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RESEARCH ARTICLE

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How is science clicked on Twitter? Click metrics for Bitly short links to scientific publications

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Abstract

To provide some context for the potential engagement behavior of Twitter users around science, this article investigates how Bitly short links to scientific publications embedded in scholarly Twitter mentions are clicked on Twitter. Based on the click metrics of over 1.1 million Bitly short links referring to Web of Science (WoS) publications, our results show that around 49.5% of them were not clicked by Twitter users. For those Bitly short links with clicks from Twitter, the majority of their Twitter clicks accumulated within a short period of time after they were first tweeted. Bitly short links to the publications in the field of Social Sciences and Humanities tend to attract more clicks from Twitter over other subject fields. This article also assesses the extent to which Twitter clicks are correlated with some other impact indicators. Twitter clicks are weakly correlated with scholarly impact indicators (WoS citations and Mendeley readers), but moderately correlated to other Twitter engagement indicators (total retweets and total likes). In light of these results, we highlight the importance of paying more attention to the click metrics of URLs in scholarly Twitter mentions, to improve our understanding about the more effective dissemination and reception of science information on Twitter.

1 | INTRODUCTION

Sharing research outputs and other relevant information on Twitter has arguably become a common way of scholarly communication, thereby making Twitter mentions one of the most important altmetric events for scientific publications (Haustein, 2019; Sugimoto, Work, Larivière, & Haustein, 2017). Such scholarly Twitter mentions imply that science is no longer restricted to the ivory tower, but expands beyond the borders of the scientific community and interests various types of people and institutions (Yu, Xiao, Xu, & Wang, 2019). The weak or negligible correlations confirmed between Twitter mentions and scholarly impact indicators, such as citation counts and journal citation scores (Bornmann, 2015; Costas, Zahedi, & Wouters, 2015; Zahedi, Costas, & Wouters, 2014), support the idea that scholarly Twitter mentions might reflect a wider and different type of influence of scientific publications beyond the science landscape (Thelwall, Haustein, Larivière, & Sugimoto, 2013).

In order to better comprehend the impact that shared scientific publications made in the Twittersphere, instead of merely counting the absolute number of Twitter mentions accrued, it is necessary to explore users' online activities and specific interactions with research objects, which was referred to as "the second generation of Twitter metrics" by Díaz-Faes, Bowman, and Costas (2019). This more interactive perspective will help to characterize the underlying mechanisms by which Twitter users interact with research outputs, and to further interpret the impact of research outputs generated through the processes of engagement among different stakeholders on Twitter (Robinson-Garcia, van Leeuwen, & Ràfols, 2018).

1.1 | Twitter interactions on the basis of scientific publications

Several studies have investigated the interactions between Twitter users and scientific publications. For scientific publications, being shared on Twitter is usually coupled with or followed by a series of interaction behavior. On the one hand, Twitter users might organize their tweet content about the mentioned scientific publications in different ways, and on the other hand, those scholarly Twitter mentions might attract diverse types or levels of engagement from the audiences after being posted. The majority of prior research on Twitter users' interaction behavior has either focused on the tweet content or the engagement around scholarly Twitter mentions.

Tweet texts have usually been scrutinized to unravel the patterns of tweeting (Robinson-Garcia, Costas, Isett, Melkers, & Hicks, 2017), the quality of interactions (Didegah, Mejlgaard, & Sørensen, 2018), and the types of sentiment (Friedrich, Bowman, Stock, & Haustein, 2015; Hassan et al., 2020) of scholarly Twitter mentions. Some functions used in tweets, like user mentions and hashtags, reflect specific interactions around scientific publications as well. For instance, user mentions establish the relationships among users who might be related to or interested in the mentioned research, based on which the communities of users sharing interest can be detected (Araujo, 2020; Pearce, Holmberg, Hellsten, & Nerlich, 2014; Said et al., 2019; Van Schalkwyk, Dudek, & Costas, 2020). Hashtags added in scholarly Twitter mentions indicate particular concepts in relation to the mentioned publications (Haustein, Bowman, & Costas, 2016); therefore, the adoption of hashtags provides the opportunities of identifying not only the connections among tweets or users focusing on the same topics (Costas, Rijcke, & Marres, 2020; Hellsten & Leydesdorff, 2020), but also the broader public concerns about some specific research topics (Haunschild, Leydesdorff, Bornmann, Hellsten, & Marx, 2019; Lyu & Costas, 2020).

In terms of engagement around scholarly Twitter mentions, there are some interactions, such as retweets, likes, and replies, that tell stories about the impact of scholarly Twitter mentions made in the Twitter landscape. Since retweets account for a considerable share of scholarly Twitter mentions (Didegah et al., 2018), it is the most studied engagement behavior. As described by Haustein (2019), retweets represent a specific form of diffusing information, so they have been widely used to construct the retweeting networks and examine the diffusion patterns of science information (Alperin, Gomez, & Haustein, 2019; Fang, Dudek, & Costas, 2020b; Robinson-Garcia et al., 2017). Díaz-Faes et al. (2019) considered the number of likes given by Twitter users as one of the factors for measuring the social media activity of users around science. Overall, in contrast to the investigations of tweet content, there is less research of how Twitter audiences engage with scholarly Twitter mentions.

1.2 | Click metrics for URLs embedded in tweets

In addition to the aforementioned Twitter functions, URLs have also been found to be frequently used by scholars on Twitter (Bowman, 2015). In a survey of 37 identified astrophysicists, Haustein, Bowman, Holmberg, Peters, and Larivière (2014) observed that more than one third of their tweets contained URLs. The ratio reported in a study by Weller and Puschmann (2011) was even higher: they found that more than 55% of tweets by scientists included at least one URL. Besides, scholars were found to be more inclined to frame their professional tweets with URLs, rather than their personal tweets (Bowman, 2015). Based on a coding sample of 2,322 tweets by scholars containing hyperlinks, Priem and Costello (2010) found that 6% of them referred to scientific publications. These embedding URLs offer audiences a portal to more abundant information than limited tweet texts would contain. They also serve as digital traces of the Twitter reception of scientific publications, leading to the scholarly Twitter metric data which are detected and tracked by many altmetric data aggregators (Zahedi & Costas, 2018).

Compared to other engagement behavior with scholarly Twitter mentions, clicking URLs cited in tweets to get access to the mentioned scientific publications has been less analyzed on a large scale due to the unavailability of traceable data on URL clicking. Relying on the referral sources[1] of visitors offered by *PeerJ* for its published papers, Wang, Fang, and Guo (2016) investigated how a selection of 110 *PeerJ* papers got visits from different web referral sources, and found that URLs shared on Twitter and Facebook attracted the majority of visits among social media platforms. Given that embedded URLs in tweets are usually shortened to comply with the maximum character length restriction of Twitter,[2] some publicly available *click metrics* for short links open a novel window for scrutinizing the visits to online resources driven by the shortened URLs posted on Twitter. For example, enabled by the click metrics provided by Bitly (https://bitly.com) for its generated short links, Gabielkov, Ramachandran, Chaintreau, and Legout (2016) studied the extent to which URLs from five leading news domains were clicked on Twitter. Similarly, both Wang, Ramachandran, and Chaintreau (2016) and Ramachandran, Wang, and Chaintreau (2018) utilized Bitly click data to measure and model the click dynamics of the links to news tweeted by a group of BuzzFeed (https://buzzfeed.com) Twitter accounts. The same methodology was also employed by Holmström et al. (2019) to analyze the temporal accumulation dynamics of clicks of Bitly links associated with seven major news websites.

These previous studies experimentally showed that click metrics provide a practical method to gain a more in-depth understanding of the impact of Twitter mentions. Different from observable Twitter engagement behavior such as retweeting and liking, conceptually speaking, clicking is a type of digital behavior related to a deeper engagement with tweets by Twitter users, moving from merely viewing the tweets, to actually trying to access more detailed content by clicking the URLs included. Clicking behavior embodies a further Twitter reception of shared information by Twitter users, which could substantially increase the visits of the tweeted content. Therefore, click metrics capture a type of *potential* impact that Twitter mentions made in creating a greater awareness of shared information. Based on this idea, we could argue that those Twitter mentions with URLs being more clicked (in contrast to those with URLs not or just scarcely clicked) are more effective in disseminating information.

1.3 | Conceptualizing click metrics as social media metrics

In Figure 1, several forms of possible interactions *within* and *between* science and Twitter are represented. Conceptually speaking, there are two different interactive landscapes: one is the *science landscape* where scientific work and publications are produced, and within the science landscape there are interactions such as citing, reading, and so on, taking place. At the other side, there is the *Twitter landscape*, where Twitter users interact by tweeting, liking, retweeting, and replying, and so on. We argue that when a scientific publication is tweeted, the Twitter mention establishes a bridge connecting the two landscapes, through which an information flow moves from the science landscape to the Twitter landscape. The generated scholarly Twitter mentions offer Twitter users the chance to engage with science information within the Twittersphere. In addition, it is possible for Twitter users to click the URLs embedded in scholarly Twitter mentions to access the corresponding scientific publications. In those cases, we would argue that through the established bridge, the information flow would move back from the Twitter landscape toward the science landscape (in practical terms, any Twitter user clicking the URL of a scientific publication in a tweet would leave the Twitter platform, to move to another [scholarly] platform to view the publication or its metadata).

In this model, the meaning of clicking behavior in the context of altmetric research is twofold:

(1) From a social media metric point of view, for scholarly Twitter mentions, the fact that the embedded URLs are being clicked by different Twitter users implies that the audiences are motivated by the tweet content (or features) to seek for more details about the scholarly information. Clicks would then represent a type of impact related with the success of scholarly Twitter mentions in creating effective forms of scholarly dissemination and communication, thus offering a new perspective on "secondary social media metrics" (Díaz-Faes et al., 2019), which focus on the characterization of social media activities and interactions with science by social media users.

(2) From an impact measurement point of view, the act of clicking the URLs of publications embedded in tweets represents an expanded form of altmetric impact, capturing not only the interest raised by the tweeting users (who originally posted the tweets or retweeted them), but also by the clicking ones (i.e., the audiences further interested in the content posted by the tweets).

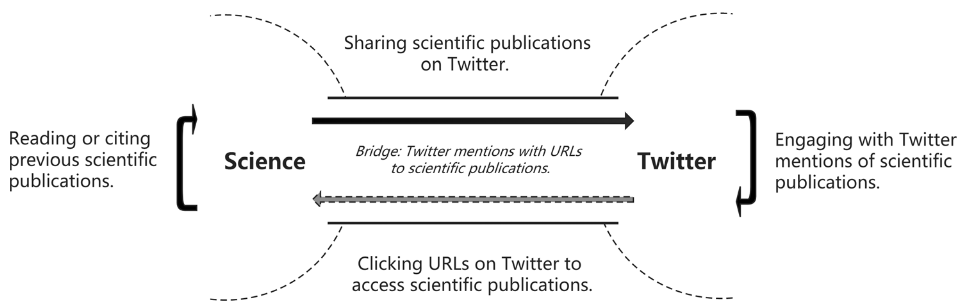

FIGURE 1 Four conceptual interactions within and between the science landscape and the Twitter landscape

Simply put, publications that get tweeted and clicked might exhibit a larger altmetric impact than those merely being tweeted (or retweeted).

Both points of view above support the idea that including click metrics in the altmetric toolset allows for a fundamental broadening of the analytical scope of altmetrics, moving beyond the notions of impact of scholarly outputs on social media (which is achieved by the information flow from science to Twitter), toward the notions of impact of social media on scholarly outputs (which is reflected by the information flow from Twitter back to science). Nevertheless, as mentioned earlier, due to the technical difficulties in obtaining click data on a large scale (since it is not evidence currently disclosed by Twitter), it remains unclear whether or not shared scientific publications' URLs directly drive traffic to the websites of these scientific publications. Against this background, click metrics for short links are expected to quantitatively depict such underlying Twitter reception of science information and add a missing piece to the puzzle of interactions between the science and Twitter landscapes.

1.4 | Objectives

By leveraging the click metrics tracked by Bitly for its generated short links, the main objective of this study is to disclose how Bitly short links to scientific publications are clicked on Twitter. Specifically, this study seeks to address the following explicit research questions:

RQ1. How frequently are Bitly short links to scientific publications clicked by Twitter users? And how do Twitter clicks accumulate over time?

RQ2. Do clicks of Bitly short links to scientific publications vary across subject fields? In which subject fields do Bitly short links have relatively more Twitter clicks?

RQ3. As a new type of indicator for measuring the potential impact of scholarly Twitter mentions, to what extent do clicks on Twitter correlate with other scholarly impact indicators (i.e., citation counts and Mendeley readers) and other Twitter engagement indicators (i.e., retweets and likes)?

2 | DATA AND METHODS

2.1 | Dataset

Bitly is a link management platform that was launched in 2008.[3] Its link shortening service has been employed by many Twitter users for the sake of, on the one hand, complying with the tweet length limit, and on the other hand, tracking the clicks for their generated short links. The latter offers the possibilities of monitoring how Bitly short links to scientific publications are clicked on different sources and on different dates.

This study focuses on the click metrics for Bitly short links to scientific publications that have been tweeted to unravel to what extent scholarly content is accessed by being clicked on Twitter. Our dataset stems from the scholarly Twitter mention data recorded by Altmetric.com up to October 2017. Based on the tweet IDs provided by Altmetric.com, we further collected the detailed information of tweets through the Twitter API in September 2019. After excluding unavailable tweets caused by deletion, suspension, or protection of Twitter accounts (Fang et al., 2020b), we obtained 1,422,266 distinct original tweets[4] with 1,103,819 distinct short links using the "bit.ly" domain that refer to Web of Science (WoS) indexed publications. As Altmetric.com started to track Twitter data since October 2011, only WoS publications published from 2012 onwards were taken into account. Moreover, to ensure that selected Bitly short links refer to the webpages of scientific publications, Twitter mentions were restricted to those containing only one URL.[5]

2.2 | Click data of Bitly short links

Bitly provides APIs for retrieving link-level analytics, making it possible to collect click metrics for the selected Bitly short links. In December 2019, for each Bitly short link in the abovementioned dataset, we collected their click metrics as follows:

1. *Total number of clicks*: This is the overall number of accumulated clicks after the short link was generated, considering all referral sources together.[6]
2. *Number of clicks on different sources*: This information details how many times the short link was clicked on each referral source, from which the number of clicks on Twitter can be extracted ("Twitter clicks" hereafter).
3. *Number of clicks on different dates*: This information details how many times the short link was clicked on different dates after it was generated.

A total of 1,102,622 Bitly short links have valid and complete metric data extracted from the APIs, involving a total of 1,420,588 Twitter mentions of 783,433 distinct WoS publications. These Bitly short links were selected as the main dataset for this study.

When studying the temporal distribution of clicks for a given short link, an important limitation in Bitly is that the date information of the clicks (i.e., the dates when the clicks were performed) retrieved through the APIs is aggregated without distinguishing the sources from where the clicks were performed. This means that if a short link has been clicked from more than one source, it is not possible to isolate the clicks coming only from Twitter. As a solution, in order to explore the temporal distribution of clicks happened specifically only on Twitter, the set of 171,430 Bitly short links with all clicks only from the source Twitter was drawn as one of the subsamples.

2.3 | CWTS publication-level classification system

For the comparison of click metrics among subject fields, the CWTS publication-level classification system (Waltman & Van Eck, 2012) was employed to assign publications with subject field information. This scheme clusters WoS publications into micro-level fields based on their citation relationships and then algorithmically assigns them to five main subject fields of science, including Social Sciences and Humanities (SSH), Biomedical and Health Sciences (BHS), Physical Sciences and Engineering (PSE), Life and Earth Sciences (LES), and Mathematics and Computer Science (MCS).[7] For our dataset, a total of 697,644 distinct publications (accounting for around 89%) have the subject field information assigned by the CWTS classification, involving 944,686 distinct Bitly short links. This set of publications and short links were used as a subsample to explore how Twitter clicks vary across the five subject fields. Table 1 lists the presence of these publications and short links in each subject field.[8]

2.4 | Indicators and analytic approaches

To better understand the relationships between Twitter clicks and scholarly impact indicators and other Twitter engagement indicators, we calculated the following four indicators to measure their correlations with Twitter clicks for each Bitly short link:

Scholarly impact indicators:

1. *WoS citations*: the number of WoS citations of the publication that the Bitly short link refers to.
2. *Mendeley readers*: the number of Mendeley readers of the publication that the Bitly short link refers to.

Twitter engagement indicators:

1. *Total retweets*: the total number of retweets received by all scholarly Twitter mentions containing the Bitly short link.
2. *Total likes*: the total number of likes received by all scholarly Twitter mentions containing the Bitly short link.

Regarding the data collection date of these four indicators, WoS citations were retrieved from the CWTS in-house WoS database that contains WoS data up to March 2020, Mendeley readers were collected through the Mendeley API in July 2019, while total retweets and total likes were obtained in the process of Twitter data collection in September 2019 as well. Finally, Spearman correlation analysis was performed at the Bitly short link level to measure the extent to which Twitter clicks correlate with the above indicators.

3 | RESULTS

This section consists of three main parts: the first part presents the frequency and accumulation speed of Twitter clicks of Bitly short links to scientific publications. The second part shows the variations of Twitter clicks across publications from different subject fields. The last one focuses on the correlation analysis between Twitter clicks and two scholarly impact indicators (i.e., WoS citations and Mendeley readers) and other two Twitter engagement indicators (i.e., total retweets and total likes).

TABLE 1 Number of publications (P) and Bitly short links (BL) in each subject field

Subject field	Abbr.	P	Percentage	BL	Percentage
Social Sciences and Humanities	SSH	77,031	11.0%	106,521	11.3%
Biomedical and Health Sciences	BHS	433,419	62.1%	612,628	64.9%
Physical Sciences and Engineering	PSE	83,465	12.0%	93,700	9.9%
Life and Earth Sciences	LES	88,442	12.7%	111,730	11.8%
Mathematics and Computer Science	MCS	15,287	2.2%	20,107	2.1%

3.1 | Overall distribution of Twitter clicks

On the whole, Bitly short links in our dataset received nearly 12 million clicks in total, 52% of which (about 6.2 million) are contributed by Twitter. Although Twitter plays a key role in directing traffic to scientific publications, as shown in Figure 2a, the overall distribution of Twitter clicks among Bitly short links is highly skewed. About 49.5% of Bitly short links were not clicked after being tweeted, and most Bitly short links only got a few clicks on Twitter—around 89.7% of short links were clicked by Twitter users no more than 10 times. For comparison, the distribution of total clicks with all referral sources considered is shown in Figure 2b. As the more visible in multiple platforms, the higher the possibility of being clicked, there are less Bitly short links without clicks (about 36.5%) and more being clicked at different levels.

The majority of Twitter mentions of scientific publications accrued in a very short period of time after publication (Fang & Costas, 2020; Yu, Xu, Xiao, Hemminger, & Yang, 2017). As shown in Figure 3a, the same accumulation speed can be observed for Twitter clicks. For each Bitly short link, we selected the day when it was tweeted for the first time as the original point, and then calculated the time intervals between the original point and the date when it was clicked. Overall, around 26.3% of Twitter clicks happened in the day when the short links were first tweeted, and the number of Twitter clicks increases dramatically in the next few days. It exceeds 60% in the following day and reaches 80.5% in the first 10 days, and then flattens out. On the whole, there are about 86.2% of Twitter clicks accumulated in the first month after the Bitly short links appeared on Twitter. Similarly, Figure 3b exhibits the temporal accumulation pattern of total clicks with all referral sources counted. We used the same original point for calculating time intervals. Compared to Twitter clicks, there are slightly more clicks before the Bitly short links were tweeted because they might be posted on some other platforms earlier, yet the temporal accumulation pattern of total clicks is similar to that of Twitter clicks, with 24.6% of total clicks accrued by the day in which the first Twitter mentions came into view and 83.8% of total clicks accumulated in a month.

3.2 | Twitter clicks across subject fields

To make a comparison of the coverage of Twitter clicks among subject fields, Figure 4 plots the percentage of Bitly short links with different levels of Twitter clicks for the five main subject fields. Generally speaking, Bitly short links in the field of SSH show the highest coverage of Twitter clicks, followed by LES and BHS, while the coverage in the fields of MCS and PSE is relatively lower. As to the percentage of Bitly short links with at least one

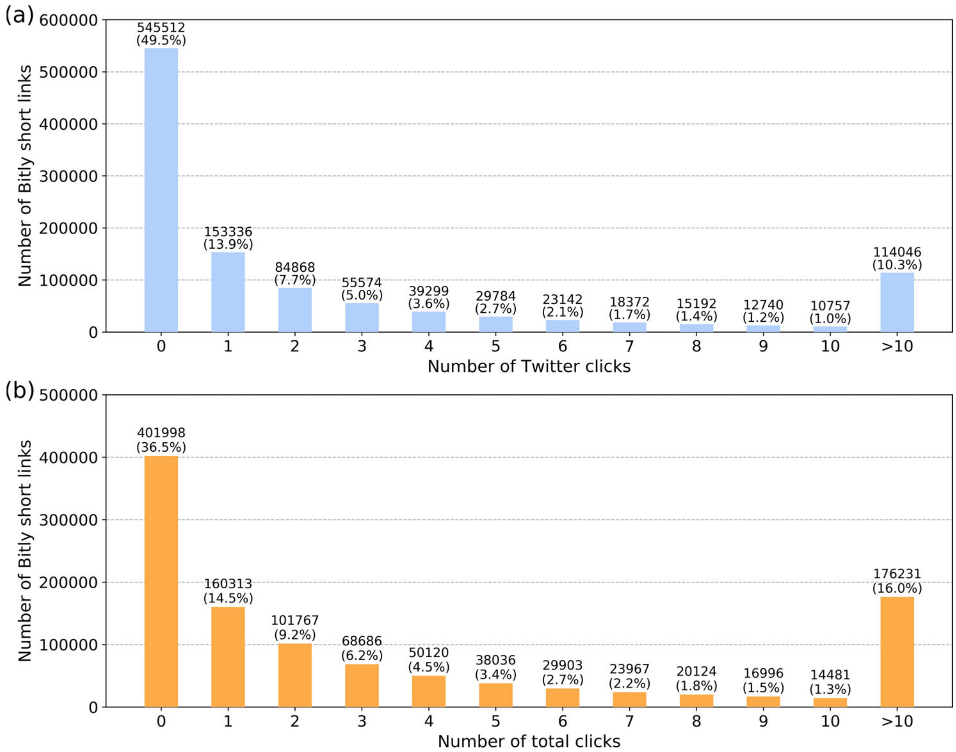

FIGURE 2 Distribution of Bitly short links with different numbers of (a) Twitter clicks and (b) total clicks [Color figure can be viewed at wileyonlinelibrary.com]

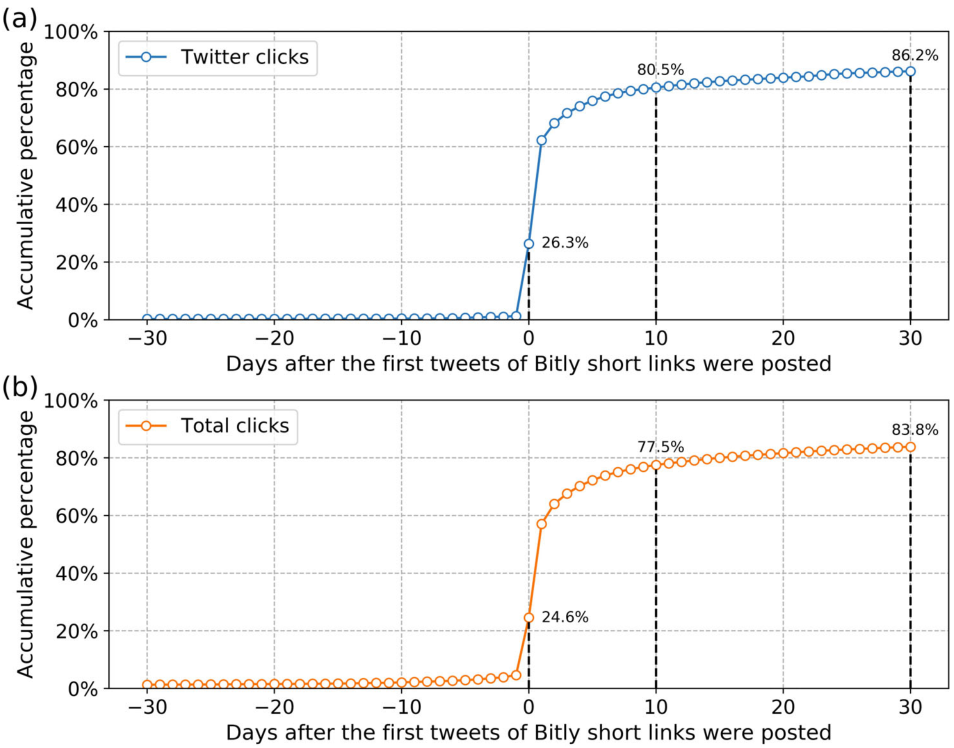

FIGURE 3 Temporal accumulation patterns of (a) Twitter clicks and (b) total clicks [Color figure can be viewed at wileyonlinelibrary.com]

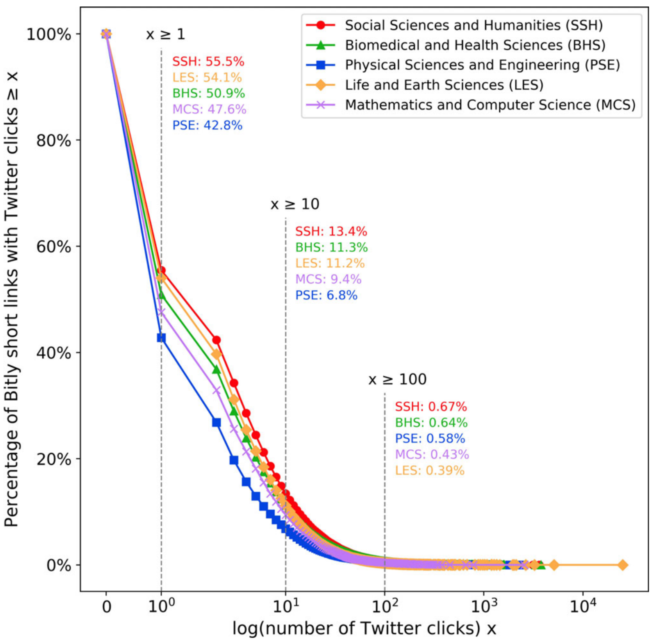

FIGURE 4 Percentage of Bitly short links with different levels of Twitter clicks across five subject fields [Color figure can be viewed at wileyonlinelibrary.com]

Twitter click received, obvious variations can be observed among subject fields ranging from about 42.8% for PSE up to 55.5% for SSH. Subject fields rank differently as the number of Twitter clicks increases, especially for BHS and LES. BHS, by contrast, tend to have a higher percentage of Bitly short links with a relatively larger quantity of Twitter clicks, but not for LES, which means that although LES has proportionally more Bitly short links with Twitter clicks received, it is proportionally less abundantly clicked than BHS does.

Table 2 presents the descriptive statistics of Twitter clicks of Bitly short links in five subject fields. In general, Bitly short links in the field of SSH achieve not only the highest coverage but also the largest average number of Twitter clicks. As discussed earlier, even though the overall coverage of Twitter clicks for LES is higher than that for BHS, the latter has more Twitter clicks accrued on average. MCS and PSE always rank last in terms of both the coverage and the average Twitter clicks accumulated. The indicator of 90th percentile tells the story in a consistent way. Bitly short links in the field of SSH have the top 10% received at least 13 Twitter clicks, both BHS and LES have their top 10% of Bitly short links received at least 11 Twitter clicks, while MCS and PSE come in last with at least 9 and 6 Twitter clicks for their top 10% of Bitly short links, respectively.

3.3 | Correlation analysis

In order to know more about the relationships between Twitter clicks and other impact indicators, we selected two scholarly impact indicators within the science landscape (i.e., WoS citations and Mendeley readers) and two Twitter engagement indicators within the Twitter

TABLE 2 Descriptive statistics of Twitter clicks of Bitly short links in five subject fields

Subject field	TNL	TNC	PL (C ≥ 1)	Mean_all	Mean_clicked	Min	Max	90th *P*	*SD*
SSH	106,521	644,164	55.5%	6.05	10.90	0	3,617	13	30.20
BHS	612,628	3,211,001	50.9%	5.24	10.30	0	3,777	11	24.70
PSE	93,700	355,963	42.8%	3.80	8.88	0	2,534	6	25.48
LES	111,730	553,588	54.1%	4.95	9.17	0	25,127	11	80.55
MCS	20,107	83,648	47.6%	4.16	8.74	0	2,557	9	24.34

Abbreviations: Max, maximum value of Twitter clicks; Mean_all, mean value of Twitter clicks of all Bitly short links; Mean_clicked, mean value of Twitter clicks of Bitly short links with at least one Twitter click; Min, minimum value of Twitter clicks; PL(C ≥ 1), percentage of Bitly short links with at least one Twitter click; TNC, total number of Twitter clicks; TNL, total number of Bitly short links; 90th *P*, 90th percentile of Twitter clicks; SD, standard deviation.

TABLE 3 Spearman correlation analysis of Twitter clicks, scholarly impact indicators, and Twitter engagement indicators

	Twitter clicks	WoS citations	Mendeley readers	Total retweets	Total likes
Twitter clicks	1.000	0.094	0.151	0.499	0.458
WoS citations		1.000	0.744	0.071	0.046
Mendeley readers			1.000	0.118	0.114
Total retweets				1.000	0.617
Total likes					1.000

landscape (i.e., total retweets and total likes) to compare their correlations with Twitter clicks. Table 3 presents the results of the Spearman correlation analysis among Twitter clicks, WoS citations, Mendeley readers, total retweets, and total likes. Citation counts and Mendeley readers are moderately correlated ($r_s = 0.744$), which has also been confirmed by many previous studies (Thelwall & Wilson, 2016; Zahedi et al., 2014). The correlation between the two Twitter engagement indicators—total retweets and total likes received—is also relatively moderate ($r_s = 0.617$). According to the results, Twitter clicks of Bitly short links correlate positively to scholarly impact indicators and Twitter engagement indicators. In comparison, Twitter clicks are more correlated with the two indicators rooted in the Twitter landscape than with the scholarly impact indicators. Both total retweets and total likes received by Bitly short links are moderately associated with Twitter clicks ($r_s = 0.499$ and $r_s = 0.458$, respectively), while Twitter clicks only show weak correlations with WoS citations and Mendeley readers of publications ($r_s = 0.094$ and $r_s = 0.151$, respectively). The results remain consistent even if only the Bitly short links with at least one Twitter click are considered (see Table A3 in the Appendix).

To present the change trends of the analyzed indicators with the number of Twitter clicks increases, Figure 5 graphically shows the relationships between Twitter clicks and (a) WoS citations, (b) Mendeley readers, (c) total retweets, and (d) total likes. For clear visualization, the change trends of the indicators were restricted to the Bitly short links with Twitter clicks ranging from 0 to 20, which account for 94.7% of all Bitly short links in our dataset. The indicators show an upward trend with the number of Twitter clicks. Since the number of Twitter clicks weakly and positively correlates with both WoS citations and Mendeley readers as presented in Table 3, the uptrend of these two indicators is relatively flat. The difference of accumulated citations and readers between relatively highly clicked Bitly short links and those with less Twitter clicks is not significant. By comparison, total retweets and total likes rise at a faster pace because they are moderately correlated with Twitter clicks. In general, Bitly short links with more retweets and likes also tend to receive more clicks on Twitter.

4 | DISCUSSION

Though scholarly Twitter mentions have been proven to be able to increase the online visibility and dissemination of scientific publications (Allen, Stanton, Di Pietro, & Moseley, 2013; Shu, Lou, & Haustein, 2018; Wang, Cui, Li, & Guo, 2017), as of yet, very little work has been done to uncover the mechanism of how scholarly Twitter mentions serve as bridges to direct users to view the tweeted scholarly content. That is to say, even though nowadays scholarly Twitter mentions are widespread and, therefore, are believed to represent a kind of social media attention that scientific publications received, it is still

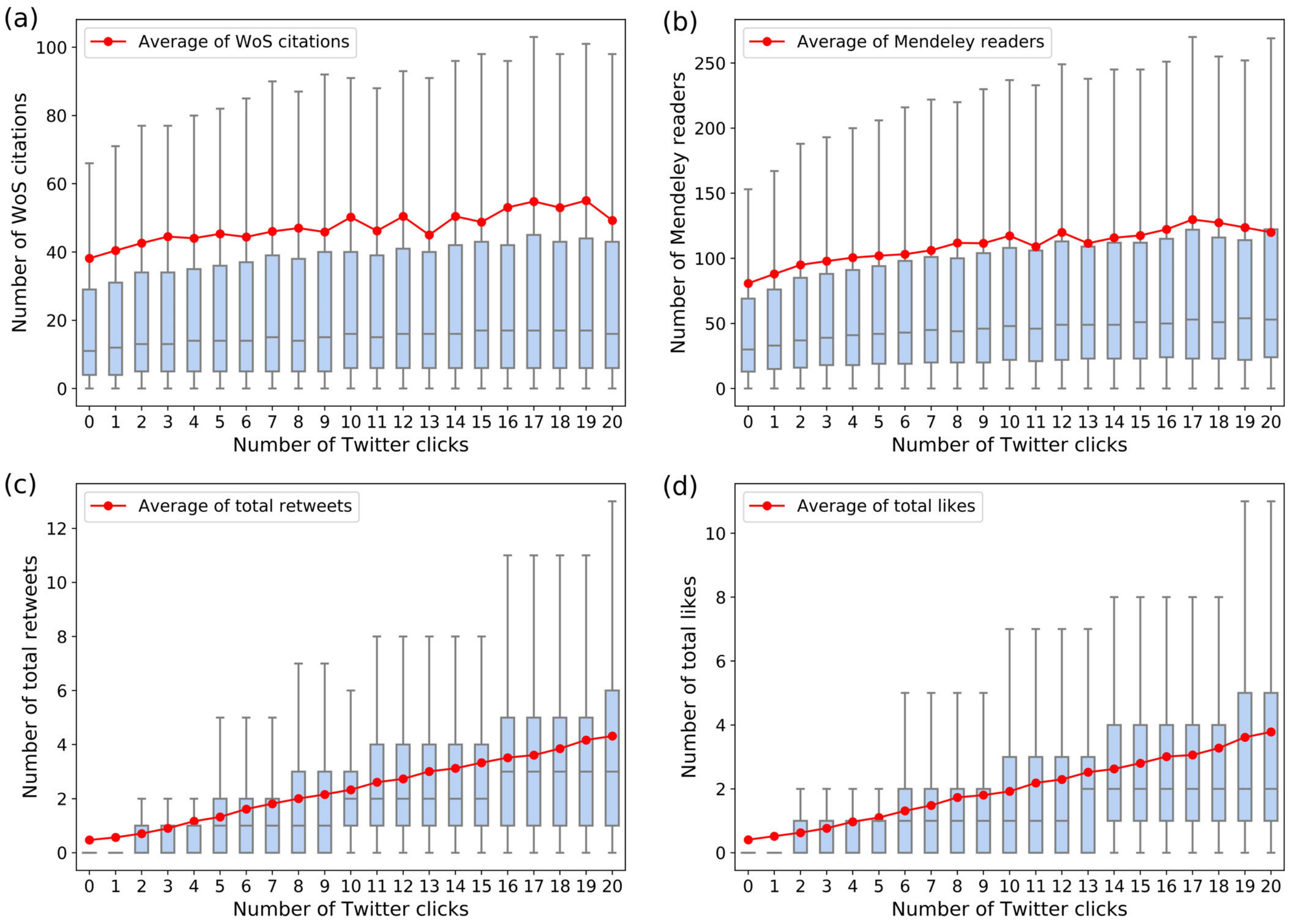

FIGURE 5 Relationships between the number of Twitter clicks and (a) WoS citations, (b) Mendeley readers, (c) total retweets, and (d) total likes [Color figure can be viewed at wileyonlinelibrary.com]

unclear whether they really result in any specific impact by attracting users to access the mentioned scientific publications.

A strong example of the importance of unveiling the mechanism behind the act of tweeting and its actual access to scientific content came from Twitter itself. On June 10, 2020, the official Twitter account of "@TwitterSupport" tweeted that, in order to promote informed Twitter discussion, they were testing a new prompt on Android devices to ask users if they would like to open the link of the article first before they retweet it.[9] This was interpreted as an attempt to "nudge some users into rethinking their actions on the social network", and thus improving platform health (Hern, 2020), particularly given the common problem of users sharing links without reading them—it was estimated that 59% of the URLs mentioned on Twitter were not clicked at all (Gabielkov et al., 2016).

In the case of scholarly Twitter mentions, based on a large-scale analysis of over 1.1 million Bitly short links referring to WoS publications, we first found that there are about 49.5% of the Bitly short links that were never clicked on Twitter, while the remaining 50.5% successfully led at least one Twitter user to the detail pages of scientific publications. These empirical results indicate that, although the scholarly Twitter mentions improved the online visibility of publications, nearly half of the tweeted Bitly short links failed to stimulate Twitter users to open the links and increase access to the publications. Put this in the conceptual framework proposed in Figure 1, even if the bridges established by scholarly Twitter mentions widely brought science information into the Twitter landscape, the assumed two-way information flows only happened on about half of the established bridges, while the remaining bridges did not guide users back to the science landscape.

Just as conceptualized by Haustein et al. (2016), there are various heterogeneous acts that relate to research objects. They summarized three act categories, including *access* (i.e., the acts of accessing and showing interest in the research objects), *appraise* (i.e., the act of mentioning the research objects on various platforms), and *apply* (i.e., the act of using significant parts of, adapting, or transforming the research objects), and assumed that the level of engagement of these acts increased from *accessing* over *appraising* to *applying*. Therefore, accessing can be seen as the starting point of a sequence of possible engagement around scientific publications. One may hypothesize that scholarly Twitter mentions could promote the access of publications, thus raising the possibility for them of being appraised or applied next. However, according to our findings, the capacity for increasing the access of scientific publications is limited for the majority of scholarly Twitter mentions, thus precluding the occurrence of subsequent academically related behavior such as viewing, downloading, reading, or citing. This large-scale absence of the information flow bridging back from Twitter to the science landscape might partly contribute to explain the weak correlations between Twitter mentions and scholarly impact indicators usually found in the altmetric literature (Bardus et al., 2020; Haustein, Costas, & Larivière, 2015; Sugimoto et al., 2017).

For those Bitly short links with Twitter clicks received, we investigated their temporal accumulation patterns and subject field variations. The distribution of Twitter clicks of Bitly short links shows very similar characteristics to Twitter mentions of scientific publications. For example, Twitter was found to be one of the fast sources as the majority of scholarly Twitter mentions emerged very soon after the publications were accessible (Fang & Costas, 2020; Shuai, Pepe, & Bollen, 2012). Clicks by Twitter users also concentrate in a very short period of time after the Bitly short links were tweeted, with over 60% of Twitter clicks accrued by the following day after the Bitly short links were first tweeted, and about 80.5% accumulated within 10 days. In terms of subject field variations, many prior studies have confirmed that the fields of SSH, BHS, and LES had the highest share of publications with Twitter mention data, while the presence of Twitter mentions in the fields of PSE and MCS was much lower (Costas et al., 2015; Fang, Costas, Tian, Wang, & Wouters, 2020a; Haustein et al., 2015). Our results also show that Bitly short links to publications in the fields of SSH, BHS, and LES are more frequently clicked than those in the fields of MCS and PSE. Regarding the stronger attention paid to SSH and BHS by social media users, Haustein et al. (2015) and Costas et al. (2015) interpreted that it would be motivated by social media users having a preference for engaging with social and health-related topics over other more technical, mathematical, or physical topics. Thus, social media users would more likely be intrigued and triggered by the research that are relatively easier to be understood or more closely bound up with social phenomena and healthcare. The results depicted in this article support this interpretation, since a similar reason can be applied to the subject field variations in terms of Twitter clicks: those short links included in tweets related to SSH and BHS publications would be more frequently clicked due to the stronger interest of Twitter users in social and health-related topics.

In contrast to other engagement behavior with respect to science on Twitter, clicking represents a more deep-seated Twitter reception because Twitter users' attention is not only limited to the tweet content, but spreads to the original content of the tweeted publications. Clicking makes a potential impact on scholarly content by substantially increasing the visits. Therefore, click metrics mirror such potential impact. In this study, we also assessed the correlations between this new type of impact indicator and other scholarly impact indicators and Twitter engagement indicators. WoS citations, Mendeley readers, total retweets, and total likes were aggregated at the Bitly short link level to conduct the Spearman correlation analysis with Twitter clicks. Given the confirmed weak or negligible correlations between Twitter mentions and scholarly impact indicators (Bardus et al., 2020; Haustein et al., 2015; Sugimoto et al., 2017), it is not surprising that Twitter clicks showed relatively weak correlations with the two scholarly impact indicators, since the existence of Twitter mentions is the precondition for the generation of Twitter clicks. In comparison, Twitter clicks showed moderate correlations with the two other Twitter engagement indicators, indicating the possible intrinsic relationships among the engagement behavior in the Twitter universe. Put differently, it could be argued that clicks from Twitter to publications are more related to elements and dynamics coming from the Twitter landscape (e.g., retweets and likes) than from the science landscape (e.g., citations and readership), therefore reinforcing the interest in understanding the social media dynamics and factors that would enable a smoother interaction between the two landscapes.

This study provides an overview of the extent to which Bitly short links pointing to scientific publications are clicked on Twitter. It has particular implications for quantifying the traffic to scientific publications derived from Twitter and evaluating the Twitter reception of science information in depth. Another implication of this study is that we put clicks as a novel form of subsequent type of impact emanating from social media activities on the science landscape. The study of click metrics can be seen as an enrichment of the scope of altmetrics, by incorporating a new quantitative and reproducible approach, able to expand the perspectives of how science is used and received in the Twittersphere. It must be noted that clicking the short links to scientific publications does not necessarily entail the reading of them.

After clicking the tweeted URLs to publications, users might only briefly view the abstract or just look into the figures, but from a conceptual point of view, these two examples both represent deeper levels of engagement with the scholarly material than just the social media activities (e.g., retweeting or liking tweets) usually tracked by altmetric sources. As mentioned earlier, the opening of URLs before retweeting them is officially encouraged by Twitter for the sake of "promoting informed discussion." This suggests that the idea of bridging to and from social media regarding external information (e.g., scholarly papers, news media) is seen by Twitter as a relevant form of engagement, important to improve the validity and pertinence of the information circulating on Twitter.

In order to better understand what kinds of Bitly short links to scientific publications are more likely to be clicked on Twitter (i.e., what are the features that improve bridging the information flow from the Twitter landscape back to the science landscape?), future research should explore the potential influencing factors on the clicking behavior of Twitter users, considering three main dimensions of relevant science-social media interaction features: (1) the bibliometric features of the tweeted publications (e.g., journal impact factor, authors' reputation, open access status); (2) the textual and interactive features of the tweets (e.g., originality of tweet texts, sentiment, mentions to other users, inclusion of hashtags, number of retweets or likes); and (3) the activities and profile features of the Twitter users (e.g., number of followers, degree of science focus, number of tweets posted, description as academic users). Moreover, given the different levels of Twitter clicks observed across subject fields, it would be necessary to explore the possible causes of these clicking disciplinary differences, particularly by comparatively studying the tweeting behavior of Twitter users across different disciplinary contexts.

There are some limitations that should be acknowledged in this study. First, the employed methodology is highly dependent on the click metrics provided by Bitly, so for short links generated through other services or those unshortened URLs there is no reliable way to harvest click metric data. Second, Twitter users come from very different social groups (e.g., academic users, professionals, or the general public), and they may access Twitter from different devices (e.g., mobile phones, tablets, or computers). This diversity of users and the devices used for accessing Twitter might have some influence on their clicking behavior. However, the click metrics provided by Bitly are aggregated numbers at the short link level. This means that it is not currently possible to conduct more in-depth research about who are the clicking users and from what kinds of devices they clicked the short links. Such lack of data, which is also bound by legal privacy constrains, hinders the possibility of studying the clicking behavior of Twitter users from a more fine-grained perspective, particularly in order to understand better whether the devices from where the users access social media platforms may also be related to their clicking behavior (e.g., it may be that users who access Twitter from their mobile phones are less prone to click the URLs of scientific publications, as this is a type of device less friendly for reading longer scholarly texts), or whether some types of academic users (e.g., researchers, students) are more prone to click the URLs of scholarly content, in contrast to other nonacademic users (e.g., professionals, the general public). Third, only those Bitly short links using the "bit.ly" domain were considered, while customized domains of some companies were not included in this study (e.g., the "go.nature.com" domain customized by some *Nature* journals). Finally, there is still a remote possibility that some Twitter users would copy and paste or type the short links in their browsers instead of directly clicking them from the tweet. In such cases, although the publication would get actual visits, they would not be counted as valid Twitter clicks as in this study, and therefore the actual number of Twitter clicks would be underestimated. Ideally, it should be Twitter directly the one that could best report the number of clicks resulting from the tweets, thus making it possible the more thorough and systematic study of the clicking behavior of Twitter users around scientific publications. Such type of information, as announced by the aforementioned tweet of "@TwitterSupport", would also support the aim of Twitter to "help promote informed discussion" by better understanding how scientific content gets disseminated and actually accessed by its users.

5 | CONCLUSIONS

The bridges established by scholarly Twitter mentions enable the analysis of bidirectional information flows between the science and Twitter landscapes. The information flow going from the science landscape to the Twitter landscape (e.g., by someone tweeting scientific publications) has been extensively studied, constituting an important part of the altmetric research literature. However, whether the tweeting of scientific publications was related to Twitter users also going back to the science landscape (e.g., by users clicking the tweeted URLs of publications) is a form of information flow that has remained largely unexplored in the altmetric research area. This study represents the first attempt of studying how Twitter users try to access the scientific information embedded in tweets, by analyzing their clicks to Bitly short links to scientific publications. Based on the click metrics of over 1.1 million Bitly short links referring to WoS publications, we found that nearly half of them were not clicked on Twitter at all, and the majority of Bitly short links performed poorly in attracting Twitter users to access the original scholarly content, thereby revealing that most scholarly Twitter mentions played a relatively ineffective role in driving traffic from Twitter back to the science landscape. There are still some Bitly short links that have received a substantial number of Twitter clicks. When this is the case, and there are substantial clicking activities around scientific publications, they showed similar characteristics as general scholarly Twitter mentions in terms of both accumulation speed and subject field variations. Timewise, Twitter users tended to click short links to scientific publications within a short period of time after they were tweeted. Twitter users also showed stronger preferences for clicking links to publications from the fields of SSH, BHS, and LES, arguably to access social and health-related research. Publications in the fields of PSE and MCS tended to be less frequently clicked, also in accordance with the lower tweeting activities previously reported for these fields. Finally, Twitter clicks were more correlated with other Twitter engagement indicators such as total retweets and total likes, rather than with scholarly impact indicators (WoS citations and Mendeley readers), suggesting that Twitter clicks are more a form of *Twitter engagement indicator*, rather than an academic-related impact indicator.

Building on the findings of this study, it is clear that there is a future research agenda regarding the understanding of the mechanisms of the Twitter reception of science information, particularly from an interactive point of view, in which many factors both from the Twitter landscape (e.g., users, retweets, likes, conversations) and from the science landscape (e.g., reputation of authors, journals, topics) interplay in order to attract broader audiences to scientific content, paving the way to the evaluation of the success of Twitter dissemination strategies of scientific knowledge.

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ENDNOTES

[1] Referral sources are Internet addresses or hostnames that users used to visit the website where they are located now. The referral source information is one type of article-level metrics provided by *PeerJ* for tracking the web referrals through which visitors access *PeerJ* papers.

[2] Currently, the text content of a tweet is allowed to contain up to 280 characters. See more details about the tweet length at: https://developer.twitter.com/en/docs/basics/counting-characters.

[3] See more introduction to Bitly at: https://support.bitly.com/hc/en-us/articles/230895688-What-is-Bitly-.

[4] Here original tweets are tweets originally posted by Twitter users, including both original tweets and reply tweets. Retweets are not studied because they have the same embedding URLs as the corresponding original tweets.

[5] In the Altmetric.com database, there are a total of 7,446,310 unique tweeted URLs meeting the criteria we set. Table A1 in the Appendix lists the usage rate of Bitly short links (i.e., the proportion of Bitly short links in all tweeted URLs) over the tweet post years, together with the usage rates of short links generated by three other frequently used link shortening services (i.e., Ow.ly, Goo.gl and TinyURL) for comparison. Overall, as one of the most used link shortening services, the selection of 1,103,819 short links using the "bit.ly" domain accounts for about 14.8%.

[6] Bitly records clicks from different types of referral sources, such as social media platforms (e.g., Twitter, Facebook, Reddit, LinkedIn), YouTube, and Email.

[7] See more introduction to the CWTS classification system at: https://www.leidenranking.com/information/fields.

[8] As there are more tweeted publications from the field of BHS, this field contributed the most Bitly short links in our dataset. To reflect the variations of the usage rates of Bitly short links across subject fields, Table A2 in the Appendix presents the proportion of Bitly short links in all URLs for each subject field. Among the total set of 7,446,310 unique tweeted URLs meeting the criteria we set, 6,507,861 of them (accounting for 87.4%) have the CWTS classification information. Although BHS is the field with quantitatively more Bitly short links, in relative terms the usage rates of Bitly short links are quite similar across the five main subject fields, ranging from 12.4% for LES up to 17.5% for PSE.

[9] See the detailed tweet texts at: https://twitter.com/TwitterSupport/status/1270783537667551233.

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APPENDIX A

TABLE A1 Usage rates of short links generated by four link shortening services over the tweet post years

Post year	Total number of tweeted URLs	Bitly short links	Ow.ly short links	Goo.gl short links	TinyURL short links
≤ 2012	561,932	175,082 (31.2%)	51,681 (9.2%)	18,145 (3.2%)	8,575 (1.5%)
2013	833,308	172,168 (20.7%)	93,659 (11.2%)	28,050 (3.4%)	10,553 (1.3%)
2014	1,141,654	177,701 (15.6%)	113,018 (9.9%)	33,202 (2.9%)	11,377 (1.0%)
2015	1,655,277	226,516 (13.7%)	154,993 (9.4%)	40,780 (2.5%)	12,272 (0.7%)
2016	1,881,691	250,198 (13.3%)	161,301 (8.6%)	61,455 (3.3%)	11,691 (0.6%)
2017	1,533,613	113,547 (7.4%)	120,925 (7.9%)	66,630 (4.3%)	9,533 (0.6%)
Total	7,446,310	1,103,819 (14.8%)	693,386 (9.3%)	247,623 (3.3%)	63,334 (0.9%)

Note: For URLs which have been tweeted in multiple years, full counting was used to calculate the number of URLs in each year.

TABLE A2 Usage rates of Bitly short links across five main subject fields

Subject field	Total number of tweeted URLs	Number of tweeted Bitly short links	Proportion
Social Sciences and Humanities	753,646	106,521	14.1%
Biomedical and Health Sciences	4,196,291	612,628	14.6%
Physical Sciences and Engineering	536,380	93,700	17.5%
Life and Earth Sciences	898,614	111,730	12.4%
Mathematics and Computer Science	122,930	20,107	16.4%

TABLE A3 Spearman correlation analysis of Twitter clicks, scholarly impact indicators, and Twitter engagement indicators considering only the Bitly short links with at least one Twitter click

	Twitter clicks	WoS citations	Mendeley readers	Total retweets	Total likes
Twitter clicks	1.000	0.083	0.141	0.562	0.519
WoS citations		1.000	0.752	0.045	0.013
Mendeley readers			1.000	0.082	0.078
Total retweets				1.000	0.615
Total likes					1.000