case-specific; it focuses on the technological requirements for particular projects (e.g. the Open Science Grid).

The technical infrastructure is a cyclic element for all identified schools in this paper (no one can imagine open data without online data repositories). It is the new technological possibilities that change established scientific practices or constitute new ones, as in the case of altmetrics or scientific blogging. Still, we decided to include the infrastructure school as a separate and superordinate school of thought due to discernible infrastructure trends in the context of Open

Science; trends that in our eyes enable research on a different scale.

We will therefore not list the multitude of Open Science projects and their technological infrastructure but instead dwell on two infrastructure trends and selected examples that signify a sever change in the scientific practice.

It has to be said that these trends are not mutually exclusive but often interwoven. The trends are:

- Distributed computing: Using the computing power of many users for research
- Social and collaboration networks for scientists: Enabling researcher interaction and collaboration

A. Distributed Computing

A striking example for distributed computing in science is the Open Science Grid, "*a large distributed computational infrastructure in the United States, which supports many different high-throughput scientific applications (...) to form multi-domain integrated distributed systems for science.*" [23, p202]. Put simply, the Open Science Grid enables large-scale, data-intensive research projects by connecting multiple computers to a high-performance computer network. Autonomous computers are interconnected in order to achieve high throughput research goals. The Open Science Grid provides a collaborative research environment for communities of scientists and researchers to work together on distributed computing problems [24].

It is thus not completely accurate to confine the Open Science Grid to its computational power alone as it also provides access to storage resources, offers a software stack and uses common operational services. Nonetheless, its core strength resides in the computational power of many single computers that allows scientists to realize data-intensive research projects, high throughput processing and shared storage. Typical projects that use the Open Science Grid are therefore CPU-intensive, comprise a large number of independent jobs, demand a significant amount of database-access and/or implicate large input and output data from remote servers.

Foster encapsulates the increasing importance of grids as an essential computing infrastructure: "*Driven by increasingly complex problems and by advances in understanding and technique, and powered by the emergence of the Internet (...),today's science is as much based on computation, data analysis, and collaboration as on the efforts of individual experimentalists and theorists*" [24, p52]. He further emphasizes the potential to enable large-scale sharing of resources within distributed, often loosely coordinated and virtual groups—an idea that according to the author is not all new. He refers to a case from 1968, when designers of the Multics operating system envisioned a computer facility operating as a utility [24]. What is new though, according to Foster is the performance of such network utilities in the light of the technological progress [24].

Distributed computing allows scientists to realize research almost independently from the individual computing resources. It is thereby an opportunity to untie a researcher from locally available resources by providing a highly efficient computer network. Considering the importance of big data, scientific computing will be an essential research infrastructure in the near future. One could say the objective of scientific computing is the increase of performance by interconnecting many autonomous and dispersed computers.

B. Social And Collaboration Networks

A second, more researcher-centric, infrastructure trend focuses on platforms that foster interaction between locally dispersed individuals and allow collaboration by implementing Web 2.0 tools. Drawing on the example of myExperiment, De Roure et al. propose four key capabilities of what they consider a Social Virtual Research Environment (SVRE) [25]:

- According to the authors, a SVRE should *firstly* facilitate the management and sharing of research objects. These can be any digital commodities that are used and reused by researchers (e.g. methods and data).
- *Secondly*, it should have incentives for researchers to make their research objects available.
- *Thirdly*, the environment should be open and extensible—meaning that software, tools and services can be easily integrated.
- *Fourthly*, it should provide a platform to action research. Actioning research is, in the authors' understanding, what makes a platform an actual research environment. Research objects are in this regard not just stored and exchanged but they are used in the conduct of research (De Roure, 2008, p. 182).

This depiction of a SVRE does of course not exclude, mass computation (the third capability in fact endorses the integration of additional services)—it does however clearly focus on the interaction and collaboration between researchers. Further, it becomes apparent that the authors' notion of 'virtual social research' involves a multitude of additional tools and services enabling collaborative research. It implies (directly or indirectly) integrated large-scale data repositories that allow researchers to make their data publicly available in the first place.

Nentwich and König [26] point towards other social networks for scientists, such as ResearchGate, Mendeley, Nature Networks, Vivo or Academia.edu. The authors state that present academic social networks are principally functional for scientists and do not (yet) feature a convergence towards one provider. They point towards the use of multi-purpose social networks (such as Facebook, LinkedIN or Xing) among scientists. These are used for thematic expert groups (not only scientists), self-marketing or job exchange.

TABLE 6

V. The Measurement School

The measurement school is concerned with alternative standards to ascertain scientific impact. Inarguably, the impact factor, which measures the average number of citations to an article in a journal, has a decisive influence on a researcher's reputation and thereby his/her funding and career opportunities. It is therefore hardly surprising that a discourse about Open Science is accompanied by the crucial question of how scientific impact can be measured in the digital age.

Advocates of the measurement school express the following concerns about the current impact factor:

- The peer review is time-consuming ([27] [28]).
- The impact is linked to a journal rather than directly to an article [27].
- New publishing formats (e.g. online open access journals, blogs) are seldom in a journal format to which an impact factor can be assigned to ([28], [29], [30]).

Accordingly, this school argues the case for an alternative and faster impact measurement that includes other forms of publication and the social web coverage of a scientific contribution. The general credo is: As the scholarly workflow is increasingly migrating to the web, formerly hidden uses like reading, bookmarking, sharing, discussing and rating are leaving traces online and offer a new ground to measure scientific impact. The umbrella term for these new impact measurements is altmetrics.

Yeong and Abdullah state that altmetrics differ from webometrics, which are, as the authors argue, relatively slow, unstructured and closed [30]. Altmetrics instead rely on a wider set of measures that include tweets, blog, discussions and bookmarks. Altmetrics measure different forms of significance and usage patterns by looking not just at the end publication but also the process of research and collaboration [30]. As a possible basis for altmetrics, Priem et al. mention web pages, blogs, downloads but also social media like Twitter or social reference managers like CiteULike, Mendeley and Zotero [29]. As a result of a case study with 214 articles, they present the two open-source online tools CitedIn and total-impact as potential alternatives to measure scientific impact as they are based on a meaningful amount of data from more diverse academic publications. At the same time, they emphasize that there is still a need for research regarding the comparability of altmetrics, which is difficult due to the high dimensionality of altmetrics data.

While many authors already recognize the need for new metrics in the digital age and a more structured and rapid alternative to webometrics, research on this matter is still in its infancy [30]. There is scarcely research on the comparability of altmetrics and virtually no research on their potential manipulations and network effects. Furthermore, altmetrics does not yet broadly applied in the scientific community; raising the question what hinders their broad implementation. A possible reason is the tight coupling of the existing journal system and its essential functions of archiving, registration, dissemination, and certification of scholarly knowledge [31]. All the more, it appears that future research should also focus on the overall process of science, its transformative powers and, likewise, restrainers

TABLE 7

VI. Discussion

Even though the paper implies a certain lack of conceptual clarity of the term Open Science, we do not promote a precisely defined concept. We aimed at offering an overview of the leading discourses by suggesting five (more or less) distinct schools of thought, their core aims and argumentations. We suggest that this classification can be a starting point for structuring the overall discourse and locating its common catchphrases and argumentations.

Although Open Science covers in the broadest sense anything about the opening of knowledge creation and dissemination, not necessarily all developments described in this paper are novel. In fact core demands and argumentations existed long before the dawn of the Internet and the digital age. Some would even argue that science is per definition open since the aim of research is, after all, to publish its results, and as such *to make knowledge public*. Nonetheless, science certainly experiences a new dynamic in the light of modern communication technology. Collaborative forms of research, the increasing number of co-authored scientific articles, new publication formats in the social web, the wide range of online research tools or the increasing emergence of open access journals bear witness to the dawn of a new era of science.

The entirety of the outlined developments in this paper marks a profound change of the scientific environment. And even if the most prominent accompaniments of this change (be it Open Access, Open Data, citizen science or collaborative research) are possibly overdue for a knowledge industry in the digital age and welcomed by most people who work in it, they still depend on comprehensive implementation. They depend on elaborate research policies, convenient research tools and, not least, the participation and devotion of the researchers themselves. In many instances Open Science appears to be somewhat like the proverbial electric car—an indeed sensible but expenseful thing that better parks in the neighbor's garage; a great idea that everybody agrees upon but urges the others to take the first step.

References

[1] E. Hand, "Citizen science: People power," *Nature*, vol. 466, no. 7307, pp. 685-687, Aug. 2010. [Online]. Available: http://dx.doi.org/10.1038/466685a

[2] Christina L. Catlin-Groves, "The Citizen Science Landscape: From Volunteers to Citizen Sensors and Beyond," International Journal of Zoology, vol. 2012, Article ID 349630, 14 pages, 2012.

[3] A. Irwin, "Constructing the scientific citizen: Science and democracy in the biosciences," *Public Understanding of Science*, vol. 10, no. 1, pp. 1-18, Jan. 2001.

[4] M. C. Powell and M. Colin, "Participatory paradoxes: Facilitating citizen engagement in science and technology from the Top-Down?" *Bulletin of Science Technology Society*, vol. 29, no. 4, pp. 325-342, Aug. 2009.

[5] O. Tacke, "Raus aus dem Elfenbeinturm: Open Science," blog, 23 November 2012; http://www.olivertacke.de/2011/10/23/raus-aus-dem-elfenbeinturm-open-science/

[6] J. Cribb and T. Sari. Open Science: Sharing Knowledge in the Global Century. Collingwood, 2010, pp. 1-20.

[7] C. Puschmann and K. Weller, “Twitter for Scientific Communication: How can Citations/References be Identified and Measured?”, unpublished.
[8] A. Grand, C. Wilkinson, K. Bultitude and A.F.T. Winfield (2012, Sept.). "Open Science. A New "Trust Technology?"". Science Communication. 34(5), pp. 679-689.
[9] P. Murray-Rust (2008, March). “Open Data in Science”. 34(1), pp. 52-64.
[10] J. C. Molloy, "The open knowledge foundation: Open data means better science," *PLoS Biol*, vol. 9, no. 12, pp. e1 001 195+, Dec. 2011. [Online]. Available: http://dx.doi.org/10.1371/journal.pbio.1001195
[11] T. J. Vision, "Open data and the social contract of scientific publishing," *BioScience*, vol. 60, no. 5, p. 330, May 2010. [Online]. Available: http://dx.doi.org/10.1525/bio.2010.60.5.2
[12] G. Boulton, M. Rawlins, P. Vallance, and M. Walport, "Science as a public enterprise: the case for open data." *Lancet*, vol. 377, no. 9778, pp. 1633-1635, May 2011.
[13] C. Haeussler, "Information-sharing in academia and the industry: A comparative study," *Research Policy*, vol. 40, no. 1, pp. 105-122, Feb. 2011. [Online]. Available: http://dx.doi.org/10.1016/j.respol.2010.08.007
[14] R. Reyaz, G. Sumeer and S. Tariq-Ahmad. (2011, July). "Open Access Journals in Library and Information Science: The Story so Far." 7(2)
[15] L. Phelps, B. Fox, and F. Marincola, "Supporting the advancement of science: Open access publishing and the role of mandates," *Journal of Translational Medicine*, vol. 10, no. 1, pp. 13+, Jan. 2012. [Online]. Available: http://dx.doi.org/10.1186/1479-5876-10-13
[16] M. W. Carroll, "Why full open access matters," *PLoS Biol*, vol. 9, no. 11, pp. e1 001 210+, Nov. 2011. [Online]. Available: http://dx.doi.org/10.1371/journal.pbio.1001210
[17] O. Tacke, "Open science 2.0: How research and education can benefit from open innovation and web 2.0," in *On Collective Intelligence*, ser. Advances in Soft Computing, T. Bastiaens, U. Baumöl, and B. Krämer, Eds. Berlin, Heidelberg: Springer Berlin / Heidelberg, 2011, vol. 76, ch. 4, pp. 37-48. [Online]. Available: http://dx.doi.org/10.1007/978-3-642-14481-3_4
[18] L. Hunter and E. Leahey, "Collaborative research in sociology: Trends and contributing factors," *The American Sociologist*, vol. 39, no. 4, pp. 290-306, Dec. 2008. [Online]. Available: http://dx.doi.org/10.1007/s12108-008-9042-1
[19] B. Bozeman and E. Corley, "Scientists' collaboration strategies: implications for scientific and technical human capital," *Research Policy*, vol. 33, no. 4, pp. 599-616, May 2004. [Online]. Available: http://dx.doi.org/10.1016/j.respol.2004.01.008
[20] M. Nielsen, *Reinventing Discovery: The New Era of Networked Science*. Princeton University Press, Oct. 2011. [Online]. Available: http://www.worldcat.org/isbn/0691148902
[21] C. Neylon and S. Wu, "Open science: tools, approaches, and implications." *Pacific Symposium on Biocomputing. Pacific Symposium on Biocomputing*, pp. 540-544, 2009.
[22] M. Altunay, P. Avery, K. Blackburn, B. Bockelman, M. Ernst, D. Fraser, R. Quick, R. Gardner, S. Goasguen, T. Levshina, M. Livny, J. McGee, D. Olson, R. Pordes, M. Potekhin, A. Rana, A. Roy, C. Sehgal, I. Sfiligoi, and F. Wuerthwein, "A science driven production cyberinfrastructure—the open science grid," *Journal of Grid Computing*, vol. 9, no. 2, pp. 201-218, Jun. 2011.
[23] I. Foster, "The grid: A new infrastructure for 21st century science," pp. 51-63, 2003. [Online].
[24] D. De Roure and C. Goble, "Software design for empowering scientists," *IEEE Software*, vol. 26, no. 1, pp. 88-95, Jan. 2009.
[25] M. Nentwich and R. König"Cyberscience 2.0: Research in the Age of Digital Social Networks." Frankfurt. Campus, June. 2012.
[26] M. McVeigh, “Open Access Journals in the ISI Citation Databases: Analysis of Impact Factors and Citation Patterns. A citation study from Thomson Scientific” Internet: http://ip-science.thomsonreuters.com/m/pdfs/openaccesscitations2.pdf [Jan. 29, 2013]
[27] J. Priem and K. L. Costello, "How and why scholars cite on twitter," in *Proceedings of the 73rd ASIS&T Annual Meeting on Navigating Streams in an Information Ecosystem - Volume 47*, ser. ASIS&T '10. Silver Springs, MD, USA: American Society for Information Science, 2010.
[28] J. Priem, D. Taraborelli, P. Groth and C. Neylon. “altmetrics: a manifesto“ Internet: http://altmetrics.org/manifesto/, Oct. 26, 2010 [Jan. 29, 2013]
[30] C. H. Yeong and B. J. J. Abdullah, "Altmetrics: the right step forward," *Biomedical Imaging and Intervention Journal*, vol. 8, no. 3, pp. 1-2, 2012. [Online]. Available: http://www.biij.org/2012/3/e15/e15.pdf
[31] J. Priem and B. H. Hemminger, "Scientometrics 2.0: New metrics of scholarly impact on the social web," *First Monday*, vol. 15, no. 7, Jul. 2010.
[32] P. Miller, R. Styles and T. Heath. “Open Data Commons. A License for Open Data.” Internet: http://events.linkeddata.org/ldow2008/papers/08-miller-styles-open-data-commons.pdf, April 22, 2008 [Feb. 12, 2013]
[33] A. Löh and R. Hinze, "Open data types and open functions," in *Proceedings of the 8th ACM SIGPLAN international conference on Principles and practice of declarative programming*, ser. PPDP '06. New York, NY, USA: ACM, 2006, pp. 133-144.
[34] S. Auer, C. Bizer, G. Kobilarov, J. Lehmann, R. Cyganiak, and Z. Ives, "DBpedia: A nucleus for a web of open data the semantic web”, in *The Semantic Web*, ser. Lecture Notes in Computer Science, K. Aberer, K.-S. Choi, N. Noy, D. Allemang, K.-I. Lee, L. Nixon, J. Golbeck, P. Mika, D. Maynard, R. Mizoguchi, G. Schreiber, and P. Cudré-Mauroux, Eds. Berlin, Heidelberg: Springer Berlin / Heidelberg, 2007, vol. 4825, ch. 52, pp. 722-735.
[35] K. Antelman, "Do Open-Access articles have a greater research impact?" *College & Research Libraries*, vol. 65, no. 5, pp. 372-382, Sep. 2004.
[36] S. Harnad, T. Brody, F. Vallières, L. Carr, S. Hitchcock, Y. Gingras, C. Oppenheim, H. Stamerjohanns, and E. R. Hilf, "The Access/Impact problem and the green and gold roads to open access," *Serials Review*, vol. 30, no. 4, pp. 310-314, Jan. 2004.
[37] S. Harnad and T. Brody, “Comparing the Impact of Open Access (OA) vs. Non-OA Articles in the Same Journals.” Internet: http://www.dlib.org/dlib/june04/harnad/06harnad.html, 10 June 2004 [Feb. 12, 2013]
[38] T. Gowers and M. Nielsen, "Massively collaborative mathematics." *Nature*, vol. 461, no. 7266, pp. 879-881, Oct. 2009.
[39] O. F. E. R. Arazy, W. Morgan, and R. Patterson, "Wisdom of the crowds: Decentralized knowledge construction in wikipedia," *Social Science Research Network Working Paper Series*, Dec. 2006.
[40] A. Weiss, "The power of collective intelligence," *netWorker*, vol. 9, no. 3, pp. 16-23, Sep. 2005.
[41] T. Hey and A. E. Trefethen, "Cyberinfrastructure for e-Science," *Science*, vol. 308, no. 5723, pp. 817-821, May 2005.
[42] L. Björneborn and P. Ingwersen, "Perspective of webometrics," *Scientometrics*, vol. 50, no. 1, pp. 65-82, Jan. 2001.

Table 1: Five Open Science Schools of Thought				
School of thought	**Central assumption**	**Involved groups**	**Central Aim**	**Tools & Methods**
Democratic	The access to knowledge is unequally distributed.	Scientists, polititians, citizens	Making knowledge freely available for everyone.	Open access, intellectual property rights, Open data, Open code
Pragmatic	Knowledge-creation could be more efficient if scientists collaborated.	Scientists	Opening up the process of knowledge creation.	Wisdom of the crowds, network effects, Open Data, Open Code
Infrastructure	Efficient research depends on the available tools and applications.	Scientists & platform providers	Creating openly available platforms, tools and services for scientists.	Collaboration platforms and tools
Public	Science needs to be made accessible to the public.	Scientists & citizens	Making science accessible for citizens.	Citizen Science, Science PR, Science Blogging
Measurement	Scientific contributions today need alternative impact measurements.	Scientists & politicians	Developing an alternative metric system for scientific impact.	Altmetrics, peer review, citation, impact factors

Table 2: The Public School		
Author (Year) Type of Publication	**Title**	**Content**
Cribb & Sari (2010) Monograph	*Open Science - Sharing Knowledge in the digital age*	The accessibility of scientific knowledge is a matter of its presentation. *“Science is by nature complicated, making it all the more important that good science writing should be simple, clean and clear.” (p. 15)*
Grand et al (2012) Journal Article	*Open Science: A New “Trust Technology”?*	Scientists can raise public trust by using web 2.0 tools *“As mainstream science—and comment on science— follows the pioneers into the realm of Web 2.0, to be able to navigate the currents of the information flow in this relatively unmapped territory, scientists and members of the public will all need reliable and robust tools.” (p. 685)*
Morris & Mietchen (2010) Proceedings	*Collaborative Structuring of Knowledge by Experts and the Public*	Using web 2.0 tools to make knowledge production accessible for the public. *“(...) there is still plenty of opportunities for reinventing and experimenting with new ways to render and collaborate on knowledge production and to see if we can build a more stable, sustainable and collegial atmosphere (...) for experts and the public to work together.” (p. 32)*
Tacke (2012) Blog entry	*Out of the Ivory Tower: Open Science.*	The Web 2.0 gives scientists new opportunities to spread scientific knowledge to a wider public. *“Im einfachsten Fall können Wissenschaftler etwa in Blogs über Themen aus ihrem Fachgebiet berichten und Fragen von interessierten dazu beantworten.” (p. 2)*
Irwin (2006) Monograph	*The politics of talk*	Due to modern technology, citizens can participate in scientific knowledge creation. *"(...) this book is committed both to an improved understanding of 'science, technology and citizenship' and to better social practice in this area (...)" (p. 8)*
Hand (2010) Article	*Citizen science: People power*	Citizens possess valuable knowledge from which science can benefit. *“By harnessing human brains for problem solving, Foldit takes BOINC’s distributed-computing concept to a whole new level.” (p. 2)*
Ebner & Maurer (2009) Article	*Can microblogs and weblogs change traditional scientific writing?*	Blogs can contribute to make research more accessible to the public. Yet they cannot replace articles and essays in scholarly communication. *“Weblogs and microblogs can enhance lectures by bringing the resources of the WorldWideWeb to the course and making them discussable. Both new technologies, however, cannot replace writing essays and articles, because of their different nature.” (p. 55)*
Catlin-Groves (2012) Review article	*The Citizen Science Landscape: From Volunteers to Citizen Sensors and Beyond*	Citizens can help monitoring on a large scale. *“The areas in which it [citizen science] has, and most probably will continue to have, the greatest impact and potential are that of monitoring ecology or biodiversity at large geographic scales.” (p. 2)*
Powell & Colin (2009) Article	*Participatory paradoxes: Facilitating citizen engagement in science and technology from the Top-Down?*	Citizen science projects are often short-lived “Most participatory exercises do not engage citizens beyond an event or a few weeks/months, and they do not build citizens’ participatory skills in ways that would help them engage with scientists or policy makers independently.” (p. 327)

Table 3: The Democratic School: Open Data		
Author (Year) **Type of Publication**	**Title**	**Content**
Murray-Rust (2008) Preceedings	*Open data in science*	Open data depends on a change of the joournal practice regarding the witholding of supporting information. *"The general realization of the value of reuse will create strong pressure for more and better data. If publishers do not gladly accept this challenge, then scientists will rapidly find other ways of publishing data, probably through institutional, departmental, national or international subject repositories. In any case the community will rapidly move to Open Data and publishers resisting this will be seen as a problem to be circumvented." (p. 64)*
Vision (2010) Journal Article	*Open Data and the Social Contract of Scientific Publishing*	Data is a commodity. The sharing of data enables benefits other researchers. *"Data are a classic example of a public good, in that shared data do not diminish in value. To the contrary, shared data can serve as a benchmark that allows others to study and refine methods of analysis, and once collected, they can be creatively repurposed by many hands and in many ways, indefinitely." (p. 330)*
Boulton et al. (2011) Comment	*Science as a public enterprise: the case for open data*	Data needs to be prepared in a usable format. *"Conventional peer-reviewed publications generally provide summaries of the available data, but not effective access to data in a usable format." (p. 1634)*
Molloy (2011) Open Access Article	*The open knowledge foundation: Open data means better science*	Data should be free to reuse and redsitribute without restrictions. *"The definition of "open", crystellised in the OKD, means the freedom to use, reuse, and redistribute without restrictions beyond a requirement for attribution and share-alike. Any further restrictions make an item closed knowledge." (p. 1)*
Auer et al. (2007)	*DBpedia: A nucleus for a web of open data the semantic web*	Open Data is a major challenge for computer scientists in future. *"It is now almost universally acknowledged that stitching together the world's structured information and knowledge to answer semantically rich queries is one of the key challenges of computer science, and one that is likely to have tremendous impact on the world as a whole." (p. 1)*
Löh & Hinze (2006)	*Open Data types and open functions*	The problem of supporting the modular extensibility of both data and functions in one programming language (known as expression problem) *"The intended semantics is as follows: the program should behave as if the data types and functions were closed, defined in one place." (p.1)*
Miller et al. (2008)	*Open Data Commons, A Licence for Open Data*	Practicing open data is a question of appropriate licencing of data. *"Instead, licenses are required that make explicit the terms under which data can be used. By explicitly granting permissions, the grantor reassures those who may wish to use their data, and takes a conscious step to increase the pool of Open Data available to the web." (p. 1)*
Andreoli-Versbach & Mueller-Langer (2013)	*Open Access to Data: An Ideal Professed but not Practised*	Data sharing is not yet practiced in economics and often depends on the academic status. *„The likelihood to share is positively associated with sharing other material, being full professor and being affiliated with a higher ranked institution." (p. 8)*

Table 4: The Democratic School: Open Access to Research Publications		
Author (Year) **Type of Publication**	**Title**	**Content**
Cribb & Sari (2010) Monograph	*Open Science - Sharing Knowledge in the Global Century*	Open access to knowledge is a tool for development. *"As humanity progresses the 21st century (...) many scholars point to the emergence of a disturbing trend: the world is dividing into those with ready access to knowledge and its fruit, and those without." (p. 3)*
Rufai et al. (2012) Journal Article	*Open Access Journals in Library and Information Science: The Story so Far.*	Open access helps underdeveloped countries to bridge the gap between them and developed countries. *"The sustainability of open access journals in the field of LIS is evident from the study. Countries falling in the low-income economic zones have to come on open access canvas." (p. 225)*
Phelps, Fox & Marincola (2012) Journal Article	*Supporting the advancement of science: Open access publishing and the role of mandates*	Open access increases the dissemination of a scholar's work *"Maybe one of the reasons that open access is an increasingly popular choice for society journals is that it fits well with many society missions to encourage the advancement of knowledge by providing the widest possible dissemination with no barriers to access." (p. 3)*
Carrol (2011) Journal Article	*Why full open access matters*	Open access helps overcoming the inefficiancy of traditional peer-review journals *"Pricing of traditional, subscription-financed scientific journals is highly inefficient. The growth in digital technologies and in digital networks should be driving down the price of access to the scholarly journal literature, but instead prices have increased at a rate greatly in excess of inflation" (p. 1)*
Harnad & Brody (2004)	*Comparing the Impact of Open Access (OA) vs. Non-OA Articles in the Same Journals*	Open access can increase the number of citations and helps skirting the high access tolls of journals. *"Access is not a sufficient condition for citation, but it is a necessary one. OA dramatically increases the number of potential users of any given article by adding those users who would otherwise have been unable to access it because their institution could not afford the access-tolls of the journal in which it appeared; therefore, it stands to reason that OA can only increase both usage and impact."*

Harnad et al. (2004)	*The Access/Impact Problem and the Green and Gold Roads to Open Access*	Only 5% of journals are gold, but over 90% are already green (i.e., they have given their authors the green light to self-archive); yet only about 10-20% of articles have been self-archived. *"Along with the substantial recent rise in OA consciousness worldwide, there has also been an unfortunate tendency to equate OA exclusively with OA journal publishing (i.e., the golden road to OA) and to overlook the faster, surer, and already more heavily traveled green road of OA self-archiving." (p. 314)*
Antelmann (2004)	*Do Open-Access Articles Have a Greater Research Impact?*	Open access articles have a higher research impact than not freely available articles. *"This study indicates that, across a variety of disciplines, open-access articles have a greater research impact than articles that are not freely available."* (p. 379)

Table 5: The Pragmatic School

Author (Year) Type of Publication	Title	Content
Tacke (2008) Proceedings	*Open science 2.0: How research and education can benefit from open innovation and web 2.0*	Complex situations can be better judged by the collective wisdom of the crowds. *"However, several critics emphasize that one person can never possess enough knowledge in order to judge complex situations expediently, and that it may more appropriate to use the collective wisdom of crowds." (p. 37)*
Haeussler (2011) Journal Article	*Information-sharing, social capital, open science*	Scientists expect a benefit from sharing information. *"My study showed that factors related to social capital influence the impact of the competitive value of the requested information on a scientist's decision to share or withhold information." (p. 117)*
Neylon & Wu (2009) Symposium Workshop	*Open science: tools, approaches, and implications*	Open science tools need to fit to the scientific practice of researchers. *"Tools whether they be social networking sites, electronic laboratory notebooks, or controlled vocabularies, must be built to help scientists do what they are already doing, not what the tool designer feels they should be doing" (p. 543)*
Nielsen (2012) Monograph	*Reinventing Discovery: The New Era of Networked Science*	*"We need to imagine a world where the construction of the scientific information commons has come to fruition. This is a world where all scientific knowledge has been made available online, and is expressed in a way that can be understood by computers" (ibid., p. 111)*
Weiss (2005)	*The Power of Collective Intelligence*	Participation in collective knowledge-creation depends on the tools and services available. *"With ever more sophisticated APIs and Web services being shared, attracting a critical mass of developers to build tools on those services, and a critical mass of users contributing to the services' value by aggregating shared knowledge and content, we have the makings of a truly collaborative, self-organizing platform." (p. 4)*
Arazy et al. (2006)	*Wisdom of the Crowds: Decentralized Knowledge Construction in Wikipedia*	Participation in the co-creation of knowledge depends on the entry barriers *"To entice participation, organizations using wikis should strive to eliminate barriers (e.g. allow users to post anonymously) and provide incentives for contributions." (p. 5)*
Gowers & Nielsen (2009)	*Massively Collaborative Mathematics*	Natural sciences can profit from collaboration of researchers. *"But open sharing of experimental data does at least allow open data analysis. The widespread adoption of such open-source techniques will require significant cultural changes in science, as well as the development of new online tools. We believe that this will lead to the widespread use of mass collaboration in many fields of science, and that mass collaboration will extend the limits of human problem-solving ability." (p. 881)*

Table 6: The Infrastructure School

Author (Year) Type of Publication	Title	Content
Altunay et all. (2011) Article	*A Science Driven Production Cyberinfrastructure—the Open Science Grid*	Science grid can be used for high-throughput research projects. *"This article describes the Open Science Grid, a large distributed computational infrastructure in the United States which supports many different high-troughput scientific applications (...) to form multi-domain integrated distributed systems for science." (p. 201)*
De Roure et al. (2010) Conference Paper	*Towards open science: the myExperiment approach*	*"myExperiment is the first repository of methods which majors on the social dimension, and we have demonstrated that an online community and workflow collection has been established and is now growing around it." (p. 2350)*
Foster (2003) Journal Article	*The grid: A new infrastructure for 21st century science*	Computation is a major challenge for scientific collaboration in future. *"Driven by increasingly complex problems and by advances in understanding and technique, and powered by the emergence of the Internet (...), today's science is as much based on computation, data analysis, and collaboration as on the efforts of individual experimentalists and theorists." (p. 52)*
De Roure et al. (2003)	*The Semantic Grid: A Future e-Science*	Knowledge layer services are necessary for seamlessly automatiing a significant range of actions

Book Chapter	*Infrastructure*	*"While there are still many open problems concerned with managing massively distributed computations in an efficient manner and in accessing and sharing information from heterogenous sources (...), we believe the full potential of Grid computing can only be realised by fully exploiting the functionality and capabilities provided by knowledge layer services." (p. 432)*
Hey & Trefethen (2005) Article	*Cyberinfrastructure for e-Science*	Service-oriented science has the potential to increase individual and collective scientific productivity by making powerful information tools available to all, and thus enabling the widespread automation of data analysis and computation *"Although there is currently much focus in the Grid community on the lowlevel middleware, there are substantial research challenges for computer scientists to develop high-level intelligent middleware services that genuinely support the needs of scientists and allow them to routinely construct secure VOs and manage the veritable deluge of scientific data that will be generated in the next few years." (p. 820)*

Table 7: The Measurement School

Author (Year) Type of Publication	**Title**	**Content**
Priem & Light Costello (2010) Proceedings	*How and why scholars cite on twitter*	Tweets can be used as an alternative basis to measure scientific impact. *"Twitter citations are much faster than traditional citations, with 40% occurring within one week of the cited resource's publication. Finally, while Twitter citations are different from traditional citations, our participants suggest that they still represent and transmit scholarly impact."*
Weller & Puschmann (2011) Poster	*Twitter for Scientific Communication: How Can Citations/References be Identified and Measured?*	Scientific tweets can be identified in numerous ways
Priem et al. (2012) Proceedings	*Uncovering impacts: CitedIn and total-impact, two new tools for gethering altmetrics*	CitedIn and total-impact are tools that can measure scientific impact. *"CitedIn and total-impact are two tools in early development that aim to gather altmetrics. A test of these tools using a real-life dataset shows that they work, and that there is a meaningful amount of altmetrics data available"*
McVeigh (2012) News paper article	*Twitter, peer review and altmetrics: the future of research impact assessment*	*"So why is a revolution needed? Because long before the tools even existed to do anything about it, many in the research community have bemoaned the stranglehold the impact factor of a research paper has held over research funding, careers and reputations."*
Priem & Hemminger (2012) Journal article	*Decoupling the scholarly journal*	*"This tight coupling [of the journal system] makes it difficult to change any one aspect of the system, choking out innovation."*
Yeong & Abdullah (2012) Position paper	*Altmetrics: the right step forward*	Altmetrics are an alternative metric for analysing and informing scholarship about impact. *"Altmetrics rely on a wider set of measures [than webometrics] (...) are focused on the creation and study of new metrics based on the social web for analysing and informing scholarship."*
Björneborn & Ingwerson (2001) Journal article	*Perspectives of webometrics*	The lack of metadata attached to web documents and links ↄз and the lack of search engines exploiting metadata ↄз affects filtering options, and thus knowledge discovery options, whereas field codes in traditional databases support KDD (Knowledge Discovery in Databases). *"As stated above, the feasibility of using bibliometric methods on the Web is highly affected by the distributed, diverse and dynamical nature of the Web ↄзand by the deficiencies of search engines. That is the reason that so far the Web Impact Factor investigations based on secondary data from search engines cannot be carried out." (p. 78)*