WEB INDICATORS FOR RESEARCH EVALUATION. PART 2: SOCIAL MEDIA METRICS

Indicadores web para evaluación de la investigación. Parte 2: Métrica de medios sociales

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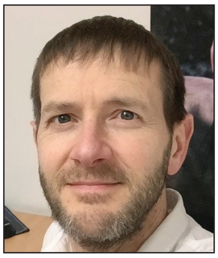

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Abstract
This literature review assesses indicators derived from social media sources, including both general and academic sites. Such indicators have been termed altmetrics, influmetrics, social media metrics, or a type of webometric, and have recently been commercialised by a number of companies and employed by some publishers and university administrators. The social media metrics analysed here derive mainly from *Twitter*, *Facebook*, *Google+*, *F1000*, *Mendeley*, *ResearchGate*, and *Academia.edu.* They have the apparent potential to deliver fast, free indicators of the wider societal impact of research, or of different types of academic impacts, complementing academic impact indicators from traditional citation indexes. Although it is unwise to employ them in formal evaluations with stakeholders, due to their susceptibility to gaming and lack of real evidence that they reflect wider research impacts, they are useful for formative evaluations and to investigate science itself. *Mendeley* reader counts are particularly promising.

Keywords
Altmetrics; Alternative metrics; Alternative indicators; Citation analysis; Web indicators; Webometrics; Scientometrics; Social media metrics; *Twitter*; *Mendeley*.

Resumen
Esta revisión bibliográfica evalúa indicadores derivados de medios sociales, tanto generales como académicos. Tales indicadores han sido llamados, influmétricos, altmétricos, métricas de medios sociales, o tipo de webmetría. Recientemente los han comercializado algunas empresas y los emplean algunos editores y administradores universitarios. Las métricas de medios sociales analizados aquí se derivan principalmente de *Twitter*, *Facebook*, *Google+*, *F1000*, *Mendeley*, *ResearchGate* y *Academia.edu*. Tienen el aparente potencial de ofrecer indicadores rápidos y gratuitos del impacto social de la investigación, o de impactos académicos de un tipo diferente, que complementan los indicadores obtenidos de los tradicionales índices de citas. Aunque no es prudente emplearlos en las evaluaciones formales de personas e instituciones, debido a que pueden ser falseados fácilmente y a la falta de evidencia real de que reflejen fielmente el impacto de la investigación en

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la sociedad, son útiles para las evaluaciones experimentales y para investigar la ciencia misma. Los conteos de lectores de *Mendeley* son particularmente prometedores.

Palabras clave

Altmétricas; Indicadores alternativos; Indicadores alternativos; Análisis de citas; Indicadores web; Webometrics; Scientometrics; Métricas de medios sociales; *Twitter*; *Mendeley*.

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1. Introduction

Academic research is sometimes discussed in social web sites like *Twitter* that are widely used outside academia. In conjunction with the availability of applications programming interfaces (APIs), which allow third party programs to access data from many of these sites, it has become relatively easy to create many new social impact indicators for academic research (**Priem**; **Taraborelli**; **Groth**; **Neylon**, 2010). These have sometimes been termed altmetrics and, in theory, they may help to give information about the wider societal impacts of research than would be visible through traditional citation counts (**Bornmann**, 2014) and may be less gender biased (**Paul-Hus**; **Sugimoto**; **Haustein**; **Larivière**, 2015). Indicators can also be derived from academic social network sites, such as *ResearchGate* and *Academia.edu*, and article-focused academic sites with user inputs, such as *F1000*, *Mendeley* and *Bibsonomy*. Interest in altmetrics has led to their use by publishers (**Adie**; **Roe**, 2013 – see below) and some universities, their provision by data providers including *ImpactStory*, *Plum Analytics* and *Altmetric.com*, their recommendation by initiatives such as *Snowball Metrics*, as well as a government-commissioned panel in the UK to assess, in part, whether they could be used for formal research evaluations (**Wilsdon** *et al.*, 2015). For example, the *Snowball Metrics* recipe book of institutional indicators lists many potential sources of data about "online events that have been stimulated by an institution's output", splitting them into indicators of scholarly activity (e.g., *Mendeley* readers), scholarly commentary (e.g., science blogs), social activity (e.g., tweets) and mass media (**Colledge**, 2014).

Social web indicators have predecessors in terms of data about public interest in the form of readership-based indicators such as reading factors (**Darmoni** *et al.*, 2000), readership rates (**Kurtz** *et al.*, 2000, 2005) or called just alternative metrics (**Bollen**; **Van De-Sompel**; **Smith**; **Luce**, 2005). Even before this, library usage statistics, such as photocopy requests (**Cooper**; **McGregor**, 1994), or journal reshelving counts (**Tsay**, 1998) had been proposed as alternatives to bibliometric indicators. The advent of the social web, however, has seen an explosion in both the range of indicators that could be calculated as well as the ease with which relevant data can be collected (even in comparison to web impact metrics). Of particular interest are comments, ratings, social bookmarks, and microblogging (e.g., **Taraborelli**, 2008; **Neylon**; **Wu**, 2009; **Priem**; **Hemminger**, 2010). There has been interest in evaluating them from the scientometrics community (e.g., **Wang**; **Wang**; **Xu**, 2013) as well as from publishers, with *Elsevier* (via *Scopus*), *Wiley*, *Springer*, *BioMed Central* and *Nature* all adding social media metrics to articles in their collections.

The term altmetrics has been coined to refer to indicators for research assessment derived from the social web (**Priem**; **Taraborelli**, **Groth**; **Neylon**, 2010), but some scholars have proposed other names, such as influmetrics (**Cronin**; **Weaver-Wozniak**, 1995) to reflect the fact that social media might reflect influence rather than impact (**Rousseau**; **Fred**, 2013), metrics of social impact (**Eysenbach**, 2011), social media metrics (**Haustein**; **Larivière**; **Thelwall**; **Amyot**; **Peters**, 2014) or just non-standard indicators (**Donovan**; **Butler**, 2007; **Mohammadi**; **Thelwall**, 2013). The term *alternative* in alternative metrics or its implicit inclusion within altmetrics has been criticised because of its implication that they may replace rather than complement traditional citation-based indicators (**Rousseau**; **Fred**, 2013). In contrast, the phrase social media metrics does not carry this implication and also does not contain the connotation that the metrics are measuring *science* and so this seems to be a preferable term.

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There have been concerns about validity and the quality of social media metrics or altmetrics due to the ease with which they can be manipulated (**Birkholz**; **Wang**, 2011; **Rasmussen**; **Andersen**, 2013; **Wouters**; **Costas**, 2012) and the varied reasons for which articles may be mentioned in the social web, such as for buzzwords in their titles (**Colquhoun**; **Plested**, 2014). One of the main criticisms is that they do not measure the quality of research because of the trivial reasons for which research is sometimes cited in them. This may be due to a misunderstanding of the term metric in this context: A social media metric should not be viewed as measuring research quality or impact, but only as measuring something about the *social media site* (e.g., how many mentions an article has received). A social media metric may also be an *indicator* of a type of academic, societal or other impact if it can be shown to have some desirable properties. At the most basic level, in order to be an impact indicator a social media metric score should tend to be higher for an article that has more impact (as assessed by a credible source) than for a similar article with less impact. If this is true then a social media metric may be useful to help to point to more impactful articles or groups of articles even though its results may be misleading in many individual cases. In this review, therefore, the terms altmetric and social media metric are interpreted as meaning a metric of social media rather than a metric of academic research. It is up to scientometricians to show that any given social media metric can be used as an impact indicator and this is the focus of most of the studies reviewed here. For example, a range of social media metrics have been shown to correlate significantly and positively with bibliometric indicators for individual articles (e.g., **Priem**; **Piwowar**; **Hemminger**, 2012; **Thelwall**; **Haustein**; **Larivière**; **Sugimoto**, 2013; **Costas**; **Zahedi**; **Wouters**, 2014), giving evidence that, despite the uncontrolled nature of the social web, social media metrics may be related to scholarly activities in some way. This is perhaps most evident when the social media metrics are aggregated to entire journals (**Alhoori**; **Furuta**, 2014; **Haustein**; **Siebenlist**, 2011), however.

This article reviews published research about the value of social media metrics as research impact indicators, covering both general social web sites and specialist academic sites. In most cases, the main evidence presented is a correlation between the social media metric and citation counts. A positive correlation suggests that the new potential indicator is related to academic communication in some way and the correlation strength may point to the likely prevalence of spam or irrelevant content (i.e., a high correlation would suggest that there was little spam or irrelevant content), and content analyses can also help to assess the face validity of new indicators (**Sud**; **Thelwall**, 2014b). The ages of the articles and the range of fields affect the correlation strengths in any test (**Thelwall**; **Fairclough**, 2015), and this should also be taken into account when comparing correlation coefficients.

2. *Faculty of 1000* web recommendations

Scientific papers are typically peer reviewed before being published in journals or conference proceedings. Several countries (e.g., UK, Australia and Italy) also employ expert post-publication peer judgments of (normally) peer reviewed research in order to allocate public funds (*ARC*, 2015; **Franceschet**; **Costantini**, 2011; *REF*, 2012). Although this double peer review approach has been criticised on the basis that the first should be sufficient (**Bence**; **Oppenheim**, 2004), post-publication reviews can provide critical analyses from a wider spectrum of experts and help to standardise between journals (e.g., **Crotty**, 2012; **Hunter**, 2012; **Teixeira-Da-Silva**, 2013).

The Faculty of 1000 (*F1000*) commercial website provides post-publication peer review scores in the form of recommendations and ratings for selected biomedical science publications. Although the recommendations are provided to subscribers for literature searching purposes, they may also be useful for research evaluation. In July 2015, *F1000* claimed to gather the judgements of 11,000 "leading experts" in Biology and Medicine to review journal articles (*f1000.com*). An early investigation found a medium significant correlation (Spearman r=0.445) between *F1000* ratings and peer judgments from *Wellcome Trust* (a UK based funding research institution) for a small sample of 48 original research papers (**Allen** *et al.*, 2009). A study of 1,530 articles published in seven leading ecological journals in 2005 compared citations from *WoS* with *F1000* recommendations, finding that the 103 articles recommended by *F1000* tended to attract more citations (median: 23) than did typical publications in the dataset (median: 16) (**Wardle**, 2010). There were outliers, however, because 11 highly cited articles (cited 120-497 times) were not recommended and just under half (46%) of the recommended publications were not highly cited. Geographical biases in reviewers and uneven coverage of *F1000* could be the reasons why *F1000* was unable to identify all high impact articles. *F1000* should not be used in areas for which it has only partial coverage, however, such as Ecology (**Wardle**, 2010).

A study of 1,397 journal articles published in 2008 in Genomics and Genetics found statistically significant correlations, albeit low, between *F1000* judge rating scores and *Web of Science* (*WoS*) / *Scopus* / *Google Scholar* citation counts (0.295, 0.293 and 0.290, respectively) and between *F1000* scores and journal Impact Factors (r=0.359) (**Li**; **Thelwall**, 2012), confirming their usefulness for biomedical research. Another study compared *F1000* scores and *Scopus* citations to 344 and 533 Medical Science articles published in 2007 and 2008, respectively, finding low but statistically significant Spearman correlations for both years (r=0.383 and r=0.300, respectively). A lower correlation was found between the number of labels assigned by *F1000* reviewers and *Scopus* citation counts (r=0.201) (**Mohammadi**; **Thelwall**, 2013). The study suggested that labels indicating applied value, such as "Changes clinical practice" could be particularly useful in research evaluation exercises to recognise the importance of practical findings.

Another systematic study of *F1000* ratings assessed correlations between seven bibliometric indicators from *Thomson Reuters InCites* and *F1000* article scores. Of 5,204 papers from *InCites* in Cell biology or Immunology published in 2008, 125 (2.4%) had *F1000* ratings (**Bornmann**; **Leydesdorff**, 2013). The 'Journal actual/Expected citations' indicator explained only 1% of the variance in *F1000 article factor* (FFa) (the lowest correlation), whereas 'Percentile in subject area' explained 20% of the variance in FFa scores (the highest correlation), suggesting that *F1000* scores tend to reflect something substantially different from, albeit overlapping with, citation counts.

The above results align with another study that also reported low but significant correlations between *F1000* article scores and journal Impact Factors (r=0.28). However, a further analysis using standardized regression coefficients between assessor scores and journal Impact Factors and numbers of citations showed that *F1000* ratings are more strongly dependent on the journal Impact Factors than on the number of citations, suggesting that post-publication assessors "might tend to rate papers in high IF journals more highly irrespective of their intrinsic merit" (**Eyre-Walker**;

Stoletzki, 2013, p. 2). Alternatively, the journal in which an article is published may be a better indication of its overall value than its citation count.

The largest-scale academic investigation of *F1000* so far matched all 132,662 *F1000* recommendations with *WoS*, finding 95,385 (93%) matching publications in *WoS* that were recommended 124,320 times in *F1000* (**Waltman**; **Costas**, 2014). However, only about 2% of the Biological and Medical Sciences publications had *F1000* recommendations, so its coverage is too low for systematic research assessment exercises. About half of the recommended articles were published in the top 10% most highly cited journals, although three quarters of the top 1% most highly cited articles had not been recommended (**Waltman**; **Costas**, 2014). In terms of associations between *F1000* scores and citation indicators, the number of *F1000* recommendations that publications received significantly correlated with their citations (Pearson r=0.26) and journal citation scores (Pearson r=0.34). Similar low correlations were found between both *F1000* maximum recommendation scores and weighted numbers of recommendations with citation counts and journal citation scores. The low correlations confirm that recommendations and citations probably reflect different types of impact to some extent.

In summary, *F1000* is valuable for its expert ratings of articles that may identify impacts that do not necessarily attract citations, such as utility for clinical practice. It is not clear yet, however, whether the ratings are biased by perceptions of journal Impact Factors. Moreover, the coverage of *F1000* is restricted to Biomedical Science and is very low there. It is also not clear that any similar system would be financially viable for any other research fields.

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3. *Mendeley* and other online reference managers

One method to capture publication usage evidence from social media tools is to count bookmarks in online reference management software, such as *Mendeley* (**Henning**; **Reichelt**, 2008), *CiteULike* (**Bogers**; **Van Den Bosch**, 2008), *Zotero* (**Ritterbush**, 2007), *Bibsonomy* (**Borrego**; **Fry**, 2012), and *Connotea* (**Hull**; **Pettifer**; **Kell**, 2008). These websites allow users to register for free and then enter information about publications of interest. They then help users to create reference lists from their saved publication information and share their libraries of reference information with others. Although these sites may have social features, a survey of *Mendeley* users suggested that they are not frequently used (**Jeng**; **He**; **Jiang**, 2015).

The assumption behind counting users bookmarking a publication and then using this count as a research indicator is that the users are likely to use the articles for their research, and perhaps cite them later, or use them in other academic activities (teaching or lectures). This is supported by evidence from a survey of *Mendeley* users that found, for example, that except in the arts and humanities, most users had already read or stated that they would read most of the articles that they had bookmarked (**Mohammadi**, 2014; **Mohammadi**; **Thelwall**; **Kousha**, in press). After individual users have bookmarked articles in *Mendeley* the number of bookmarks for each article in the system can be automatically downloaded with the *Mendeley* API and exploited as usage information. *Mendeley* seems to be the most attractive tool for altmetric data because it is relatively easy to automatically extract bookmark counts from the *Mendeley* API, its data seems to be high quality (see below), and it seems to have at least as many users as other reference managers (see **Li**; **Thelwall**; **Giustini**, 2012). *Mendeley* bookmarks positively and moderately correlate with counts of citations to published journal articles in many different research fields, as discussed in detail below (see also: **Bar-Ilan** *et al.*, 2012).

Early investigations of *Mendeley* analysed individual journals. An analysis of papers published in *Nature* (793) and *Science* (820) in 2007 found significant Spearman correlations between *Mendeley* bookmark counts and *WoS* citation counts (0.559 and 0.540) and *Google Scholar* citation counts (0.592 and 0.603) for both journals (**Li**; **Thelwall**; **Giustini**, 2012). There were also significant, but lower (0.304, 0.396) correlations between *CiteULike* bookmarks and citations, perhaps because 93% of the articles had at least one bookmark in *Mendeley* in comparison to 60% for *CiteULike*. Based upon a sample of over 24,000 articles in seven journals from the open-access publisher *Public Library of Science* (*PLoS*), 80% had at least one *Mendeley* bookmark, in comparison to 30% in *CiteULike*. For articles published in *PLoS one*, *PLoS biology* and *PLoS pathogens* there were moderate Spearman correlations (0.3, 0.4 and 0.4 respectively) between *Mendeley* bookmarks and *Web of Science* citations (**Priem**; **Piwowar**; **Hemminger**, 2012). Similarly, for 1,706 *PLoS biology* research articles (published up to May 20, 2013) 95% and 65% had *Mendeley* and *CiteULike* bookmarks (**Fenner**, 2013). All of these studies have the limitation that they are restricted to high profile journals, however. A different approach compared indicators derived from *arXiv*, *Scopus* and *Mendeley* for publications from a sample of 100 European astrophysicists (**Bar-Ilan**, 2014). The *Mendeley* readership counts were much lower than the *Scopus* citations (e.g., 90 readers compared with 1,168 *Scopus* citations) and the overlap between *Scopus* and *Mendeley* was about 22%. In contrast with previous studies, a much lower Spearman correlation was found between *Scopus* citations and *Mendeley* readership counts for articles (r=0.227), perhaps because many physicists do not use *Mendeley*.

Within Science and Medicine, several studies have analysed entire subject areas in order to assess the value of *Mendeley*. A study of 1,397 journal articles from *F1000* in Genomics and Genetics found strong and statistically significant correlations between *Mendeley* bookmarks and *WoS* / *Scopus* / *Google Scholar* citations (0.686, 0.682 and 0.694, respectively) which were larger than the correlations between *CiteULike* bookmarks and citation counts (0.354, 0.346 and 0.377, respectively) (**Li**; **Thelwall**, 2012). In Engineering, Chemistry and Physics, about 30% of *WoS* articles published in 2008 had at least one *Mendeley* bookmark, in comparison to 60% for Clinical medicine (**Mohammadi**, **Thelwall**, **Haustein**; **Larivière**, 2015), showing that there are substantial disciplinary differences in the coverage (and presumably users) of *Mendeley*. Correlations between citations and *Mendeley* bookmarks were moderate and higher in Clinical medicine (r=0.463) than in Chemistry (r=0.369), Engineering and Technology (r=0.327) and Physics (r=0.308). Within Medicine, *Mendeley* readers correlate strongly with citation counts in most subfields, with an average Spearman coefficient of 0.7 and with 78% of articles having one or more readers (**Thelwall**; **Wilson**, in press). This article also confirmed that reader counts are highly skewed, conforming to a hooked power law or lognormal distribution. In summary, *Mendeley*'s coverage of Science and Medicine seems to be generally high, and bookmark counts seem to correlate moderately with citation counts in Science and strongly in Medicine.

In the Social Sciences and Humanities, *Mendeley*'s coverage is lower than in the Sciences. The largest-scale investigation of *Mendeley* so far analysed *WoS* articles published in 2008 in five Social Sciences (n=62,647) and in five Humanities (n=14,640) disciplines, finding low and medium Spearman correlations between *Mendeley* bookmarks and citation counts (**Mohammadi**; **Thelwall**, 2014). About 58% and 28% of the *WoS* articles were in the *Mendeley* catalogue in the Social Sciences and Humanities, respectively, suggesting that *Mendeley*'s coverage of the academic literature may not be as high outside of Science as was found for Science in previous studies. The correlation was higher in Business; Economics (0.573), Information Science; Library Science (0.535) and Psychology (0.514) than in Religion (0.363), Philosophy (0.366) and Literature (0.403), perhaps because citations are less common, less important and used for different purposes in the Humanities. Moderate correlations (*WoS* 0.458, *Scopus* 0.502, *Google Scholar* 0.519) and extensive *Mendeley* coverage (97%) have been found for articles published in the *Journal of the American Society for Information Science and Technology* (*Jasist*) during 2001-2011 (**Bar-Ilan**, 2012), probably because of its disciplinary focus on libraries and information management. Edited books and monographs are important in the Humanities and *Mendeley* has limited coverage of them. Based on a sample of 310 journal articles in 2012 in Humanities from 30 Swedish universities, *Mendeley* had greater coverage (61%) than other altmetric data sources and on average articles had 3.4 readers in *Mendeley* compared with 2.4 *Google Scholar* citations (**Hammarfelt**, 2014), and so *Mendeley*'s coverage of the Humanities, whilst low, may still be higher than comparable sources.

The results above are consistent with the findings of a large random sample of 20,000 *WoS*-indexed publications across different fields 2005-2011, which found that 63% had at least one *Mendeley* bookmark and this was a bit higher for articles (66%) (**Zahedi**, **Costas**; **Wouters**, 2014). The overall Spearman correlation between *Mendeley* bookmarks and *WoS* citations was moderate (r=0.49).

Some of the above results may underestimate the value of *Mendeley* through using incomplete methods to identify the number of readers for articles. The best method currently seems to be to combine DOI searches with traditional queries (**Zahedi**; **Haustein**; **Bowman**, 2014).

An analysis of articles with many *Mendeley* readers but few *Scopus*-indexed citations can shed light on the core differences between them. It found both technical and legitimate reasons (**Thelwall**, in press). The legitimate reasons included articles being primarily of interest to non-publishing readers, and this points to the potential for *Mendeley* to reflect non-academic uses of research in some cases. Conversely, articles may have relatively many *Scopus*-indexed citations if their readers are unlikely to use, or be able to access, *Mendeley*. This article also found some but not strong evidence that *Mendeley* could reflect specifically educational impacts.

Mendeley records some information about users and reports this with bookmark counts in its API (although only the three most popular categories are revealed on its website). This shows, for example, the countries of origin and disciplines of readers. One of these categories, "Other professionals," could be used, in theory, to identify non-academic users of research but this category is rare, suggesting that *Mendeley* is mainly used inside academia (**Mohammadi**; **Thelwall**; **Haustein**; **Larivière**, 2015), although apparently rarely by senior researchers (**Mas-Bleda**; **Thelwall**; **Kousha**; **Aguillo**, 2014). It includes a substantial minority of non-publishing members, however, such as undergraduates and master's students. Perhaps because of this, articles that are useful for teaching tend to attract readers that might not be researchers (**Bornmann**; **Haunschild**, 2015). User information can also be used to assess the nationality of (some) bookmarking users. From this information, it is clear that some countries, including China, are underrepresented compared to the population of academic authors (**Haunschild**; **Stefaner**; **Bornmann**, 2015).

An important property of *Mendeley* is timeliness: *Mendeley* bookmarks should appear before citations because citing authors would presumably bookmark referenced articles in *Mendeley* before completing their research and submitting an article for publication. Hence a *Mendeley* bookmark might appear about a year before the citation is indexed. In support of this, there is some evidence of the value of *Mendeley* for early impact indicators in one field (**Maflahi**; **Thelwall**, in press). A larger scale study analysed 50 different subject areas, with similar findings. Within the first year after publication articles can be expected to have more *Mendeley* readers than citations, with the numbers of citations overtaking the number of readers after several years, depending on the discipline (**Thelwall**; **Sud**, in press). Primarily due to the low numbers of citations in the first few years after publication, correlations between readers and citations are normally low in the year of publication but increase to a stable maximum after about five years. This suggests that *Mendeley* reader counts may be a better source of impact evidence than are citation counts in the first few years after publication. Moreover, *Mendeley* reader counts seem to be better for the early identification of highly cited articles than the citation impact of the publishing journal, as reflected in its average citations per paper (**Zahedi**; **Costas**; **Wouters**, 2015).

The most direct evidence of the value of *Mendeley* readership counts is their correlation with peer review judgments of academic articles. Only one study has reported this data so far, using articles submitted for the UK *Research Excellence Framework* (*REF*) 2014 and their evaluations on a five point scale (0, 1*, 2*, 3*, 4*; although most were 3* or 4*) by 36 panels of disciplinary experts (*Hefce*, 2015). These articles are pre-selected by the submitting academics to be their best outputs and so they are an artificially high quality sample, which reduces the size of the correlation with peer review scores. For the subset of these articles published in 2008, the correlations between *Mendeley* reader counts and peer review judgements varied from 0.441 for Clinical medicine (n=2770) to -0.073 for Music, Drama, Dance and Performing arts (n=90). Overall, the correlations tended to be highest in the Life Sciences and Medicine and were negative in only three areas. This gives the first and only concrete evidence that *Mendeley* reader counts are indicators (but not measures or metrics) of publication quality, at least in some fields. The report data also suggested that *Mendeley* readers may be better than citation counts as quality indicators in the immediate year after publication of an article.

> *Mendeley* readership bookmarks seem to be the most promising social media metric

Overall, *Mendeley* readership bookmarks seem to be the most promising social media metric because of the ease of automatic data collection, the wide coverage of articles (a majority of recent articles are bookmarked in *Mendeley* in most fields checked so far, except for the Humanities) and evidence of low, moderate and strong correlations between readership bookmarks and citation counts. Moreover, *Mendeley* may give earlier evidence of impact than can citation counts. Nevertheless, this social media is not subject to quality control, could be spammed by asking other users to bookmark articles or to create fake *Mendeley* profiles, and does not seem to be used much in the Humanities. *Mendeley* also has international biases due to differing national levels of uptake of the service (**Haunschild**; **Stefaner**; **Bornmann**, 2015) and the tendency for people to bookmark articles with at least one author from their own country (**Thelwall**; **Maflahi**, 2015). In addition, *Mendeley* seems to reflect a similar kind of impact to that of citation counts (rather than reflecting educational impact or other wider research impacts) and so it is not clear that it would be useful additional information to supplement citation counts, except perhaps for indications of early impact for recently-published articles. *Mendeley* can also provide information about readers of publications in terms of their fields, countries and academic positions, which may be useful for more detailed evaluations.

4. *Twitter* and microblog citations

Twitter is one of the most popular web social network and microblogging services, allowing free short instant posts of up to 140 characters. A study of tweet citations to *PubMed* articles from *altmetric.com* found that they were more numerous than ten other social media outputs, including *Facebook* wall posts, *Google+* posts and blog citations (**Thelwall**; **Haustein**; **Larivière**; **Sugimoto**, 2013) and another did the same for articles tweeted with a DOI or other identifiable ID July-December, 2011, finding *Twitter* again to have the wider coverage (13% of a multidisciplinary sample of *WoS* articles) than the other social media metrics considered (**Costas**; **Zahedi**; **Wouters**, in press). Hence, tweets are particularly promising from a purely numerical point of view. *Twitter* also seems to have greater coverage of academic articles than does *Mendeley* (**Robinson-García**; **Torres-Salinas**; **Zahedi**; **Costas**, 2014).

Several studies of academic-related *Twitter* use have surveyed researchers (e.g., **Letierce**; **Passant**; **Decker**; **Breslin**, 2010; **Letierce**; **Passant**; **Breslin**; **Decker**, 2010) or analysed the content of tweets sent during conferences or meetings (e.g., **Ross**; **Terras**; **Warwick**; **Welsh**, 2010; **Desai** *et al.*, 2012; **McKendrick**; **Cumming**; **Lee**, 2012; **Hawkins**; **Duszak**; **Rawson**, 2014; **Neill** *et al.*, 2014; **Wen**; **Lin-Ru**; **Trattner**; **Parra**, 2014 see also **Weller**; **Dröge**; **Puschmann**, 2011). In brief, these studies indicate that *Twitter* is used to share basic information about conference talks, discussions and academic papers. There are disciplinary differences in how researchers use *Twitter*, however. For instance, conversations in tweets in one small study were more common in Digital Humanities and Cognitive Science (both 38%), Astrophysics (31%) and History of Science than in Biochemistry and Economics (both 16%). In Biochemistry, 42% of tweets are retweets, whereas in nine other fields the proportion varied from 18% in Social Network Analysis to 33% in Sociology (**Holmberg**; **Thelwall**, 2014). Whilst these tweets could theoretically be read by any *Twitter* user, the posting of such content by academics is not evidence of successfully attracting a wider audience for research.

Assuming that counts of tweets sent by researchers or academics that mention a scholarly work may be an indication of intellectual impact of the tweeted publications, several investigations have examined tweets as a potential source of social media metrics. **Priem** and **Costello** (2010) interviewed 28 academics and coded 2,300 tweets with hyperlinks from them, finding that about 6% were *Twitter* citations. Whilst half of the *Twitter* citations directly cited a resource, articles were also cited indirectly, such as via discussions. More promisingly, however, tweet citations were much faster to appear than conventional citations, with 40% occurring within a week of publication. A study of 37 astrophysicists on *Twitter* found that those who published more tended to tweet less and that the text of tweets was not similar to the text in the abstracts of the publications tweeted about (**Haustein**; **Bowman**; **Holmberg**; **Peters**; **Larivière**, 2014).

Eysenbach (2011) compared over 1,570 tweets with links to 55 articles published in his *Journal of medical internet research* (2009-2010) against subsequent citation counts from *Scopus* and *Google Scholar* 17 to 29 months later. Highly tweeted papers were 11 times more likely to be highly cited than were their less-tweeted counterparts and tweets correlated with later citations moderately well. A study of 4,600 articles submitted to the *arXiv.org* preprints archive during a half-year period also found significant moderate correlations between *Twitter* mentions and article citations (Pearson r=0.452) and *arXiv* downloads (Pearson r=0.505). *Twitter* mentions had shorter delays than did *arXiv* downloads for predicting citations (**Shuai**; **Pepe**; **Bollen**, 2012). This relatively high figure is probably misleading because the Pearson correlation is sensitive to skewed data, such as citation and tweet counts. For example, removing the top two tweeted articles reduced the correlation by 0.2 (**Shuai**; **Pepe**; **Bollen**, 2012). In contrast, another study found negative low Spearman correlations (Spearman r=-0.236) between tweets and citations to a set of *PubMed* articles from 2010 (**Thelwall**; **Haustein**; **Larivière**; **Sugimoto**, 2013; see also: **Haustein**; **Peters**; **Sugimoto**; **Thelwall**; **Larivière**, 2014; **Costas**; **Zahedi**; **Wouters**, in press). This was due to more recent articles having been tweeted more frequently (due to rapid growth in *Twitter* users at the time), whereas older articles had been cited more. This time effect was strong enough within individual years to create a negative correlation. Using more sensitive statistical methods designed to correct for all time biases, however, the same data was shown to contain a positive association between tweets and citations (**Thelwall**; **Haustein**; **Larivière**; **Sugimoto**, 2013). Another analysis of altmetric data, this time with articles tweeted with a DOI or other identifiable ID in July-December, 2011 found low positive Spearman correlations between tweet counts and the total number and field normalized number of citations of publications (Spearman 0.167 and 0.141, respectively) (**Costas**; **Zahedi**; **Wouters**, in press). This low positive correlation, in contrast to the small negative correlation for the previous study with similar data, may be due to the time span being half of a year rather than a year. Overall, however, it is clear that whilst tweets associate with citations, this association is very weak and is only evident for units of analysis below a year or specially designed non-correlation statistical measures.

Tweets about academic articles have been correlated with peer review judgments for articles submitted for the UK *REF* 2014 and their evaluations by 36 panels of disciplinary experts (*Hefce*, 2015). Surprisingly, the correlations between peer judgements and tweet counts were positive for a majority of the 35 panels with enough papers to assess, varying from 0.234 for Art and Design: History, Practice and Theory (n=130) to -0.073 for Music, Drama, Dance and Performing arts (n=90). The two areas of scholarship with correlations above 0.2 might be of particular public interest (Earth Systems and Environmental Sciences), for the first time suggesting that tweet counts could be relevant in academic fields with substantial public interest. This perhaps aligns with a finding that tweets are more common in the Social Sciences and Humanities than elsewhere (**Haustein**; **Costas**; **Larivière**, 2015). Nevertheless, the strongest correlation is quite weak, and it is possible that the correlations are inflated by gaming from institutions if academics or universities promoted their best *RAE* submissions on *Twitter*.

Information about who tweets academic articles and why is needed to give face validity to tweet counts as an academic impact indicator. A content analysis of 270 tweets linking to articles in four journals (*PLoS one*, *PNAS*, *Science*, and *Nature*), four digital libraries (*Wiley*, *ScienceDirect*, *Springer*, and *Jstor*) and two DOI URLs attempted to identify why articles were tweeted and whether there was evidence uptake outside of academia. The results found no evidence of this, with 83% of the tweets merely repeating an article title or a brief summary of it without giving any context that could be evidence of the type of impact that the articles had had. Only 4% of tweets were positive about the articles and none were critical, suggesting that tweet links to articles reflect the popularity or visibility of an article rather than a particular type of impact (**Thelwall**; **Tsou**; **Weingart**; **Holmberg**; **Haustein**, 2013). This may explain why editorials and news items attract relatively many tweets compared to other types of article (**Haustein**; **Costas**; **Larivière**, 2015). A study of accounts tweeting links to articles in four major general Science journals (e.g., *Nature*) found that they were mostly scientists (half had a PhD or were studying for one) active in fields related to the articles (**Tsou**; **Bowman**; **Ghazinejad**; **Sugimoto**, 2015). In partial contrast, three highly tweeted papers (two about health risks from radioactivity; one on human memory) in one study may have been mainly tweeted members of the public (**Haustein**; **Larivière**; **Thelwall**; **Amyot**; **Peters**, 2014).

> *Twitter* seems to be mainly used for information sharing between academics as well as for other types of informal scholarly communication

Overall, tweet citations are unlikely to be useful for impact evaluations of academic articles. Their biggest advantage is that tweet citations often appear within days of publication whereas the first citation may take years. Although *Twitter* is used by a wide section of the public outside of academia, no study yet has found much evidence of a substantial non-academic audience in *Twitter* for academic research. Overall, however, *Twitter* seems to be mainly used for information sharing between academics as well as for other types of informal scholarly communication. An international limitation of *Twitter* is that its uptake is not uniform across the globe and so its results will be biased against areas of research that are popular in countries that tend not to use it. For example, *Twitter* seems to be rarely used and sometimes blocked in China, with *Sina Weibo* being popular instead, and has also been blocked in Iran. In general, tweets correlate at a low positive level with citations if they are analysed over time periods of under 6 months, but this, together with the extensive use of *Twitter* for publicity and the ease with which tweets can be gamed, is probably not be enough for tweet counts to be a useful indicator, except perhaps for publishers' websites as indicators of early interest in an article or for identifying individual articles with very high levels of tweeting (**Adie**; **Roe**, 2013).

5. *Facebook* and *Google+* citations

Facebook wall posts and *Google+* posts seem to be similar to tweets in the way that they are used and the findings for *Twitter* probably also apply to citations and links from them too. Some studies using data from *altmetric.com* have confirmed that articles tend to be more highly cited if they are mentioned in *Facebook* or *Google+*, although they appear to be much less common than are tweets for academic articles (**Costas**; **Zahedi**; **Wouters**, in press; **Thelwall**; **Haustein**; **Larivière**; **Sugimoto**, 2013). *Facebook* data seems to be more difficult to collect systematically, however. As with *Twitter*, a limitation with using general social network sites is that their uptake varies internationally and some countries have their own popular sites, such as *VK* in Russia and in *Tencent Qzone* in China. Hence any impact data from *Facebook* and *Google+* would be internationally biased.

6. Academic social network sites: Usage and follower counts

The academic social network sites *ResearchGate.net* and *Academia.edu* help scholars to disseminate research and to interact with other academics but also provide some usage and impact-related statistics. However, most scholars probably do not use these sites or use them but not to systematically record their publications in them. For instance, a survey of 100 researchers in an Indian university showed that under a quarter used *ResearchGate* to find out about others' research (**Chakraborty**, 2012) and an investigation of 1,500 highly cited scientists working at European institutions revealed that few had profiles in major social network sites (e.g., a quarter had *LinkedIn* profiles and even fewer had Academia profiles) (**Mas-Bleda**; **Thelwall**; **Kousha**; **Aguillo**, 2014).

6.1. *ResearchGate*

ResearchGate.net is a free social network site for academics, researchers and students that claims over seven million members and 80 million publications by July 2015:
https://www.ResearchGate.net/press

Each member can report information about themselves and upload or list their publications, whether peer-reviewed or not. Its uptake is not comprehensive, however. For example, out of over 2,090 teaching or research staff in *Nicolaus Copernicus University* in Poland, about 14% had *ResearchGate* profiles (**Stachowiak**, 2014). For registered publications, *ResearchGate* provides the number of full-text downloads, views and citations (based on information in its database). It also provides some information for individual members, such as the total number of publication views and downloads, as well as how many followers they have (**Kadriu**, 2013). Rankings of institutions based on *ResearchGate* statistics correlate moderately well with other rankings of academic institutions (e.g., *The Times Higher Education Ranking* or *The CWTS Leiden Ranking*), suggesting that *ResearchGate* use broadly reflects traditional academic capital at the institutional level (**Thelwall**; **Kousha**, 2014).

ResearchGate views, downloads and citation counts could be potentially useful for the assessment of individual articles when authors register on *ResearchGate* and upload their articles to their profiles, especially prior to formal publication, but these statistics can be easily manipulated or spammed (e.g., usage statistics may be inflated by authors or robots). Moreover, it is difficult to automatically gather *ResearchGate* statistics because it does not have an API and it is probably used only by a minority of academics and so it is likely to have weak coverage of the academic literature. In terms of the wider influence of academics, however, *ResearchGate*'s use for academic social networks may be valuable to assess the social impact of scholars within academia based on followers, although there is no evidence yet that this would be effective and the partial usage of *ResearchGate* suggests that it might be problematic.

6.2. *Academia.edu*

Like *ResearchGate*, *Academia.edu* has facilities for sharing information about publications and their full text. *Academia.edu* claimed over 23 million academic members and over 6.2 million papers by July 2015:
https://www.academia.edu/about

> *ResearchGate*'s use for academic social networks may be valuable to assess the social impact of scholars within academia based on followers

Academia.edu provides some usage statistics for individual papers and authors (aggregating the results for all of their papers) as well as their follower counts. A study of user profiles in philosophy departments found that faculty members tend to attract more profile views than did students but female philosophers did not attract as many profile views as their male counterparts, suggesting that academic capital drives philosophy usage of the site more than does friendship and networking (**Thelwall**; **Kousha**, 2014a). Conventional bibliometric indicators (h-index and citations) did not correlate significantly with any *Academia.edu* metrics (profile views and document views) for philosophers, perhaps because more senior academics use the site less extensively or because of the range informal scholarly activities that cannot be measured by bibliometric methods. Hence it is not clear whether *Academia.edu* could provide useful indicators to help in evaluations of individual scholars, and no evidence has been gathered yet to evaluate the value of *Academia.edu* usage statistics for individual articles.

The top 15 broad research interests registered by *Academia.edu* users are related to the humanities and Social Sciences (excluding Computer Science in third), indicating that it is heavily used by academics in these fields and suggesting that its greatest potential is outside of Science (**Thelwall**; **Kousha**, 2014a, p. 731).

Usage statistics from *Academia.edu* seem to have the same potentials and spam limitations as those from *ResearchGate*, especially perhaps in the humanities, where bibliometric indicators probably do not reflect the usage of research by students or other academics who do not usually publish journal articles. Nevertheless, there is little hard evidence of the value of the indicators that can be derived from its data and, like *ResearchGate*, it does not have an API and therefore data collection is not simple.

7. Summary

There is empirical evidence that a wide range of social media metrics for scholars or their outputs are related to scholarly activities in some way because they correlate positively and significantly with citation counts. In many cases these metrics can also be harvested on a large scale in an automated way with a high degree of accuracy. Nevertheless, most are easy to game or spam (e.g., see **Dullaart**, 2014) and nearly all are susceptible to spam and unwanted content to some extent. Moreover, none clearly reflect types of impact that are different from that of traditional citations, and so their main advantage is timeliness. Of all the indicators reviewed in this article series, only *Google Patents* citations and clinical guideline citations clearly reflect wider societal impact and no social media metrics do. In addition, many are too rare to help to distinguish between the impacts of typical publications, and international and demographic biases in their users undermine their utility as indicators. Overall, then, despite the considerable body of mostly positive empirical evidence reviewed above, with some exceptions social media metrics are not useful to capture wider social impact and are not robust enough to be used in formal evaluations in which it is in the interest of stakeholders to manipulate the results. In other words, social media metrics are not suitable as a "control" management tool (**Wouters**; **Costas**, 2012). Even if no manipulation took place, which seems unlikely, the results would be suspected to be affected by manipulation and in the worst case the results would be extensively manipulated and scientists would waste their time and money on this manipulation.

In case of spamming by academics (which is a completely different type of offence to research fraud, see: **Steen**, 2011) may be thought to be unlikely, *RePEc* (*Research Papers in Economics*) archive managers believe that many authors try to deliberately manipulate views-based or downloads-based public article rankings, despite the lack of direct financial rewards derived from them. For example, *RePEc* abstract views and download statistics, "are subject to manipulation, as one could repeatedly download a paper to increase its count. For this reason, various information about the abstract viewer or downloader are recorded to prevent repeat counts" (**Zimmerman**, 2013, p. 254). More seriously, "various checks and balances are implemented to recognize abnormal behaviour, mostly from authors trying to manipulate the statistics. Obviously, these safeguards are not revealed here, but let it be known that a human eye has a final look at the server logs in these cases and that several authors have been caught" (**Zimmerman**, 2013, p. 254). Hence, *RePEc* managers apparently believe that transparent automated manipulation detection would be ineffective and that human checking is necessary even with secret manipulation detection algorithms. For academia more generally, at a meeting in November 2014 of *UK Research Excellence Framework* (*REF*) 2014 panel members there was no dissention against the view, expressed several times, that gaming was common in *REF* submissions, which direct a substantial fraction of UK government research funding.

The most serious of the negative conclusions above about gaming relate to evaluations with stakeholders, such as those used to decide funding allocations (**Wilsdon** *et al.*, 2015). For evaluations without significant stakeholders, such as research funders' programme evaluations (**Dinsmore**; **Allen**; **Dolby**, 2014), or formative evaluations by researchers or research managers, all of the alternative metrics may be useful and so the choice of alternative metric should take into account practical considerations. The main advantage of altmetrics in this context is timeliness and *Mendeley* seems to be the most robust source of early evidence of scholarly impact. For example, *Mendeley* reader count data may allow funding programs to be evaluated before they could be evaluated with citation analysis and the evidence so far suggests that *Mendeley* reader counts are more useful than are citation counts (informal) evaluations of research within the first few years of publication. A different social media metric should only be chosen if the context of the informal evaluation suggests that the end users for research, or any particular target group for the evaluation, are unlikely to use *Mendeley*.

Another practical use of social media metrics is within publisher websites. Here, they have the advantage of timeliness and *Twitter* seems to be the quickest and hence perhaps the most useful. Nevertheless, the approach of *Altmetric.com* of providing a raft of metrics through a simple interface may well be the optimal solution because researchers also search for older articles. Speed is important for publishers because of academics that browse recent issues of journals for current awareness purposes. If social media metrics can help them to notice articles that are already attracting attention then they will serve a useful purpose. In this context spam and gaming seem to be less important because someone using a publisher website presumably intend to read the articles that they are looking for and hence will make the final evaluation about the usefulness of an article.

A further practical use of social media metrics is to investigate scholarly communication itself for theoretical research that seeks to understand the workings of science, such as the way in which scholars or areas of scholarship interact. In this case, the advantage of timeliness may be useful in some cases. The richer data of *Mendeley* is a substantial benefit here too, because its user information (e.g., particularly academic rank, but also subject area and country, although the latter two are also available from author information in citation analysis) can provide a particular benefit. *Twitter*, *Facebook* and *Google+* data may also be useful for investigations into how academics and/or publishers attempt to publicise research and which strategies are the most successful.

In terms of future research, as previously recommended (**Sud**; **Thelwall**, 2014), statistical correlations with citation counts are a logical first step for evaluating alternative metrics, and these should be followed up with additional qualitative evidence about the context of the mentions in social media, such as *Twitter*, that contain context with the citations but excluding *Mendeley* bookmarks because these do not give any reasons for a bookmark. Qualitative and quantitative evidence is also needed about the users of these services, such as through questionnaires and interviews, in order to help assess the extent to which indicators reflect different practices to citation. International comparisons and evaluations for different types of countries (e.g., **Araújo**; **Murakami**; **De Lara**; **Fausto**, 2015) are also important to help understand national differences and limitations. Pragmatic evaluations of the use of social media metrics from the major providers (e.g., **Jobmann**; **Hoffmann**; **Künne**; **Peters**; **Schmitz**; **Wollnik-Korn**, 2014; **Robinson-García**; **Torres-Salinas**; **Zahedi**; **Costas**, 2014) in the context of literature searching and current awareness are also needed to validate this approach. Finally, future research is needed to apply social media metrics in studies that map or seek to understand the workings of science. These studies will need to not just apply the social media metrics but also to evaluate the extent to which they give valid information in each context in which they are applied.

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http://www.hefce.ac.uk/media/HEFCE,2014/Content/Pubs/Independentresearch/2015/The,Metric,Tide/2015_metrictideS1.pdf
commissioned by the *Higher Education Funding Council for England* (*Hefce*) as part of the independent review of the role of metrics in research assessment that began in 2014:
http://www.hefce.ac.uk/rsrch/metrics

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