Who Reads Research Articles? An Altmetrics Analysis of Mendeley User Categories[1]

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Abstract

Little detailed information is known about who reads research articles and the contexts in which research articles are read. Using data about people who register in Mendeley as readers of articles, this paper explores different types of users of Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry papers inside and outside academia. The majority of readers for all disciplines were PhD students, postgraduates and postdocs but other types of academics were also represented. In addition, many Clinical Medicine papers were read by medical professionals. The highest correlations between citations and Mendeley readership counts were found for types of users that often authored academic papers, except for associate professors in some sub-disciplines. This suggests that Mendeley readership can reflect usage similar to traditional citation impact, if the data is restricted to readers who are also authors, without the delay of impact measured by citation counts. At the same time, Mendeley statistics can also reveal the hidden impact of some research papers, such as educational value for non-author users inside academia or the impact of research papers on practice for readers outside academia.

Keyword: altmetrics, Mendeley, research impact, readership analysis, social bookmarking

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Introduction

Since the 1960s, citations have been widely used in research evaluation and monitoring. However, it is acknowledged that they alone cannot capture the full spectrum of research impact (MacRoberts & MacRoberts, 1989; Kostoff, 1998). For example, uncited publications may still be useful (Bornmann & Marx, in press) partly because many non-author professionals also read research articles (Price & Gürsey, 1975; Tenopir & King, 2000). For instance, practitioners, undergraduate students (Nicholas et al., 2005), the public (Kurtz & Bollen, 2010) and lecturers use research publications for purposes such as teaching (Kousha & Thelwall, 2008) or professional activities (Schloegl & Stock, 2004), including medical practice (Bennett, Casebeer, Kristofco, & Strasser, 2004). Therefore, it is clear that the impacts of research can go beyond knowledge advancement within science, and hence the influence of research publications in social, economic, cultural and environmental contexts needs to be identified (Bornmann, 2012; Thelwall, 2012) in research evaluation. In the same way, the Higher Education Funding Council for England (HEFCE), in the new Research Excellence Framework (REF) will consider all types of research impact outside academia (HEFCE, 2011). Therefore, multiple indicators are needed (Martin, 1996) to measure the wider influence of research publications. Measures derived from usage data have been suggested (Bollen, Van De Sompel, Hagberg, & Chute, 2009) to capture broader research impact but due to a lack of information about users of academic publications (Bollen & Sompel, 2008; Haustein & Siebenlist, 2012) systematic investigations into the contexts where research papers are used have not been conducted yet.

The engagement of researchers with different social web platforms provides a novel opportunity to measure different types of research impact (Cronin, 2013a) and can help to capture many kinds of non-scientific research impact (Bornmann, in press). In particular, social web mentions of scientific publications can be retrieved from various platforms and are often grouped under the umbrella term *altmetrics* (Priem, Piwowar, & Hemminger, 2012). The academic social web site Mendeley is a platform for users to manage scholarly references, create online profiles and communicate with peers. The numerous users (approx. 2.6 million in October 2013), large database, and open Applications Programming Interface (API) of Mendeley are particularly useful for compiling usage indicators. In particular, the fact that Mendeley provides the top 3 in terms of "academic status" of readers per document makes it possible to identify the users of research publications by different types of occupations and academic titles.

The first gap that this research tries to fill is to discover how diverse the readers of scholarly papers are in Mendeley. Although several studies have found correlations between Mendeley readership counts and citations (Li, Thelwall, & Giustini, 2012; Bar-Ilan, 2012; Mohammadi & Thelwall, in press), the extent to which Mendeley readership counts actually measure readership, and in how far they capture the same or a different impact than citations is still not known. Thus, the current study aims to fill this gap by analysing the effect of academic status on the correlations between citations and Mendeley readership counts.

Literature review

Social media and scientific publications

Informetrics is the study of any form of information with quantitative approaches (Tague-Sutcliffe, 1992) including bibliometrics, scientometrics and citation analysis (Egghe & Rousseau, 1990). Cybermetrics, on the other hand, is the study of electronic information on the internet, using bibliometric methods (Björneborn, 2004). In the late 1990s, the web was suggested to be a medium through which the diverse impacts of scholars could be identified (Cronin, Snyder, Rosenbaum, Martinson, & Callahan, 1998). As a result of this and other observations about the potential of the web for bibliometrics (e.g., Almind & Ingwersen, 1997), the new area of webometrics emerged a sub-area of cybermetrics and informetrics for the study of web-based phenomena drawing upon bibliometric methods (Björneborn & Ingwersen, 2004). Recently, with the advent of the social web, the new area of altmetrics began. Altmetrics focuses on social web sites like Twitter, blogs, Wikipedia, Mendeley and other social bookmarking tools and uses open APIs for data gathering (Priem, Taraborelli, Groth, & Neylon, 2011). Like the web, social web platforms provide new opportunities to measure scholarly communication (Priem, 2013) in both formal and informal contexts (Cronin, 2013a). Rousseau and Ye (2013, p. 3289) believe that although the idea behind altmetrics is valuable, the term is not appropriate. They suggested “influmetrics” instead, as more explicitly a subdivision of webometrics. Similarly, Cronin (2013b, p.1523) argued that “complementary” can be a better term rather than alternative in this context.

Early altmetrics research characterised social media data and its appropriateness for research assessment. Social reference managers and social bookmarking tools such as Mendeley, CiteUlike, and BibSonomy provide facilities for users to save, manage and share scientific literature online. In addition, when users bookmark or save a record in their own social web profile then a reader count or bookmark will be recorded on the website. These social platforms thus provide opportunities to trace the global usage of scientific publications (Haustein et al., 2010). Some studies have used reference managers and social bookmarking websites to generate altmetrics. For example, several bookmarking-based metrics and some traditional indicators have been compared for assessing physics journals (Haustein & Siebenlist, 2011).

Priem, Piwowar and Hemminger (2012) explored a large sample of papers published by the Public Library of Science (PLoS). Around 80% of the PLoS articles were covered by Mendeley while 31% and 10% of these papers were bookmarked on CiteULike and Delicious, respectively, although it is not completely fair to compare statistics between the sites because they are used and record information in different ways. Around 10% to 12% of the sample were tweeted or mentioned on Facebook and less than 10% of the papers were cited in blogs or reviewed by Faculty of 1000 (F1000, now F1000Prime), a post-publication review site for biomedical papers. Similarly, previous studies have reported that the coverage of Mendeley is more extensive than that of CiteULike for a sample of articles published in

Science and Nature (Li et al., 2012) with similar results being found for publications in the field of bibliometrics (Haustein et al., 2013). It has also been reported that Mendeley had the highest coverage among other altmetrics resources for 20,000 random publications indexed in WoS (Zahedi, Costsas, & Wouters, 2013). Furthermore, Mohammadi and Thelwall (in press) found that 44% of Social Science articles and 13% of the Humanities papers from WoS in the year 2008 were covered by Mendeley. In contrast, analysing the entire F1000 database, Waltman and Costas (in press) discovered that as few as 2% of biomedicine articles were reviewed by F1000 experts. Again, the figures are not directly comparable because F1000 articles are reviewed whereas Mendeley articles are only recorded in the site. A large-scale study of PubMed articles in 11 social media resources (excluding Mendeley) reported that less than 20% of the papers were covered by most of the resources (Thelwall, Haustein, Larivière, & Sugimoto, 2013), with Twitter having the most extensive coverage at less than 10% for 2010 to 2012 PubMed articles and reviews (Haustein, Peters, Sugimoto, Thelwall, & Larivière, in press). In another large-scale multidisciplinary study, Costas, Zahedi, and Wouters, (2014) discovered that research papers had more coverage (13.3%) in Twitter than in several other social websites, including Facebook walls, blogs, Twitter, Google+ and News outlets. A later Mendeley analysis of the same set of 1.4 million PubMed papers reports that 66% had at least one Mendeley reader (Haustein et al., submitted). Results of a survey of bibliometricians reported that most of them had LinkedIn profiles (68%) and around half had Twitter accounts while 20% were users of Academia.edu, Mendeley, and ResearchGate (Haustein et al., 2013).

For research evaluation purposes, the value of different social web data should be validated. As a result, several studies have assessed the value of altmetrics-based indicators by comparing them with traditional metrics. One study, for example, found that tweet mentions of articles in a single open access online medical informatics journal could predict future citations (Eysenbach, 2011). Similarly, Shema, Bar-Ilan, and Thelwall (in press) reported that papers mentioned in science blogs received more citations later. Moderate correlations between F1000 scores and citations have also been reported (Waltman & Costas, 2013; Li & Thelwall, 2012) and F1000 scores are able to recognize the suitability of medical papers for clinical practice better than citations (Mohammadi & Thelwall, 2013). Finding no correlations between indicators derived from the academic social web site Academia.edu and bibliometric indicators, Thelwall and Kousha (in press) concluded that the informal scholarly communications in Academia.edu probably do not reflect traditional academic impact or prestige. Significant positive correlations between bookmarking data from CiteUlike and Mendeley and citations for a sample of articles published in Science and Nature provide evidence that bookmarking data is a promising source for research evaluation (Li et al., 2012). Nevertheless, based upon moderate correlations between Mendeley readership and citation counts for articles, Bar-Ilan (2012), Haustein et al. (2013), Haustein et al. (submitted) and Zahedi et al., (2013) all concluded that reading and citing are not similar scholarly activities. Li and Thelwall (2012) found positive correlations between Mendeley readership counts and bibliometric indicators for a sample of papers in the field of genomics and genetics. In two large-scale studies, medium positive correlations between Mendeley readership counts and citations were discovered for ten social science and humanities disciplines (Mohammadi & Thelwall, in press) and PubMed papers (Haustein et al., submitted). Both studies concluded that readership and citations reflect different types of research impact. To sum up, although many metrics derived from social media have been shown to correlate with bibliometric indicators for some specific sets of articles, it is not clear what kinds of research impact can be captured through the new indicators. Thus, new studies are needed to investigate which kinds of research influence can be reflected by altmetrics.

Professions and Science

The responsibilities of different professions and the status of academics can both affect the roles and contexts in which individuals use scholarly publications. For example, younger researchers read more papers (Tenopir, King, Spencer, & Wu, 2009) and also cite more resources in their publications (Pancheshnikov, 2007; Barnett & Fink, 2008; Larivière, Sugimoto, & Bergeron, 2013) in comparison to senior researchers. Niu and Hemminger (2012) found academic status to be an important issue in information seeking behaviour for faculty members, students and staff at five US universities. Interviewing scholars in the field of humanities, Ge (2010) revealed that PhD students and assistant professors use electronic resources more than associate professors and professors. Jamali and Nicholas (2006) found that PhD students browse electronic journals more than senior scholars in physics and astronomy. Catalano (2013) concluded that although Masters and PhD students both use the web for information searching, the latter believe that references provided by faculty members are more reliable. Whitmire (2002) argued that the information seeking behaviour of undergraduate students could be different from that of graduate students and faculty members but they can have similar information seeking behaviour because some students used resources suggested by faculty members more than other references (Korobili, Malliari, & Zapounidou, 2011).

Outside academia, practitioners and developers use research publications in their daily activities (Bollen & Van De Sompel, 2008) but the roles, tasks and the contexts in which they use information can affect their information seeking behaviours (Leckie, Pettigrew, & Sylvain, 1996). For example, a survey of non-author physicians in Canada discovered that 73% of the participants read journal articles (McAlister, Graham, Karr, & Laupacis, 1999). Another study reported that journal articles were the most useful publication type to fulfil the information needs of residents in a hospital (Schilling, Steiner, Lundahl, & Anderson, 2005). The information seeking habits of engineers in different fields (Ellis & Haugan., 1997; Kwasitsu, 2003; Freund, Toms, & Waterhouse, 2005; Taylor et al., 2010) have also been examined. Personal communications with colleagues, internal documents, journal articles, conference proceedings are all sources that engineers use to satisfy their information needs (Hertzum & Pejtersen, 2000). In principle, due to the practical nature of these professions they do not cite and may read less than university faculty members (Tenopir & King, 2000 cited by Tenopir, King, Clarke, Na, & Zhou, 2007). For instance, a survey of paediatricians at the University of Tennessee revealed that they read journal articles for updating their knowledge but read less than medical faculty members in the same organization (Tenopir et al., 2007). In summary, there is evidence that some professions outside academia read scientific articles and therefore the impact of these articles would not be fully reflected by citations − but little is known about how the impact of publications on different professions could be measured.

Research Questions

In order to holistically evaluate the use of research results, it is important to know who reads academic articles and why (Thelwall, 2012). These issues have not been systematically examined before, because of anonymity in usage data for electronic journals and because of the lack of usage data for print journals. Although some studies have explored article readership on a small scale (Niu & Hemminger, 2012; Hemminger, Lu, Vaughan, & Adams, 2007) there are no large-scale systematic studies of what types of people read scholarly articles. This study partly fills this gap from a quantitative perspective by analysing the statuses of readers (e.g., professors, PhD students, undergraduate students, non-academic users) of research articles for several disciplines in Mendeley. Additionally, the effect of users' occupations on correlations between Mendeley readership counts and citations investigated. The following research questions drive this study, focusing on several broad areas of science.

1. What are the common types of readers for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry research articles in Mendeley?
2. Does academic or professional status of readers in Mendeley affect the relationship between Mendeley readership counts and citation counts?

Research method

Data collection

The Web of Science (WoS) was chosen as the source of lists of articles in academic journals. The *Observatoire des sciences et des technologies* in-house version of the Thomson Reuters databases was used. All bibliographic information and citation data for WoS journal articles from 2008 was selected, excluding non-article document types, such as editorials and book reviews. The citation data comes from the *Science Citation Index Expanded (SCIE)*, the *Arts & Humanities Citation Index (AHCI)* and the *Social Science Citation Index (SSCI)* in December 2012. The year 2008 was chosen to allow all articles at least four years to receive citations. For defining the main research disciplines and sub-disciplines, the US National Science Foundation (NSF) classification was used. This classification is more suitable for this study than the WoS classifications because each journal is assigned to only one NSF research speciality or sub-discipline. The 22 most productive disciplines in terms of the number of publications in the year 2008 were selected for the study from the broad NSF categories of Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry (see Appendix 1). These disciplines include 44% of the journal articles from 2008 in the Thomson Reuters databases used.

In the next step, using the Mendeley API, Mendeley readership counts for each selected WoS article were automatically extracted with Webometric Analyst (lexiurl.wlv.ac.uk) relying on a query based on the last name of the first author, publication year and title of the article. Instead of relying on a document identifier such as DOI, which is often missing in the Mendeley entries, this method increases recall by relying on three main metadata elements. However, documents with at least one incorrect item of bibliographic information (e.g., author or year) were ignored to increase precision. As multiple copies of a paper could exist in Mendeley, duplicate records were identified and removed based on WoS unique IDs. Out of 480,979 WoS articles for all disciplines, 219,326 (45.6%) were found in Mendeley and 3,745 were duplicates. Removing duplicates reduced the overall readership count by 1.1% (see Table 4).

Mendeley coverage varied by discipline. Clinical Medicine articles had the highest coverage in Mendeley (71.6% had a Mendeley record, see Table 1), while in Physics, Chemistry and Engineering and Technology only about one third of the documents were saved in Mendeley. Mendeley records with zero readers in the Mendeley database were disregarded. These papers could have been added to Mendeley in several ways. For instance, Mendeley may automatically add all articles from specific publishers. Moreover, some journals administrators or researchers may add all their publications to Mendeley to publicise them. Detailed information for articles with zero readers is listed in Table 1.As shown in Table 1, 41.1% of the WoS articles had Mendeley readership statistics. All of the 197,848 of the WoS articles with Mendeley readership statistics from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry were selected for further analysis (see appendix, Table 4).

Table 1. Coverage of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley.

Discipline	Articles indexed by WoS in 2008	Unique WoS articles covered by Mendeley	Duplicate WoS records in Mendeley	Articles with readership statistics in Mendeley	Articles without readership statistics
Clinical Medicine	145,536	71.6%	1.5%	62.1%	9.5%
Engineering and Technology	109,390	34.8%	1.5%	32.6%	2.2%
Social Science	23,878	46.8%	4.8%	45.9%	0.9%
Physics	101,581	31.4%	1.2%	29.7%	1.8%
Chemistry	100,594	33.7%	1.7%	30.6%	3.1%
Total	480,979	45.6%	1.7%	41.1%	4.4%

Although the Mendeley API provides information related to the discipline, academic status and country of readers for each record, it only reports percentages rather than raw data and only gives information about the top three categories. For each article and each of the top three readers' occupations for that article, the percentage of readers with that occupation was multiplied by the total number of readers of the article and divided by 100 to obtain the estimated number of article readers from that occupation.

To understand how far the three most frequent statuses represented the entire readership of a document, the sum of the (up to) three status percentages was subtracted from the total readership counts to indicate the missing information per document. As shown in Table 2, academic status information was not available for 27% of the total readership counts due to the restrictions of the Mendeley API.

Table 2. Available and missing Mendeley user status information for readership counts for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry via the Mendeley API.

Discipline	Total readership counts	Readership counts with status information available via the API for the top 3 categories	Readership counts without status information
Clinical Medicine	699681	70.5%	29.4%
Engineering and Technology	324624	75.2%	24.7%
Social Science	140952	69.0%	31.1%
Physics	251071	76.5%	23.4%
Chemistry	231313	76.9%	24.3%
Total	1647641	73.1%	27.0%

Some of the 15 occupational categories reported by Mendeley are similar and were merged into a single category. For instance, postgraduate students and masters students were merged into a single postgraduate student category (see appendix, Table 5).

Results

Readers and occupations

Because Mendeley only reports reader counts for the top 3 occupational categories for each article and this biases the results so that they underestimate the percentages of categories which frequently do not belong to the top 3, results are also provided for documents where the top 3 categories made up 100% and at least 66% of all reader counts, respectively. As the actual unbiased percentage of readers per status cannot be exactly determined based on the data provided, the three values can thus be considered as estimates of actual values, where the true figure lies somewhere between the three values for each occupation.

Figure 1 shows that in all disciplines PhD students were the main Mendeley readers of articles in 2008 for all papers, papers with at least 66% and papers with 100% reader counts, although the percentages vary across different disciplines. Postgraduate students and Postdocs were the main readers after PhD students across different disciplines, as shown in Figure 1 and tables 5, 6 and 7. All of the professions are self-reported and it is possible that, for example, some of the people recorded as *Professor* might not be full professors. Moreover, people with other academic ranks, such as Reader or Lecturer in the UK, might not map themselves accurately to the most similar Mendeley category.

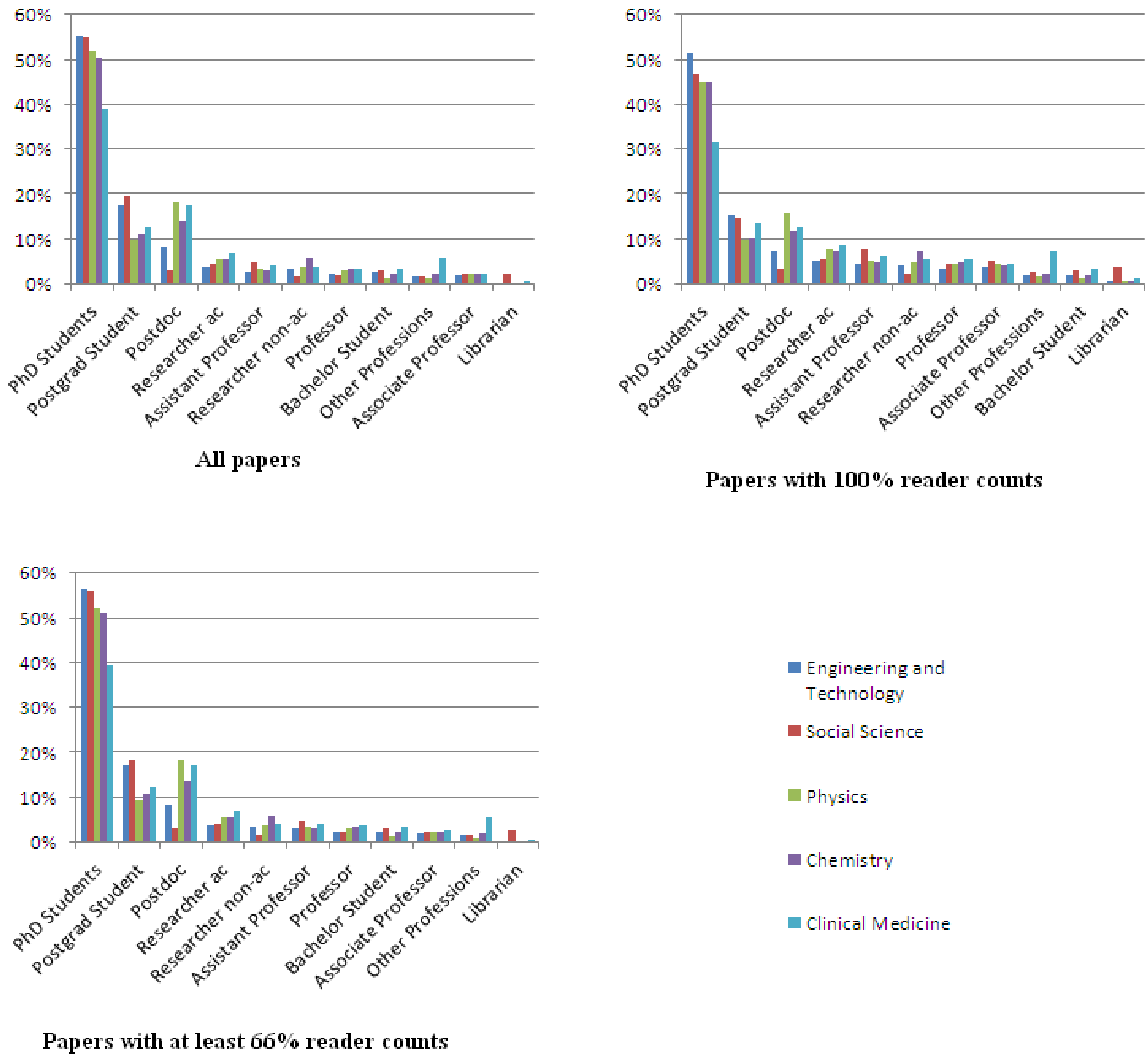

Figure 1. Readers of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley based on academic status for all papers, and for papers with 66% and 100% readership counts.

Among the selected disciplines, about 7.2%, 5.9% and 5.6% of the readers of Clinical Medicine papers were from the Other Professions category for papers with 100%, all papers and papers with 66% reader counts respectively.. Librarians were 3.7%, 2.8% and 2.5 % the reported readers of social sciences articles but were the least common readers of papers in other disciplines.

Correlations between Mendeley readership counts and citations based on users' occupations

Spearman correlations were calculated for each sub-discipline between Mendeley readership counts and citations for all articles with at least one reader in Mendeley. Values of r = 0.1+, 0.3+, and 0.5+ (whether positive or negative) were considered to be small, medium, and large, respectively (Cohen, 1988), with medium and large correlations considered to be substantial. There were statistically significant and substantial correlations between Mendeley readership counts and citations for all five disciplines (Table 3, see also Table 9). The correlations for all of the disciplines are similar but are highest in Clinical Medicine and Social Science (r=.561).

In order to investigate the effect of non-read articles on correlations between Mendeley readership counts and citations, the analysis was repeated but including articles with zero readers (including articles that were in Mendeley but which were not found by the search process). In other words, all articles not found in Mendeley were assumed to have zero Mendeley readers. As shown in Table 3 the correlations between Mendeley readership counts and citations are weaker for all examined disciplines. The median Mendeley readership counts for all Social Science sub-disciplines are higher than their median citation counts and the overall median Social Science Mendeley readership count is double the median Social Science citation count (Table 3). The opposite is true for Physics, Chemistry and Clinical medicine but there is equality in Engineering and Technology. If the dataset had included articles with zero Mendeley readership counts, then the correlations would probably have been weaker (Mohammadi & Thelwall, in press), as confirmed below.

Table 3. Spearman correlations between WoS citations and Mendeley readership counts (both zero and non-zero) for 2008 articles.

Main disciplines	WoS citation median non-zero only/ Both zero and non-zero	Mendeley readership median non-zero/ Both zero and non-zero	Spearman correlation non-zero/ Both zero and non-zero
Clinical Medicine	9 7	4 2	.561** .463**
Engineering and Technology	5 3	5 0	.501** .327**
Social Science	4 2	8 0	.561** .456**
Physics	7 4	5 0	.548** .308**
Chemistry	11 6	5 0	.554** .369**

**Significant at p=0.01

As mentioned before, only the top three occupations for Mendeley readership counts are available for each article. To partly overcome this limitation, correlations were calculated between Mendeley readership counts and citations for several occupations for three datasets based on the availability of readership data, including a) all articles, b) articles with at least 66% of reader occupations available, and c) articles with 100% of reader occupations available. The correlations for all papers are presumably overestimates, especially for those occupational categories that often do not belong to the top 3 reported ones. As the actual unbiased correlation values cannot be computed, the three values are considered as estimates where the 100% value reflects the lower bound of correlations.

There are positive correlations between Mendeley readership counts and citations for almost all the occupations, except librarians for some sub-disciplines, although the strengths of the correlations vary by occupation across the research disciplines (Figure 2). As shown in Figure 2, the correlations decrease for records with 66% of the readership occupations available in comparison to all articles and the correlations are smaller for records with 100% of the readership occupations available in contrast to the sets of articles with at least 66% of the readership occupations available. In other words, all correlations are lower for papers with 100% readership occupations available and the likely reason is that these papers are the least cited papers with the lowest total number of readers and so the correlation test is less powerful for them because the numbers are smaller. Generally, the highest correlations are for full professors, assistant professors, postdocs and PhD students while the lowest correlations are for undergraduates, other professions and librarians in all disciplines in all the three datasets. The pattern of correlations for researchers at academic and non-academic institutions is similar across the research areas for all the three datasets. However, the differences between correlations for undergraduate and postgraduate students are noticeable for all disciplines (see appendix, Tables 10, 11 and 12). The correlations between Mendeley readership counts and citations for full professors, assistant professors, post docs and PhD students, postgraduate students are substantial for all disciplines. As shown in Figure 2, the correlations for undergraduates and other professions are small. Nevertheless, the correlations for other professions are higher for Clinical Medicine among the other disciplines.

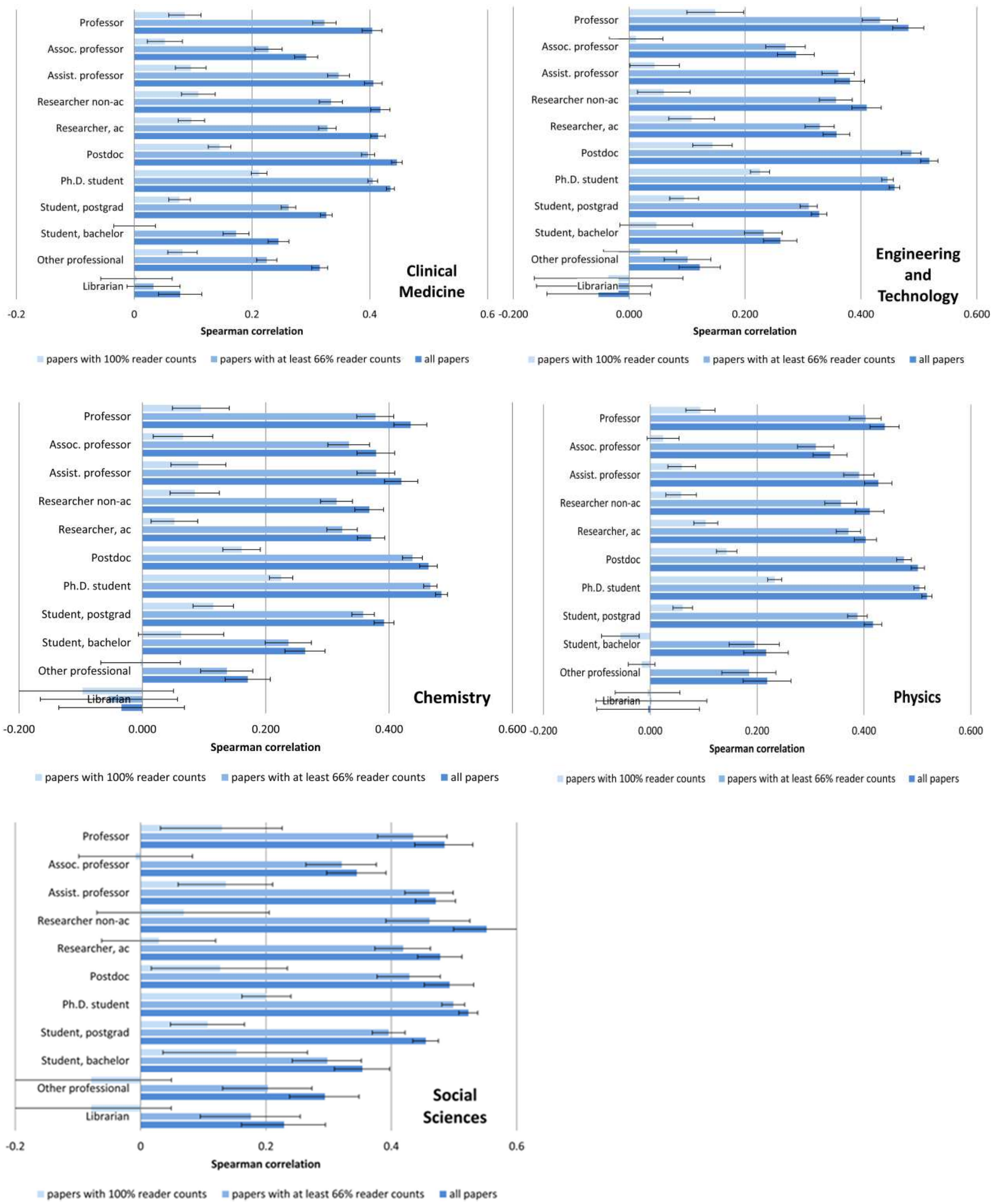

Figure 2. Spearman correlations between Mendeley readership counts and citations based on occupations for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry. Figures are reported separately for three data sets determined by the percentage of reader occupations known for an article. Error bars give a 95% confidence interval, calculated using a Fisher transformation of the correlation to give it an approximately normal distribution.

Discussion

Most readers of Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry papers in Mendeley are PhD students. Postgraduate students and postdoctoral researchers are the two most common readers of papers in Mendeley across different disciplines, after PhD students. Perhaps the most important reason is that Mendeley attracts young researchers because they adapt to new technology better than older scholars. Another possible explanation is that PhD students and postdoctoral researchers mainly research whereas the other groups are likely to have more additional responsibilities. Also, PhD students use more references in their publications than do faculty members (Larivière, Sugimoto, & Bergeron, 2013). Additionally, PhD students and postdoctoral researchers mine the literature more than senior researchers as they try to obtain comprehensive knowledge about their research topics while older researchers are often co-authors (Gingras, Larivière, Macaluso, & Robitaille, 2008) and thus probably have more supervisory roles in research projects. Alternatively, younger researchers are more adaptable to novel ideas and read more new publications, while senior scholars use older literature (Barnett & Fink, 2008). Moreover, Mendeley is a new tool and senior researchers seem to avoid using most social web services (Mas-Bleda, Thelwall, Kousha, & Aguillo, 2013) and may prefer to continue with their existing referencing practices.

Postgraduates are also readers of many articles in almost all of the sub-disciplines. They are not far behind PhD students in terms of using Mendeley. Additionally, whilst undergraduates are Mendeley readers of scholarly articles, their scarcity compared to postgraduate and PhD students could be because undergraduates tend to use reference materials and textbooks (Jamali & Nicholas, 2006) rather than journal articles as the former provide their information in a more convenient way (Fescemyer, 2000) or they do not yet know about reference management software.

A noticeable percentage of Clinical Medicine papers were read by people who are apparently not academics and this is an important issue because some articles could be useful in clinical practice even if they are not cited in the literature (Jones, Donovan, & Hanney, 2012). Moreover, a noticeable fraction of the social science papers , probably Library and Information Science articles, had librarians as readers, which is consistent with results of Schloegl and Stock (2004). Additionally, librarians bookmarked some Clinical Medicine papers and this could be an indication of medical researchers engaging clinical librarians in scholarly activities like systematic searching and information dissemination. The importance of these kinds of scholarly activities by librarians has been mentioned before (Brettle & Long, 2001).

There were substantial and positive correlations between Mendeley readership and citation counts for all the studied sub-disciplines of Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry. These findings corroborate previous studies (Bar-Ilan, 2012; Li et al., 2012; Mohammadi & Thelwall, in press) but stronger correlations were found for this dataset. A probable likely reason for the increased correlation is that the number of Mendeley users has increased over time, giving better raw readership data. As reported above, the correlations vary across different sub-disciplines.

The median Mendeley readership counts for all Social Science and some Engineering and Technology sub-disciplines are significantly higher than the median number of citations. The results could be evidence that papers in these research areas were read by many people that did not cite them, consistent with Social Science articles having many pure readers (Armbruster, 2008) and Engineering and Technology papers being used in applied contexts. Thus, it seems that Mendeley readership is able to provide evidence of using research articles in contexts other than for their science contribution, at least for Social Science and some applied sub-disciplines. Therefore, and since citation-based indicators are less effective for Social Science research evaluation than for hard Sciences research evaluation (Nederhof, 2006), Mendeley readership could compliment citations for the evaluation of Social Science articles. Moreover, it also could be used as a supplementary indicator to measure the impact of some technological or medical papers in applied contexts, as citation analysis is more useful for the assessment of theoretical research rather than applied research.

In response to the second research question, the findings indicate that there are positive correlations between Mendeley readership and citations for all of the occupations, except librarians, for all of the sub-disciplines examined. However, the highest correlations are for users that are also authors, except for associate professors in some sub-disciplines. This suggests that Mendeley readers with authorship roles probably reflect impact closer to traditional citations in comparison to readership counts for non-author types of user and goes some way towards validating Mendeley as an altmetric data source. Nevertheless, the correlations for authors are not strong enough to claim that Mendeley readership counts and citation counts are interchangeable. It is likely that academics use research articles in other activities rather than citing, for example in their teaching. The lowest correlations were found for undergraduates and non-academic users. This suggests that students often benefit from articles that are not highly cited. Thus, Mendeley provides an opportunity to monitor impact on students, which probably reflects the educational value of research articles. This would only work for a small percentage of articles, however, since undergraduates are a small minority of Mendeley users and their data is typically hidden by Mendeley as a side-effect of reporting only the three most common types of user for each article. A logical consequence of this is that low citations for undergraduate users may partly be an artefact of readership counts for undergraduate only registering in the Mendeley API when undergraduate form a disproportionately high proportion of an article's readers. Similarly, non-academic readership counts have among the lowest correlations with citation counts, suggesting that their readership counts could also help to identify individual articles and types of article that are valuable outside academia.

The results of this study are consistent with conclusions of Kurtz and Bollen (2010), which were based on case studies (e.g. Rowlands & Nicholas, 2007; Bollen & Van De Sompel, 2008) using usage datasets that were mainly local (institutional), publisher dependent and not publically-accessible, and therefore not practical for most researchers. Thus, this research gives a practical solution with global usage data for multiple disciplines for the first time.

One of the limitations of this research is that the sample is restricted to journal articles while users in particular occupations or disciplines may benefit more from other document types.

For example, engineers read relatively many conference articles in comparison to books and journals (Niu & Hemminger, 2012). Based upon advanced Mendeley searches for WoS journal articles from 2008, it seems that Mendeley has records for 837,958 journal articles from 2008, although some of these records are likely to be duplicates and so the actual number of journal articles in Mendeley is likely to be lower than this. . Within these articles, 788,260 (94%) had at least one Mendeley reader. The current study main sample includes the 197,848 WoS articles from 2008 from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry with at least one Mendeley reader, which is about 25% of in the articles from 2008 with at least one Mendeley reader.

Another limitation is that it compares individual readership counts of each article with the total citations received by an article instead of the unique number of citing authors. The latter would involve author disambiguation, which was not feasible given the large amount of citing papers. As mentioned above, data on readers' occupations was only available for three most common reader categories for each article, which resulted in losing around 27% of the readership counts. A consequence of this is that numerically small groups of readers (e.g., associate professors, professors, undergraduates, librarians), may have lower correlations due to underestimating their readership or only recording their readership values for articles for which they formed a disproportionately large share of the readers. Perhaps most importantly, the site Mendeley is perhaps most useful for those who will eventually cite an article and so its readership counts seem likely to under-represent users who will never need to cite an article, perhaps including disproportionately many practitioners. Hence Mendeley readership statistics should not be taken as an unbiased reflection of an article's readers.

Finally, from the perspective of using Mendeley as a data source for altmetrics, the biggest limitation is that probably the users of Mendeley form a small and biased minority of the readers of academic articles. In particular, assuming that Mendeley users tend to be younger than typical article readers, Mendeley readership data could not be used to estimate the proportions of readers of different types for articles. For example, although various types of professor form less than 10% of the Mendeley readers of articles and various types of student form 55%-77% (depending upon area), it is possible that professors are the majority readers of articles but rarely join Mendeley. Nevertheless, it seems reasonable to compare the proportions of Mendeley readers with different occupations between sets of articles in Mendeley (e.g., Social Sciences vs. Clinical Medicine) to identify whether readership is particularly high for one occupational group, even though the level of uptake of Mendeley between different professions could also vary between discipline.

Conclusions

This study suggests that the Mendeley readership consists of many undergraduate and postgraduate students, as well different groups of academics and non-academics. In other words, the results show that Mendeley provides evidence that research articles are read by a variety types of users inside and outside academia. A majority of Mendeley readers are PhD students in Engineering and Technology, Social Science, Physics and Chemistry, with faculty, perhaps surprisingly, being a minority in all cases. In terms of Mendeley readers outside of higher education institutions, these appear to be a small minority, with Clinical

Medicine having 7.2 % from *Other professions* for papers with 100% readership counts. Thus, Mendeley readership is able to capture a dimension of the impact of scientific documents on various activities performed within the academic community – such as “plain reading”, i.e., reading without subsequently citing, writing theses, doing assignments or drafting research proposals but also provides a little evidence of their applied use by people outside academia, such as medical doctors and surgeons.

Mendeley readership counts could perhaps supplement citation counts in the Social Sciences and in some Engineering research areas in which citation counts are lower than Mendeley readership counts. The variation in correlations between Mendeley readership counts and citations received for different types of reader suggested that the meaning of Mendeley readership counts depends upon the readers’ occupations. This implies that in some cases Mendeley readership may reflect traditional citation impact but in other cases it may reflect educational uses or impact on applied contexts. Therefore, Mendeley readership is a promising data source that is different from both citations and raw usage data. However, Mendeley is only one of many reference manager tools and other reference managers (e.g. Endnote, RefWorks, Zotero) also have many users but their data are not publically available. Thus, Mendeley seems to be the only choice to reveal aspects of the readership of research articles. This could be particularly useful in disciplines for which citation-based indicators are least reliable, such as the social sciences, arts and humanities, and perhaps also applied research. Nevertheless, more qualitative research is needed to investigate why Mendeley users register articles in order to find out how often adding a document to the Mendeley library means that the document has been, or will be, read.

Appendices

Table 4. Coverage of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley (detailed version).

Sub-discipline	Articles indexed by WoS in 2008	Unique WoS articles covered by Mendeley	Duplicated records in Mendeley	Articles with readership statistics in Mendeley	Articles without readership statistics	Total readership including duplicates	Lost readership counts after removing duplicates
Neurology & Neurosurgery	31616	77.8%	0.0%	73.0%	4.7%	288730	0.3%
Pharmacology	23276	67.7%	1.1%	60.8%	6.9%	77833	1.1%
General & Internal Medicine	22410	65.1%	5.7%	56.7%	8.3%	98005	5.5%
Cancer	19440	73.8%	0.4%	67.4%	6.3%	85627	0.7%
Surgery	16961	71.9%	0.8%	49.1%	22.7%	32396	0.4%
Immunology	16822	73.2%	0.5%	67.5%	5.7%	79388	0.3%
Cardiovascular System	15011	68.7%	1.7%	50.4%	18.3%	41586	1.7%
All	145,536	71.5%|	1.5%	62.0%	9.5%	703565	1.3%
Mechanical Engineering	13669	20.9%	2.9%	19.8%	1.1%	17620	0.5%
Computers	17768	43.2%	1.9%	41.6%	1.6%	94350	0.7%
Electrical Engineering	30271	40.4%	0.6%	35.7%	4.7%	65842	0.6%
Chemical Engineering	13486	26.7%	1.0%	26.1%	0.6%	25857	0.4%
Materials Science	34196	34.1%	1.8%	32.6%	1.4%	123535	0.9%
All	109390	34.8%	1.5%	32.5%	2.2%	327204	0.7%
Economics	12300	41.0%	3.2%	40.2%	0.7%	63950	1.7%
General Social Science	2628	40.3%	2.40%	39.6%	0.6%	11579	1.4%
Education	6620	54.6%	6.8%	53.9%	0.%	49610	4.4%
LIS	2330	62.1%	6.4%	59.5%	2.6%	20183	3.1%
All	23878	46.7%	4.8%	45.8%	0.9%	145322	2.8%
Applied Physics	29679	32.6%	1.2%	30.4%	2.1%	71050	0.6%
General Physics	36595	29.0%	1.4%	27.7%	1.2%	94520	0.6%
Nuclear & Particle Physics	10381	16.5%	0.8%	14.9%	1.5%	5225	0.8%
Optics	14229	46.9%	0.8%	43.4%	3.50%	48614	0.5%
Solid State Physics	10697	30.0%	1.6%	29.6%	0.4%	33385	0.9%
All	101581	31.4%	1.2%	29.6%	1.7%	252794	0.6%
General Chemistry	23144	29.9%	2.3%	28.8%	1.1%	70228	1.0%
Polymers	12247	22.7%	3.2%	22.0%	0.7%	19478	1.6%
Physical Chemistry	36329	35.4%	1.3%	31.0%	4.3%	85717	0.5%
Organic Chemistry	16854	28.8%	1.1%	26.9%	1.8%	24190	0.6%
Analytical Chemistry	12020	53.3%	1.3%	46.4%	6.9%	36767	0.9%
All	100594	33.6%	1.6%	30.6%	3.0%	236380	0.8%
Total	480,979	45.6%	1.7%	41.1%	4.4%	1,665,265	1.1%

Table 5. Complete and merged categories for Mendeley readers' occupations.

Occupation provided by the Mendeley API	Merged
Assistant Professor	Assistant Professor
Lecturer	
Associate Professor	Associate Professor
Senior Lecturer	
Librarian	Librarian
Other Professions	Other Professions
PhD Student	PhD Student
Doctoral Student	
Postdoc	Postdoc
Professor	Professor
Researcher (at a non-Academic Institution)	Researcher (at a non-Academic Institution)
Researcher (at an Academic Institution)	Researcher (at an Academic Institution)
Student (Bachelor)	Student (Bachelor)
Student (Postgraduate)	Student (Postgraduate)
Student (Master)	

Table 6. Readers of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley based on academic status for all papers regardless of % of available readership

	%Engineering and Technology	%Social Science	%Physics	%Chemistry	%Clinical Medicine
PhD Students	55.4%	54.9%	51.7%	50.3%	39.1%
Postgrad Student	17.4%	19.5%	9.6%	11.1%	12.6%
Postdoc	8.5%	3.0%	18.2%	13.9%	17.4%
Researcher ac	3.8%	4.4%	5.5%	5.4%	6.9%
Assistant Professor	2.9%	4.9%	3.4%	3.1%	4.2%
Researcher non-ac	3.3%	1.7%	3.7%	5.8%	3.9%
Professor	2.2%	2.1%	2.9%	3.3%	3.3%
Bachelor Student	2.8%	3.0%	1.4%	2.4%	3.5%
Other Professions	1.7%	1.7%	1.1%	2.2%	5.9%
Associate Professor	1.8%	2.3%	2.2%	2.4%	2.4%
Librarian	0.2%	2.5%	0.2%	0.2%	0.75%
Total individual readership counts	244,097	97,191	192,222	177,909	457,954

Table 7. Readers of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley based on academic status for with 66% reader counts.

	Engineering and Technology	Social Science	Physics	Chemistry	Clinical Medicine
PhD Students	56.3%	56.1%	52.1%	51.0%	39.5%
Postgrad Student	17.0%	18.3%	9.3%	10.7%	12.1%
Postdoc	8.3%	2.9%	18.2%	13.7%	17.2%
Researcher ac	3.9%	4.3%	5.6%	5.5%	7.0%
Researcher non-ac	3.3%	1.5%	3.7%	5.9%	4.2%
Assistant Professor	2.9%	4.9%	3.3%	3.0%	4.2%
Professor	2.2%	2.3%	3.0%	3.4%	3.6%
Bachelor Student	2.4%	2.9%	1.3%	2.2%	3.3%
Associate Professor	1.9%	2.4%	2.3%	2.5%	2.6%
Other Professions	1.5%	1.6%	1.1%	2.0%	5.6%
Librarian	0.2%	2.8%	0.2%	0.2%	0.7%
Total individual readership counts	194,128	60,874	159,507	142,919	302,814

Table 8. Readers of WoS articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry in Mendeley based on academic status for with 100% reader counts.

	Engineering and Technology	Social Science	Physics	Chemistry	Clinical Medicine
PhD Students	51.4%	46.9%	45.1%	45.2%	31.5%
Postgrad Student	15.5%	14.8%	9.6%	10.0%	13.8%
Postdoc	7.3%	3.5%	15.7%	11.8%	12.6%
Researcher ac	5.3%	5.6%	7.5%	7.2%	8.7%
Assistant Professor	4.5%	7.6%	5.0%	4.9%	6.1%
Researcher non-ac	4.2%	2.3%	4.7%	7.2%	5.4%
Professor	3.4%	4.6%	4.6%	4.8%	5.5%
Associate Professor	3.8%	5.2%	4.4%	4.1%	4.6%
Other Professions	2.0%	2.5%	1.6%	2.4%	7.2%
Bachelor Student	2.1%	3.1%	1.4%	2.0%	3.5%
Librarian	0.5%	3.7%	0.5%	0.4%	1.1%
Total individual readership counts	51,453	9,892	43,599	42,967	101,276

Table 9. Spearman correlations between WoS citations and Mendeley readership counts (non-zero only) for 2008 articles from Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry.

Main discipline	Sub-discipline	WoS citation median	Mendeley readership median	Correlation
Clinical Medicine	Neurology & Neurosurgery	10	7	.585**
	Pharmacology	9	4	.536**
	General & Internal Medicine	5	4	.563**
	Cancer	12	4	.604**
	Surgery	6	3	.451**
	Immunology	10	5	.573**
	Cardiovascular System	9	3	.592**
	All	9	4	.561**
Engineering and Technology	Mechanical Engineering	4	5	.533**
	Computers	3	7	.414**
	Electrical Engineering	4	4	.442**
	Chemical Engineering	7	5	.494**
	Materials Science	9	6	.682**
	All	5	5	.501**
Social Science	Economics	5	8	.629**
	General Social Science	3	8	.552**
	Education	4	9	.532**
	LIS	3	10	.546**
	All	4	8	.561**
Physics	Applied Physics	5	5	.566**
	General Physics	7	5	.595**
	Nuclear & Particle Physics	10	2	.325**
	Optics	6	5	.538**
	Solid State Physics	9	7	.628**
	All	7	5	.548**
Chemistry	General Chemistry	15	7	.648**
	Polymers	10	5	.595**
	Physical Chemistry	10	5	.527**
	Organic Chemistry	10	4	.423**
	Analytical Chemistry	10	4	.528**
	All	11	5	.554**

Table10. Spearman correlations between Mendeley readership counts and citations based on occupation for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry articles for all articles regardless of percentage of readership availability.

		Clinical Medicine	Physics	Engineering and Technology	Chemistry	Social Sciences
Professor	Spearman's rho	.404**	.439**	.482**	.435**	.485**
	N	9,549	3,345	3,142	3,550	1,048
Associate Professor	Spearman's rho	.292**	.337**	.288**	.379**	.345**
	N	8,358	3,012	3,190	3,018	1,328
Assistant Professor	Spearman's rho	.406**	.427**	.381**	.420**	.471**
	N	11,931	3,930	4,353	3,587	2,284
Researcher (at an Academic Institution)	Spearman's rho	.414**	.403**	.358**	.371**	.478**
	N	17,702	6,161	5,533	5,813	1,829
Researcher (at a non-Academic Institution)	Spearman's rho	.418**	.411**	.410**	.368**	.552**
	N	9,908	3,727	4,159	5,273	725
Post Doc	Spearman's rho	.446**	.501**	.518**	.464**	.493**
	N	30,274	14,014	9,210	11,626	1,420
Ph.D. Student	Spearman's rho	.435**	.518**	.458**	.485**	.523**
	N	53,169	23,197	29,064	23,859	8,990
Student (Postgraduate)	Spearman's rho	.326**	.417**	.328**	.392**	.455**
	N	31,106	9,723	17,141	10,715	5,765
Student (Bachelor)	Spearman's rho	.245**	.217**	.261**	.264**	.354**
	N	10,990	2,000	4,045	3,147	1,510
Other Professional	Spearman's rho	.315**	.219**	.122**	.171**	.294**
	N	16,861	1,734	2,937	2,700	1,042
Librarian	Spearman's rho	.078**	-0.003	-0.05	-0.033	.229**
	N	2,808	415	480	370	768

**Significant at p = 0.01.

Table 11. Spearman correlations between Mendeley readership counts and citations based on occupation for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry articles for articles with at least 66% readership availability.

Occupation		Clinical Medicine	Physics	Engineering and Technology	Chemistry	Social Sciences 66%
Professor	Spearman's rho	.323**	.403**	.433**	.378**	.435**
	N	7,778	3,053	2,764	3,142	826
Associate Professor	Spearman's rho	.228**	.310**	.270**	.335**	.321**
	N	6,399	2,720	2,832	2,647	977
Assistant Professor	Spearman's rho	.347**	.391**	.361**	.379**	.461**
	N	8,724	3,414	3,699	3,012	1,607
Researcher (at an Academic Institution)	Spearman's rho	.328**	.371**	.329**	.324**	.419**
	N	13,660	5,516	4,829	5,074	1,333
Researcher (at a non-Academic Institution)	Spearman's rho	.334**	.357**	.357**	.315**	.461**
	N	7,828	3,276	3,626	4,643	532
Post Doc	Spearman's rho	.397**	.475**	.487**	.438**	.429**
	N	22,413	12,140	7,796	9,673	1,005
Ph.D. Student	Spearman's rho	.405**	.504**	.446**	.467**	.499**
	N	39,887	20,368	25,314	20,361	6,531
Student (Postgraduate)	Spearman's rho	.262**	.388**	.310**	.358**	.396**
	N	22,234	8,234	14,548	8,759	3,977
Student (Bachelor)	Spearman's rho	.173**	.195**	.232**	.237**	.298**
	N	7,489	1,603	3,263	2,451	1,053
Other Professional	Spearman's rho	.225**	.185**	.101**	.137**	.203**
	N	11,683	1,397	2,313	2,068	698
Librarian	Spearman's rho	0.032	0.002	-0.060	-0.054	.176**
	N	1,886	356	386	309	567

**Significant at p = 0.01.

Table 12. Spearman correlations between Mendeley readership counts and citations based on occupation for Clinical Medicine, Engineering and Technology, Social Science, Physics and Chemistry articles for articles with 100% readership availability.

Occupation		Clinical Medicine	Physics	Engineering and Technology	Chemistry	Social Sciences
Professor	Spearman's rho	.086**	.094**	.149**	.095**	.130**
	N	5,059	1,764	1,537	1,778	394
Associate Professor	Spearman's rho	.052**	0.024	0.012	.066**	-0.008
	N	4,289	1,729	1,798	1,637	467
Assistant Professor	Spearman's rho	.096**	.059**	.044*	.091**	.136**
	N	5,578	1,954	2,102	1,905	650
Researcher (at an Academic Institution)	Spearman's rho	.097**	.104**	.108**	.052**	0.029
	N	7,473	2,740	2,401	2,662	464
Researcher (at a non-Academic Institution)	Spearman's rho	.109**	.058*	.060**	.085**	0.069
	N	4,578	1,664	1,847	2,376	202
Post Doc	Spearman's rho	.145**	.143**	.144**	.161**	.127*
	N	10,009	5,022	3,181	3,951	316
Ph.D. Student	Spearman's rho	.212**	.233**	.226**	.225**	.201**
	N	19,985	9,831	12,591	9,710	2,307
Student (Postgraduate)	Spearman's rho	.077**	.061**	.095**	.115**	.107**
	N	11,267	3,497	6,061	3,473	1,075
Student (Bachelor)	Spearman's rho	0.001	-0.056	0.047	0.063	.153*
	N	3,065	547	974	799	276
Other Professional	Spearman's rho	.082**	-0.016	0.019	-0.003	-0.079
	N	6,036	660	968	923	236
Librarian	Spearman's rho	0.004	-0.005	-0.036	-0.097	-0.079
	N	1,046	211	233	179	238

**Significant at p = 0.01.

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