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Article

Diverse roles of twitter in research evaluation: original tweets and retweets capture different types of engagements with scholarly articles

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Abstract

Altmetrics need to be more critically assessed in terms of the extent to which they reflect impact and quality of research compared to popularity or mere attention. Twitter (now rebranded as X) is a popular platform to, among other things, discuss and share scientific articles. Earlier altmetric studies have often focused on investigating whether the number of tweets mentioning scientific articles could be used as an indicator of scientific impact or attention, with results showing weak to moderate correlations with citation counts. But all tweets may not be equal, as original tweets and retweets may reflect different levels of engagement and impact. Using a dataset of over 330,000 PLOS publications, this study explores whether these two forms of Twitter activity correlate differently with traditional citation metrics and how these relationships vary across disciplines. The findings showed the correlation between citations and original tweets was consistently higher than that between citations and retweets and significant weak or moderate, but higher in Social Science and Humanities than in Natural Science, Engineering and Medicine fields. Also, including zero citation counts improved the correlation coefficients for original tweets, but reduced that of retweets. This indicates that original tweets may be more aligned with citation counts as an indicator of scholarly impact, whereas retweets might reflect broader dissemination and popularity. In conclusion, tweets and retweets are different altmetric indicators and should be considered as two different metrics and analysed separately.

Keywords Altmetrics, social media metrics, Twitter, scientific impact, research impact, online impact, multidisciplinary research impact, PLoS publications

1. Introduction

Whilst the use of quantitative methods in research evaluation is controversial, there are critical calls to make altmetrics more objective. "The value and best interpretations" of altmetrics, or alternative metrics that go beyond traditional citation counts and measure the attention and impact of research online, are uncertain (Thelwall 2024). Social media platforms extend the scope of research evaluation by offering metrics beyond traditional citations; however, user engagement in social media is complex and the varied interaction features of these platforms lead to different forms and levels of user engagement. Oversimplification is an issue with most, if not all, altmetric indicators and more common with social media mentions due to a lack of information about the diverse forms of and motivations for user interactions. For instance, the assumption of tweets indicating societal impact has failed, as tweets seem to mostly reflect the academic interest, despite majority of Twitter (rebranded as X since July 2023 and from now on simply called X in this paper) users being non-academics (Maleki and Holmberg 2026). Studies have also shown that visual content and more natural communication patterns (i.e. use of natural language and avoidance of paper title) are more engaging and play an important role in diffusion of scientific publications on X (Maleki and Holmberg 2024). While at the same time the majority of contributors to scientific content on X have been found to be academics, as well as members of the general public (Maleki and Holmberg 2024), suggesting that researchers' interest in scientific tweets is likely to be more aligned with their personal rather than professional interests (Bowman 2015). Evidence from earlier research highlights the need to more critically assess the role of X in research evaluation to ensure the extent to which tweets can reflect the impact and quality of research compared to popularity.

X is a popular social media platform where users (still often called tweeters) can publish and share content to their network of followers. Because of its easy-to-use form and the potential to rapidly reach wide audience, X has been a popular platform for a multitude of different purposes, such as news sharing, entertainment, marketing, social interaction, activism, and for research. Originally the content on Twitter was limited to short texts, but the original limit of 140 characters has increased over the years, and the content has diversified to allow for some media content. X now offers various features to share, discuss, and promote research called here as "affordances." Key X affordances that allow or encourage user interactions are tweet (or post), retweet (or repost), quote, reply, like, and bookmark. Creating an original tweet, replying to one, or quoting one, can be thought to indicate active user participation, while liking or bookmarking a tweet require minimal effort and can thus be said to indicate more passive engagement. Original tweets by researchers contribute to the immediate visibility of their work, helping to initiate conversations and attract attention from diverse audiences, while retweets indicate that the content resonates enough with the user to share it with their network. Retweets account for a significant portion of scholarly Twitter mentions (Didegah et al. 2018) and through retweeting users on X can easily disseminate content that someone else has originally published, thus retweeting can be considered as a form of simply forwarding content without contributing in any way to it. For sharing news, campaigning, or marketing, more retweeting is usually more desirable, as that means wider spread of the message or content. For some research purposes, such as when investigating people's opinions about various issues, original content might be preferred. While creating an original tweet can take a bit of effort, as one must think about how to formulate the message and possibly what media content to include in it, retweeting can easily be done just by clicking or tapping on a button. Technically, at least, retweeting does not require as much effort from the user as creating original content and tweeting it does. Because of this we argue that retweeting signals much less engagement with the shared content than creating and publishing an original tweet does, and because of this the two acts should be considered separately in altmetrics.

In altmetrics, X is one of the main data sources, as there is significant activity around scientific articles on the platform (Costas et al. 2015a; Haustein et al. 2015). Altmetric.com reports the count of tweets as a combination of original tweets and retweets and the count of X users as the unique count of users involved in posting tweets and forwarding retweets. Often in altmetrics tweets and retweets that mention scientific articles are counted as one measure, without making any distinction between the two. As both tweets and retweets are counted to the sum of attention that scientific articles have received on X, the possible difference in the level of engagement between tweets and retweets is not considered in anyway. When considering all tweets (both original and retweets), the total volume of mentions a paper receives on X can provide an overview of its visibility and the extent of its dissemination. However, the aggregated metric of all tweets might not fully capture the nuances of the engagement that has led to the visibility. For instance, a high number of retweets could inflate the perceived impact of a paper without reflecting deeper engagement or understanding of the content. This is particularly relevant as bots are more likely to generate original tweets (20%) than retweets (2%) (Maleki and Holmberg 2024), potentially skewing the metrics if not properly accounted for. Retweeting can nevertheless be considered as a deliberate choice to endorse or spread research, often leading to wider dissemination than original tweets alone can achieve, thus having important implications for altmetric studies. Because both tweeting and retweeting reflect user engagement, although possibly different levels of engagement, and have a direct and significant impact on how research is spread and perceived online, they should be given special attention in altmetrics. Also, compared to other X affordances such as likes and follower counts, tweets and retweets are more easily attainable as a metric. We argue that because the two acts are fundamentally different, indicating different levels and forms of engagement and possibly attention or impact, combining them in statistical analyses can yield different outcomes than if both were considered separately. The goal of this research is to investigate whether this is true, and whether original tweets and retweets should be analyzed separately in altmetric research.

2. Background

2.1. Diverse perceptions and roles of X in diffusing science

By the rise of social media platforms since mid-2010s scholarly communications have considerably transformed. Among them X plays a diverse and evolving role in research evaluation. Research publications have been shared over 212 million times by more than 12 million X users (as of September 2024), constituting over three quarters of any altmetric.com captures for scientific publications (Altmetric.com Explorer 2024). X has transformed the way researchers disseminate their work, engage with peers, and interact with different audiences. X users have a variety of different motivations and reasons to share research publications. Next, we summarise the key reasons for tweeting scientific publications, as discovered by earlier research.

Informing, disseminating and promoting: Tweets may provide factual information about the scientific article, such as summarizing key findings, highlighting the significance of the research, or explaining the methods used. Informative tweets often include the article's title, a brief summary, or key and critical results. A significant portion of original tweets linking to scientific articles are likely to be informative or promotional, given that researchers, institutions, publishers and journals frequently use X to disseminate their work. Several studies have found that tweets about scientific articles are simply sharing links with exact titles of the articles (e.g. Thelwall et al. 2013; Didegah et al. 2018). However, this practice has decreased as a longitudinal content analysis of tweets show that there has been a significant increase in reporting summary and other content, while mentioning the exact title has declined (Maleki and Holmberg 2024). The diversity of users who retweet informative tweets is vast, including both academic and non-academics.

- **Informative, Marketing and Promotional Accounts**: A large number of X users tend to follow journals and other aggregator accounts that consistently, and often automatically, post publication updates.
  - **Publishers and journals**: Academic journals and publishing institutions use Twitter to promote their publications and to attract attention to their articles, increase downloads, and drive engagement by simply posting titles or summaries of the findings from new publications or sometimes by maintaining journal clubs (Wray et al. 2018). Journals initiate significant number of tweets to scientific publications and are among highly active contributors to scientific content on X (Haustein 2019). Journal activity on X might influence broader research diffusion and public engagement more than other accounts and can have influence on how the articles gain future citations (Ortega 2016, 2017).
  - **Aggregators and bots**: Some X accounts serve at a broader level, posting publications on a topic or from a number of different journals or preprint databases. These accounts only inform the release of the research and they often do this automatically when they discover new content to share.
  - **Self-promotion**: Academics may also benefit from tweeting their own publications, as it may increase the visibility of their work. Researchers discussing the implications of their findings, responding to comments, and communicating their findings to non-specialists, policymakers, and the general public, can also have influence on societal impact and public understanding of science.
  - **Organizations**: For institutions, tweeting about scientific articles is also a way to enhance their brand

visibility and establish themselves as leaders or prominent knowledge centers in specific research areas.

- **Educators and science communication trainers**: It is difficult to indicate long-term educational impact or syllabus impact of scientific research on X (Maleki 2019), as it is often used for posting scientific articles immediately after they have been published while it can take years befor scientific papers to appear in course descriptions. However, students and faculty might use X to complement course material or stimulate discussion (Veletsianos et al. 2018). Early-career researchers can also practice science communication by explaining complex research ideas in scientific articles to a broader audience through tweeting (Camiel et al. 2014).

Discussion, opinion expression, including advocating and criticising: The discussion of scientific articles on X reinforces the perception of science as a dynamic and collaborative activity, where knowledge is shared, debated, and refined in public view. Such tweets express the user's personal views or interpretations of the research. They may include endorsements, criticisms, or discussions of the implications of the findings. About 2%–23% of research tweets tend to contain some form of opinion, personal interpretation and criticizing or questioning the research (Htoo and Jin-Cheon 2017). Sentiments and expressions of interestingness have been ∼5% (Thelwall et al. 2013; Sergiadis 2018), and such expressions of opinions have been found to be most common in Social Sciences and Humanities and least common in Life and Earth Sciences (Didegah, Mejlgaard and Sørensen 2018). Opinion-based tweets can influence how others perceive the research as they might attract a lot of bots and the general public (Dambanemuya et al. 2022), often shortly after the research has been published (Haunschild and Bornmann 2021). X users, researchers and the general audience alike, may tweet criticisms or concerns about the methodology, data, or conclusions of a study, that can lead to corrections or retractions (Dambanemuya et al. 2022).

Interactive Engagement: Although some tweets contain only the title of the publication or some findings, other tweets attempt to connect with the audience and encourage their engagement, for instance by asking questions or inviting feedback. Such engagement-oriented tweets often include interactive elements like polls or open-ended questions. Two studies classify 1%–11% of tweets across different disciplines as asking opinions and raising questions about research (Htoo and Jin-Cheon 2017; Didegah et al. 2018), while up to 8% of tweets contain requests to access research papers (Didegah et al. 2018).

Networking: X can also be used by researchers to build or maintain professional relationships, through acts of for instance tagging other researchers, acknowledging collaborators, or reaching out to potential collaborators. Networks of likes (Orduña-Malea and Costas 2021), retweeting users (Maleki 2014; Robinson-Garcia et al. 2017; Alperin et al. 2019; Fang et al. 2020) and interconnections between tweeters (e.g. Maleki 2018; Said et al. 2019) have been studied to examine the extent of networking around scientific tweets. Studies suggest that on average about a quarter of tweets, that can be considered as to be connected to research, contained @username mentions, a figure that has increased over time to about half of this type of tweets, suggesting that the users actively seek networking opportunities (Maleki and Holmberg 2024).

Timeliness and rapid communication: Although the correlation between tweets and citations is often weak to moderate, X activity can indicate early-stage impact (e.g. Thelwall et al. 2013) and interest from both academic and public communities. The immediacy of X uptake of scientific publications allows the scientific community and the public to be informed of the latest developments within the research fields they desire to follow. Several studies have shown the immediacy, but short-lived, X uptake compared to other altmeric indicators (e.g. Eysenbach 2011). One study has suggested that the time of day when a tweet was posted affected its engagement, with tweets posted in the afternoon and evening receiving more retweets and likes than those posted at other times (Mahendran 2022), suggesting that the level of engagement received on X might have more to do with the way research is communicated and less with the actual impact of research.

2.2. Characterization of X/Twitter in Altmetric Research

Much of early altmetrics research focused on examining whether altmetrics could be an alternative to traditional citation-based measures of impact, or possibly complementing them by demonstrating a wider societal impact of research. Using data from X, early research focused on testing for correlations between tweets and citation counts, providing some mixed results with large scale studies (e.g. Barthel et al. 2015; Costas et al. 2015a,b) showing lower correlations between tweets and citations than studies with more focused, journal or discipline specific samples (e.g. Eysenbach 2011; Shuai et al. 2012). It appeared that in some focused cases with smaller sample sizes, tweeting and citing resembled each other, leading some researchers to suggest that the quantity of attention received on X could reflect later citations. However, these studies do not reflect on possible differences between original tweets and retweets in their association with citations and their possible implications for quality or popularity of research.

Earlier research has also discovered disciplinary differences in how scientific articles get tweeted, as scientific articles from social sciences and biomedical and health sciences tend to attract more attention on Twitter than articles from mathematics and computer science, and natural sciences and engineering (Costas et al. 2015b; Haustein et al. 2015). The results do not, however, reveal if this effect comes because of frequent original tweeting (possibly by researchers themselves) or through frequent retweeting (possibly by a wider audience) of the scientific articles. Other characteristics too, such as the length of the article (Haustein et al. 2015), OA status (Holmberg et al. 2020), and research funding (Didegah et al. 2018), may be connected to the attention scientific articles receive on X. The possible influence of considering both original tweeting and retweeting as a single measure in these studies remains unclear, although some of the previous research address the content and user engagement differences between original tweets and retweets to scientific publications. Understandability of content and elements that facilitate message delivery and effective human interaction on X, such as visuals and summary of research, appear to be more frequent in retweets (Maleki and Holmberg 2024). In a sample of 6,000 tweets and retweets to PLOS publications, Original tweets were more likely to contain only the hyperlink to the article or its title (36%), compared to the same in retweets (24%); however, retweets were more likely to include additional commentary or research context (63%) than original tweets (45%). Mentioning other users by @username also significantly increases the chance of retweets (Mahendran et al. 2022), while hashtags are used to promote the reach of retweets differently across different fields (Maleki and Holmberg 2024), with medical fields using more hashtags (e.g. Mahendran et al. 2022). Media content, especially images, are significantly more common in retweets (42%, average of 2006–22 PLOS publications) compared to original tweets (24%), and show a substantial increase in scientific tweets over the past decade (Maleki and Holmberg 2024), potentially resulting even in more likes (Mahendran et al. 2022).

In the dissemination of PLOS publications on X, earlier research has shown that the types of users initiating original tweets linking to surgical research were most often created by a reader (42% of cases), followed by the paper's authors (20%), journals (17%), aggregators (16%), and official society accounts (5%) (Mahendran et al. 2022). Depending on the popularity of accounts, the papers' authors might have a higher median number of retweets (8) and likes (15) compared to those created by journals (6 retweets, 9.5 likes) or other entities. Whilst Bots, contribute more to original tweets (20%) than retweets (2%), indicating that retweeting is less automated and more likely to involve human interaction (Maleki and Holmberg 2024).

Lack of stability and privacy in sharing content on social media is another issue influencing the dependability and trustworthiness of social media content in the long-term, specifically in the context of research evaluation. As Fang et al. (2021) state it, the structure of retweets (whether they are concentrated around a few original tweets or more evenly distributed) significantly affects the stability of X metrics. Publications with retweets concentrated around a single original tweet are more vulnerable to large drops in X metrics if that original tweet becomes unavailable. This leads to instability in the perceived impact of the research as measured from X. In another study, Maleki and Holmberg (2023) showed that PLoS journal articles shared in retweets (7.6%) are about twice as likely as original tweets (4.2%) to be unavailable or inaccessible, possibly because they have been deleted or made private by the user or unavailable due to the user account being suspended. This phenomenon appears to be more likely in STEM fields than Social Sciences and Humanities.

Another study investigated how different types of user engagement behaviors on X, i.e. liking, retweeting, quoting, and replying, were used in connection to scholarly content (Fang et al. 2022), with results showing likes (44%) and retweets (36%) being more frequently used, while quotes (9%) and replies (7%) being less frequent. Research has also shown disciplinary differences in how researchers use X (Holmberg and Thelwall 2014), and the ways with which users engage with scientific content on X (Fang et al. 2022). But do the disciplinary differences extend to both tweeting and retweeting? This research seeks to investigate differences between original tweets and retweets by investigating how citation counts correlate with them when they are considered separately, and if there are any disciplinary differences between tweeting and retweeting. The main objective of this research is to investigate if tweets and retweets should be treated separately in altmetrics, which lead us to the following two research questions:

1) Are there disciplinary differences in how science is being tweeted compared to how it is retweeted?
2) Do tweet and retweet counts correlate differently with citation counts to the same articles?

3. Method

3.1. Data

A total of 330,022 PLoS publications published between 2003–23 were extracted from Scopus in April 2023. The reason PLoS was chosen was to both be able to compare a wide range of paper across different disciplines and to create a dataset that entails equality in terms of open accessibility to all of the included scientific articles. The extracted publications were published in nine PLoS journals and eight proceedings, with majority of the papers (94%) being journal articles. Altmetric.com was used to extract separate datasets of (1) all tweets and (2) original tweets, which were then used to identify and count the number of retweets for each paper.

3.2. Subject fields

As all PLoS papers are only classified as multidisciplinary in Scopus, we used the classification made by *Dimensions* and used by *altmetric.com* based on *Australian and New Zealand Standard Research Classification 2020 (ANZSRC)*[1] to assign subject fields to each article. For this analysis, we mainly used the first subject field assigned to each paper, but we have also assessed the differences of results when fields were assigned as non-primary subjects.

Table 1 shows the number of publications when counting only with the first subject field assigned. The first eleven fields in Table 1 are from Natural Science, Engineering and Medical and Health Sciences (STEM) and the second eleven fields are from Social Science and Humanities (SS&H). Of all the publications ~19% have not been assigned to a field; these mostly were Erratum and non-tweeted.

3.3. Analysis

To analyze the possible relationship between citations and all tweets, original tweets and retweets, comparisons across fields and over time were conducted. For this purpose, proportion non-zero and Geometric mean of citations, tweets and retweets were calculated and normalized for comparisons between subject fields and with the world average. In this research, the term "world" represents all PLoS publications. The data was first prepared based on Thelwall (2017) and then the calculations were conducted with Webometric Analyst (lexiurl.wlv.ac.uk).

a) *Normalized* proportion non-zero was used as an estimate for publications with non-zero Scopus citations, tweets and retweets, in 95% confidence interval.
b) *World normalised or field-equalized non-zero proportion cited of metrics (EMNPC)* were used for comparisons. EMNPC values for fields are compared for any variation from the world average (=1).
c) *Geometric mean* was calculated based on reversed exponent of the average of logarithms of raw metric counts + 1 or log-transformed metric counts (1 + raw data) (Thelwall 2017) in 95% confidence interval.

Table 1 The count of PLoS papers categorized based on both their primary subject field assignment and the total number of publications in the cases of multiple field assignments (including duplicates).

Fields of research (FoR)	First/primary field (no duplicates)	All publications in field (incl. duplicates)
Mathematical Sciences	7,787	8,312
Physical Sciences	1,506	4,319
Chemical Sciences	2,855	8,584
Earth Sciences	2,142	5,407
Environmental Sciences	8,631	15,129
Biological Sciences	92,008	129,424
Agricultural and Veterinary Sciences	1,637	19,121
Information and Computing Sciences	6,984	17,317
Engineering	2,555	9,597
Technology	851	1,071
Medical and Health Sciences	123,711	172,521
Built Environment and Design	27	748
Education	818	1,779
Economics	1,984	4,337
Commerce, Management, Tourism and Services	498	2,830
Studies in Human Society	1,854	10,976
Psychology and Cognitive Sciences	10,496	22,991
Law and Legal Studies	123	1,292
Studies in Creative Arts and Writing	84	874
Language, Communication and Culture	529	1,999
History and Archaeology	792	2,182
Philosophy and Religious Studies	100	624
No subject assigned	62,050	62,050
Total	330,022	

d) World-normalised mean metrics or *Mean Normalised Log-transformed Citation Score (MNLCS)* proposed by Thelwall (2017) were calculated in 95% confidence interval and as the name suggests on log-transformed data using log-transformed metric counts (1+raw data). *MNLCS* values need to be compared with value *one* which represents the world average.

The calculations for world normalization are detailed in Thelwall (2017).

4. Findings

4.1. Normalized proportion cited

Figure 1 shows that the total publication frequency of PLoS had significantly increased from 87 in 2003 to just below 35,000 in 2013, after which the level drops and remains at ~20,000 annually. The proportion non-zero citations show a cumulative increase over time; the proportion non-zero tweets rose from ~20% in 2010 (about the time when altmetric.com started to collect tweets) to 76% in 2016 and then a fall to ~65% in 2022; the proportion non-zero retweets shows a delayed rise since 2013, rising to 40% by 2018, levelling off after that, while proportion tweeted has slightly dropped in the same period.

Presenting the results from the normalized proportion non-zero of metrics, Fig. 2 shows that on average 92% of publications in STEM fields had been cited, while only 82% in SSH fields had received citations. On average, 75% of articles in STEM had been tweeted, compared to 85% in SSH, while only 35% of STEM articles and 50% of SSH articles had been retweeted. Despite a significant difference between number of publications in each subject category based on the first-assigned subject and all publication with a field assignment (i.e. both as primary and non-primary field) as in Table 1, Fig. 2 shows that the proportion of cited publications does not vary significantly for a field between these two subject assignment methods, despite exceptions. One exception is Psychology and Cognitive Science where publications with this field assigned as the first subject significantly tweeted and retweeted (by ~5%) higher than all publications with psychology among their multiple fields. This is seen only for retweets in Studies in Human Society and Environmental Sciences. In contrast, in Information and Computer Science, Physical Sciences and Biological Sciences the paper in first-assigned subject category significantly had smaller proportion tweeted and retweeted. This suggests that in multi-disciplinary publications stronger SSH-orientation can encourage higher tweet and retweet attention and stronger STEM-orientation can discourage tweet attention significantly.

4.2. World normalised proportion non-zero for metrics or EMNPC

Figure 3 shows that after world normalization of proportions non-zero, both tweets and retweets appear significantly above world average in SSH fields (SSH > 1); for STEM fields, the results are mixed both below and above the world average. Mathematical Science, Earth Science, Environmental Science and Information and Computing Sciences all show EMNPC > 1 for tweets and EMNPC > 1.5 for retweets, while all the other STEM fields remain below the world average. The results also showed that the diversion from the world average for retweets is at higher magnitude than for tweets across all fields. This may suggest a greater discrepancy across fields in terms of retweeting behaviour than citing and tweeting in general.

4.3. Geometric mean citations vs. original tweets and retweets

Figure 4 illustrates the changes in geometric mean metrics over time, showing that the geometric mean for citations peaked at ~49 in 2008 before gradually dropping over years. The trend is, however, almost reversed for the metrics from

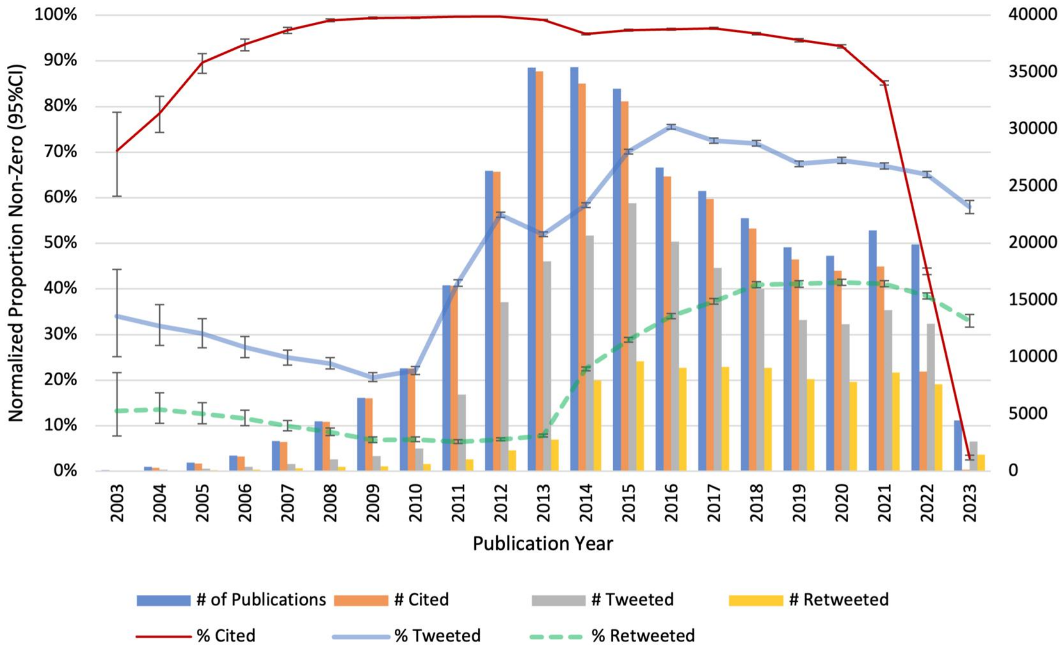

Figure 1 Frequency of total publications, publication cited, tweeted and retweeted and normalized proportion non-zero in the metrics.

X, showing a slow drop between 2003 and 2009 (<1) before rising to ∼3 for total tweets in 2018 (∼2 for original tweets and 1.25 for retweets), soon after which they all start to fall. The average geometric mean citations across STEM fields is 14, while ∼9 across SSH fields. In contrast, the average geometric mean all tweets, original tweets and retweets across STEM fields (3, 2 and 1, respectively) is approximately half the SSH fields (6, 4, and 2).

4.4. World normalised mean metrics or MNLCS

The mean of world normalized ln(1 + raw metric values) metrics from X mentions indicates subject bias (Fig. 5). In STEM fields, such as Chemical Science, the results are below the world average for tweets and retweets, while slightly above it for citations, but the case is very different for the SSH fields. A majority of SSH fields perform below world average in terms of citations, but significantly above the world average in tweets and original tweets by up to 1.5 times above the world average and in retweets by 3.5 times the world average (e.g. History and archaeology, and Studies in creative arts and writing).

4.5. Spearman's correlation between citations and different types of tweets

Table 2 gives the number of total publications, and publications with at least one citation, original tweet and retweet over the period of 2010–23. This data was statistically analysed using Spearman's correlation analysis. The analysis was conducted by both including zeros and excluding zeros. Due to significant number of publications with zero metric count in many of the altmetric indicators it is important to identify how meaningful the zeros are when examining the relationship between variables (Thelwall et al. 2013). While excluding zeros might lead to bias in the results, by only analyzing cases with some mentions, potentially overstating correlations, in altmetric research, zero mentions may be meaningful and indicate a lack of public interest in certain topics.

The correlation coefficients between citations and all tweet metrics showed stronger correlations when the zeros, i.e. articles with no citations or tweets, were included in the calculation (Fig. 6). The correlations were weak but significant across the line. The strength of the relationship between citations and tweets has, however, first increased over time and then from 2019 started to fall, suggesting that citation takes time to be accrued and hence the relationships with citations lack strength in the latest years. Furthermore, as of STEM fields when zero metric counts are included, the correlation coefficients were slightly stronger for *all tweets* than *original tweets* from 2011 ($r = 0.157 > 0.151$, respectively) through 2018 ($r = 0.299 > 0.296$), however the trend is reversed since 2019 ($r = 0.299 < 0.303$) when the relationship appears to be slightly stronger between citations and original tweets than for all tweets in both zero-included and zero-excluded datasets. The weaker correlation coefficients between retweets and citation across all years and increased proportion of retweets in the later years (see Fig. 4), suggest that increase in proportion of retweets, which is a new development due to the changes on the platform, has further debilitated the statistical association between all tweets and citations.

Including zero metric counts in the datasets resulted in *stronger* correlation coefficients between citation and all the other metrics in SSH fields (median r with original tweets = 0.409 in zero-included dataset, 0.329 in non-zero dataset), but *weaker* correlation coefficients in STEM subject fields (median r = 0.175 in non-zero dataset, r = 0.149 zero-included dataset). Biological Science, which shows significant weak but positive correlation in zero-excluded datasets with citations, both for original tweets ($r = 0.103$) and retweets ($r = 0.053$), is the only field to have significant negative correlation at both zero-included datasets of tweets ($r = -.050$) and retweets ($r = -.096$), suggesting that in biological science more than any other field, tweets might be misleading as either highly impactful academic research can lack tweets or research with little scientific impact can be significantly tweeted. Overall, impact of including zeros on the statistical

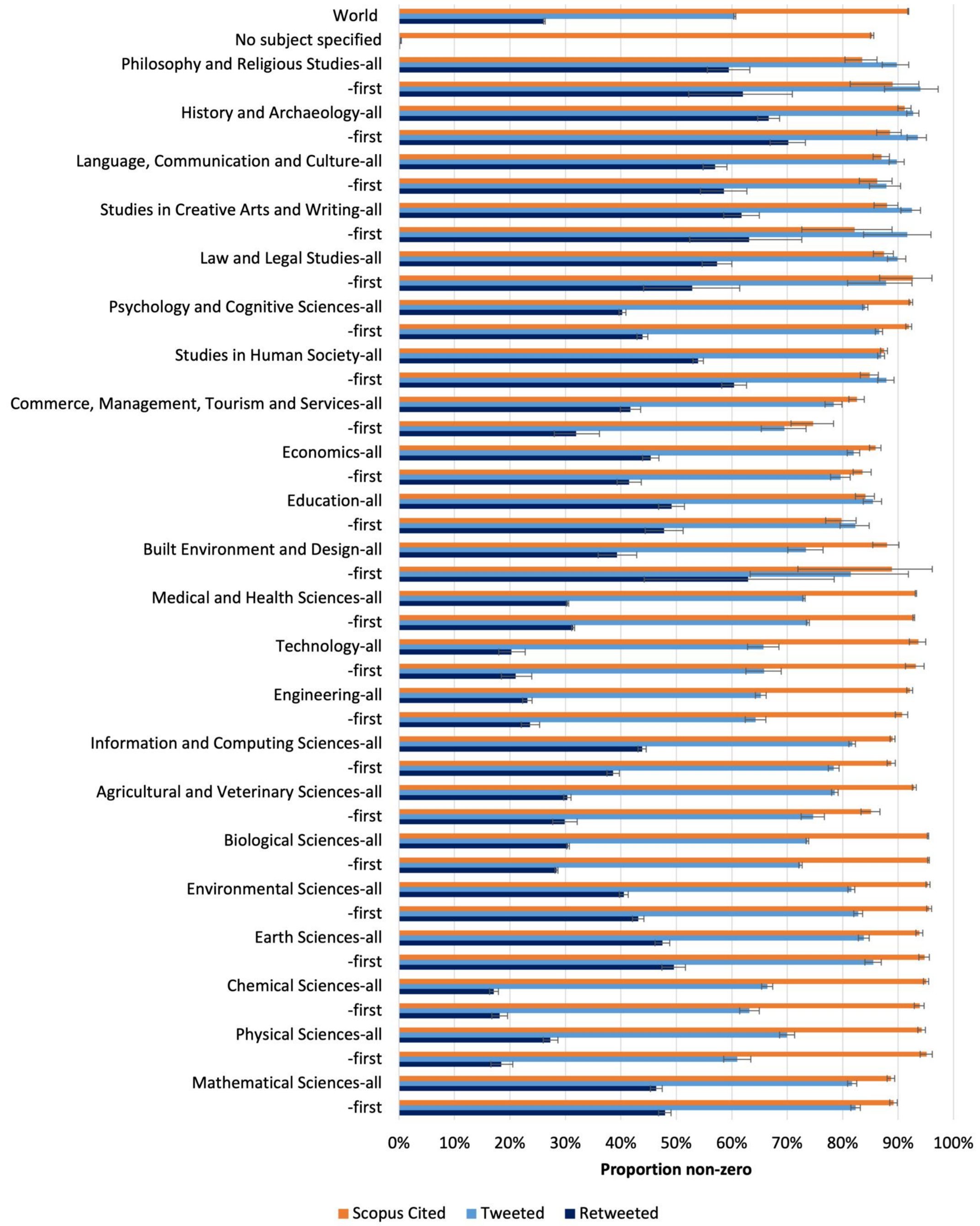

Figure 2 Normalized proportion cited, tweeted and retweeted across fields. -all: all publications in field; -first: only papers with the primary subject.

associations suggest that tweets are moderately likely to align with traditional research impact in Social Science and Humanities, but they indicate only a weak relationship and a limited usage in STEM subject fields.

Figure 7 illustrates a heatmap of the correlation coefficients between Scopus citations and the three metrics of all tweets, original tweets, and retweets across subject fields for zero and non-zero datasets. The general pattern suggests that the median correlation coefficient of Scopus citations across fields is highest with original tweets (median $r = 0.310$), while remaining weak but significant with retweets (median $r = 0.087$). However, there has been a significant disciplinary disparity, as for the SSH subject fields the median correlation coefficients between citations and original tweets were at significant medium level (median $r = 0.409$), in contrast to the significant weak correlation in STEM subject fields (median $r = 0.162$). Retweets in 7 out of 11 STEM fields indicate a significant weak negative correlation (median $r = -.044$), while staying significant positive but weak for SSH (median $r = 0.225$).

5. Discussion

Current study identified original tweets and retweets as two affordances of X for sharing scientific publications and compared use of citations, original tweets, and retweets, as measures of impact assessment over time and across different scientific disciplines. The results were in line with some of the

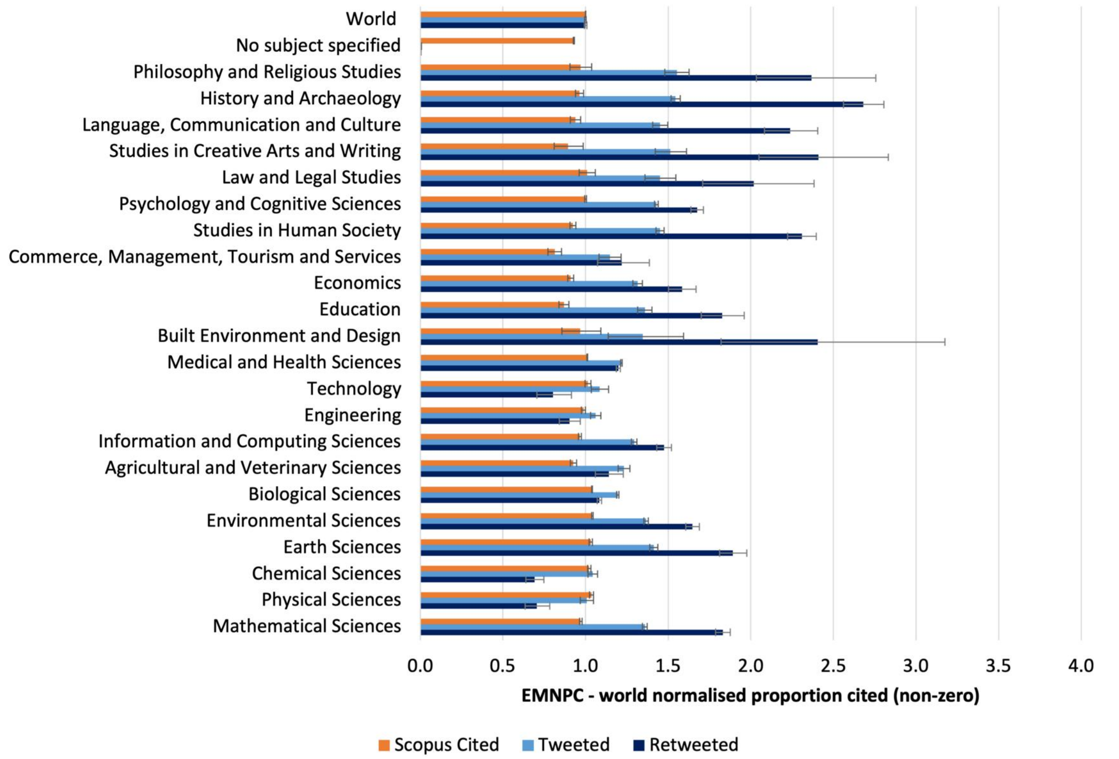

Figure 3 World normalized proportion cited, tweeted and retweeted across fields.

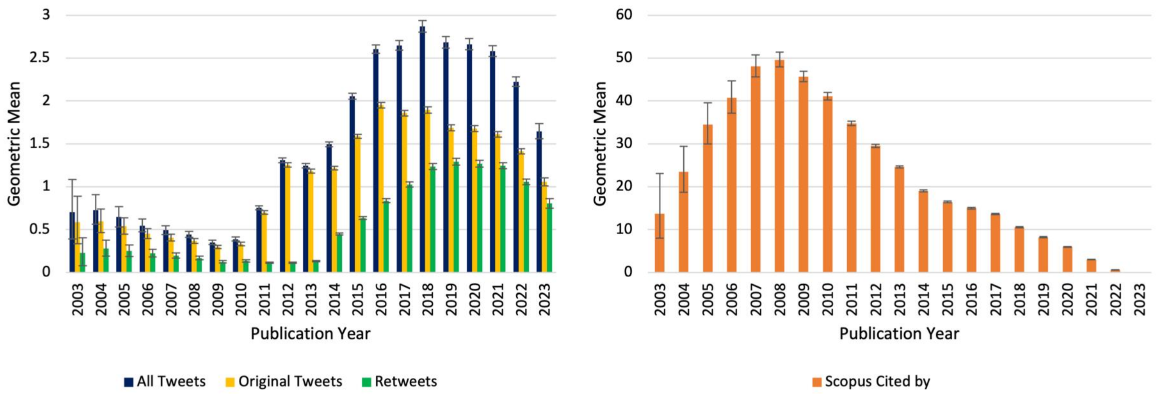

Figure 4 Geometric mean Scopus citations, tweets, original tweets and retweets over years.

findings in earlier research (e.g. Costas et al. 2015b; Haustein et al. 2015) and showed disciplinary differences in how scientific articles had been mentioned and shared on X, with articles in Social Science and Humanities receiving up to 2 to 3 times as much retweets as the world average, compared to Natural Science and Engineering, which were below the world average. There were stark disciplinary differences in user engagement and hence extent of retweeting. While scientific articles in STEM fields do not receive X posts in the amounts that would reflect the scientific attention or impact they have had as measured by citations, articles from SSH fields seem to enjoy a moderate level of alignment between scientific impact and tweets, but due to weak correlations between retweets and citations, any research assessment considering using X posts for research assessment should not mix popularity with quality factors. Most retweeting occurs in areas that more frequently use media content and visual content on X, pointing at the importance of such content in disseminating scientific content to wider audiences. Although original tweets tend to have weak to medium, but significant, correlation with citations (median $r = 0.310$), this association when considering all tweets (median $r = 0.233$) is considerably debilitated by retweets (median $r = 0.087$) which are much less aligned with citations. In other words, including retweets in the analysis consistently skews the results across fields. It is, therefore, worth noting that different types of tweets are indicating mixed signals or different types of impact. Although academics contribute significantly to the scientific content on X by sharing and discussing scientific articles, the broad tweet patterns, including all tweets, are not well aligned with that of citations.

Based on our findings the relationship between X metrics (original tweets, retweets, and total tweet counts) and traditional citation metrics is generally weak to moderate with an overall interconnection and alignment, despite obvious distinctness, between the three metrics. Previous studies also

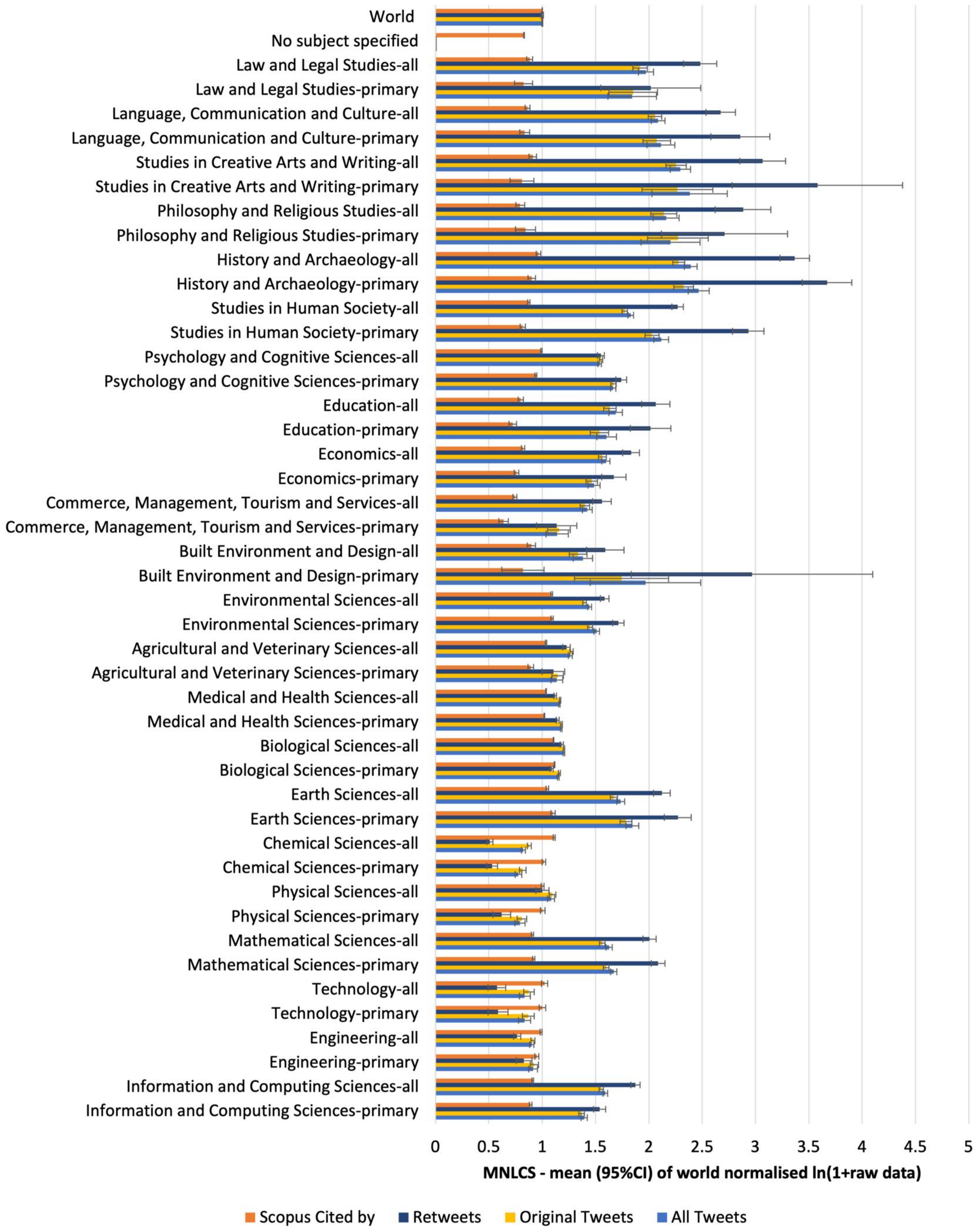

Figure 5 Mean of world normalized log-transformed metric counts (1 + raw citation, tweet, or retweet count) across fields.

consistently found weak to moderate correlation between total tweets and citations, and only low correlation coefficients between the number of retweets and citations, indicating that popularity of or attention received by a research paper on X does not necessarily translate into academic impact that would be comparable with what could be measured by citations. A relatively comparable example would be the study of scholarly X mentions containing the Bitly short URL that found a Spearman correlation coefficient of only 0.071 between retweets and Web of Science citations, while the correlation between X clicks (a more engaged form of interaction) and citations was slightly higher but still weak, at 0.094 (Fang et al. 2021). The observed weak correlation in our findings and that of earlier research, suggests that while retweets can enhance the visibility of research and have an impact on the reach of scientific content on X, they do not strongly predict the papers' academic influence that would later translate into citations. The disparity between the two metrics highlights the need for careful interpretation of tweet data.

Although we do not directly know all the motivations for sharing scientific articles on X, some earlier research has attempted to investigate them (Kumar et al. 2019). Our findings consistently show a stronger correlation between citation impact and original tweets and retweets in SSH compared to STEM fields. A straightforward explanation, as suggested in applied linguistics literature, is that SSH research is communicated in more accessible, natural human language, whereas

Table 2 Over time frequencies of all publications, and the publications with at least one Scopus citation (cited), tweet (tweeted), or retweet (retweeted).

Publication year	STEM				SS&H			
	Publications	Cited	Tweeted	Retweeted	Publications	Cited	Tweeted	Retweeted
2010	6,506	6,492	1,873	585	223	223	124	47
2011	11,994	11,958	6,298	943	539	538	419	113
2012	20,849	20,794	13,842	1,657	1,050	1,046	944	179
2013	26,624	26,496	17,100	2,447	1,416	1,406	1,225	317
2014	26,094	25,762	19,186	7,244	1,426	1,407	1,248	658
2015	27,204	26,780	21,687	8,661	1,676	1,658	1,511	925
2016	22,343	21,823	18,293	8,202	1,477	1,428	1,358	811
2017	20,246	19,813	16,260	8,345	1,357	1,320	1,252	737
2018	16,921	16,519	14,318	8,142	1,497	1,448	1,331	841
2019	14,145	13,690	11,846	7,204	1,286	1,235	1,056	751
2020	13,506	12,917	11,319	6,880	1,328	1,242	1,066	741
2021	14,368	12,674	11,353	7,124	1,650	1,404	1,213	780
2022	14,672	6,852	5,785	3,741	1,667	705	552	354
2023	2,980	104	90	63	427	14	9	7

	Citations & All Tweets		Citations & Original Tweets		Citations & Retweets	
	with zeros	non-zeros	with zeros	non-zeros	with zeros	non-zeros
Mathematical Sciences	0.027	0.063	0.092	0.149	-0.045	0.092
Physical Sciences					-0.068	
Chemical Sciences		0.087		0.139	-0.050	
Earth Sciences	0.164	0.170	0.235	0.261		
Environmental Sciences	0.071	0.115	0.136	0.207	-0.043	0.091
Biological Sciences	-0.079	0.053	-0.050	0.103	-0.096	0.053
Agricultural and Veterinary Sciences	0.210	0.232	0.238	0.290	0.139	0.184
Information and Computing Sciences	0.210	0.212	0.248	0.265	0.116	0.137
Engineering	0.143	0.115	0.162	0.151	0.057	
Technology					-0.099	
Medical and Health Sciences	0.031	0.121	0.063	0.175	-0.018	0.123
Built Environment and Design	0.546	0.447	0.637	0.605		
Education	0.346	0.257	0.412	0.329	0.178	0.198
Economics	0.362	0.266	0.388	0.297	0.234	0.150
Commerce, Management, Tourism and Services	0.373	0.335	0.409	0.369	0.215	0.363
Studies in Human Society	0.388	0.328	0.445	0.390	0.246	0.234
Psychology and Cognitive Sciences	0.233	0.222	0.310	0.307	0.043	0.131
Law and Legal Studies	0.315	0.215	0.401	0.319		
Studies in Creative Arts and Writing	0.241	0.279	0.431	0.308	0.300	
Language, Communication and Culture	0.347	0.309	0.409	0.376	0.212	0.318
History and Archaeology	0.206	0.131	0.291	0.217		
Philosophy and Religious Studies	0.469	0.449	0.484	0.481	0.360	0.394
All	**0.075**	**0.096**	**0.099**	**0.153**		**0.095**
Median of all fields	**0.233**	**0.219**	**0.310**	**0.294**	**0.087**	**0.150**
Median of 11 STEM fields	**0.107**	**0.115**	**0.149**	**0.175**	**-0.044**	**0.108**
Median of 11 SS&H fields	**0.347**	**0.279**	**0.409**	**0.329**	**0.225**	**0.234**

Figure 6 Spearman's correlation coefficients between Scopus citations and all tweets, original tweets and retweets over time. The heatmap uses a color gradient from blue to red, where blue represents the weakest correlations and red represents the strongest, indicating increasing correlation strength.

STEM research relies on specialized, technical jargon due to the nature of its subject matter (Martin 1991; Hyland 2004) which might be a barrier to public understanding (Bullock et al. 2019). In fact, lexical sophistication may negatively affect online attention because non-experts prefer to share research with simpler language (Jin et al. 2021). This linguistic difference could make SSH research easier to comprehend and thus lead to higher levels of online engagement.

Another possibility is the influence of subject matter accessibility. SSH research often aligns with pressing social, political, and cultural issues, increasing its relevance and interest among non-academic audiences. Researchers in these areas may also be more active in sharing their work, which leads to increased attention in both scholarly and non-scholarly discussions compared to articles in Natural Science and Engineering (Holmberg and Thelwall 2014). STEM, on the other hand, may sometimes be more difficult to comprehend without specialized training in the topic research, with the articles tending to be more technical, requiring additional interpretation before reaching wider audiences.

Readability could also influence online attention, but existing research provides inconclusive evidence regarding its role (Fagerlund 2022). While linguistic accessibility remains a relevant consideration, readability alone does not seem to fully explain differences in SSH and STEM engagement. The stronger correlation between citations and social media uptake in SSH is likely to stem from a combination of institutional and disciplinary factors, including topic prominence, differing

	STEM						SS&H					
	Including zeros			Only non-zeros			Including zeros			Only non-zeros		
	All	Original	Retweet	All	Original	Retweet	All	Original	Retweet	All	Original	Retweet
2010	0.205	0.206	0.165	0.202	0.213	0.135	0.404	0.415	0.234	0.339	0.375	
2011	0.157	0.151	0.156	0.201	0.183	0.11	0.27	0.259	0.257	0.264	0.247	
2012	0.2	0.195	0.179	0.217	0.206	0.153	0.325	0.319	0.293	0.312	0.305	0.303
2013	0.218	0.215	0.181	0.236	0.228	0.17	0.373	0.366	0.337	0.344	0.335	0.311
2014	0.221	0.218	0.2	0.245	0.243	0.209	0.337	0.343	0.287	0.336	0.344	0.286
2015	0.241	0.236	0.222	0.239	0.231	0.216	0.39	0.387	0.359	0.367	0.363	0.336
2016	0.284	0.275	0.277	0.291	0.283	0.252	0.395	0.376	0.389	0.372	0.354	0.33
2017	0.29	0.284	0.282	0.289	0.282	0.261	0.384	0.376	0.352	0.363	0.347	0.337
2018	0.299	0.296	0.279	0.282	0.278	0.273	0.34	0.356	0.295	0.311	0.332	0.262
2019	0.299	0.303	0.278	0.282	0.288	0.28	0.346	0.351	0.31	0.292	0.301	0.284
2020	0.301	0.311	0.27	0.278	0.293	0.25	0.277	0.295	0.256	0.231	0.25	0.193
2021	0.284	0.297	0.251	0.252	0.267	0.223	0.232	0.26	0.187	0.184	0.236	0.202
2022	0.216	0.217	0.199	0.172	0.183	0.156	0.124	0.138	0.098		0.114	**0.113**
2023	0.096	0.091	0.095									

Figure 7 Spearman's correlation coefficients between Scopus citations and all tweets, original tweets and retweets across fields. The empty cells indicate no statistical significance ($P > .05$). The heatmap uses a color gradient from blue to red, where blue represents the weakest correlations and red represents the strongest, indicating increasing correlation strength.

communication norms, and differences in audience composition and behaviour. This is consistent with prior research (Haustein et al. 2016; Vainio and Holmberg 2017) showing that both experts and non-experts, drive scholarly engagement on social media. While the (presumably higher) educational status of people on Twitter might be a contributing factor to insignificance of readability cues (Fagerlund 2022).

While our results increase our understanding of the different affordances in altmetric indicators and of their applicability in research assessment, our research also raises some new questions. Future research should investigate the influence of both publishers' and research institutions' actions and their policies on altmetric events. For instance, to what extent do publishers and/or research institutions encourage or require authors to share their work on social media? What incentives are there for researchers to share their work on social media? Do researchers in SSH and STEM perceive the value of sharing their work in social media differently? A deeper exploration of institutional and editorial policies could help explain why SSH research enjoys higher engagement on social media and how this translates into citation impact.

Our main research goal was to analyse whether original tweets and retweets should be considered as different measures or indicators and therefore analysed separately, and our findings point to significant differences between the two forms of communication on X. The results from our analyses showed how the correlations between citations and original tweets were stronger than correlations between citations and retweets, and how the correlations overall were stronger for SSH subject fields than STEM subject fields. Writing original tweets that mention or link to scientific articles seem therefore to be closer to the act of citing scientific articles, while retweeting (sometimes possibly even without reading the scientific article) is more of a disseminating function and may be more important for scientific content to reach wider audiences. Combined with earlier results about how including visual content or content that invites interaction increases the likelihood of getting retweeted (Maleki and Holmberg 2023, 2024), provides strong evidence of how original tweets differ from retweets and therefore, should be treated and analyzed separately, at least when it comes to altmetrics research. Combining tweets and retweets could potentially lead to unreliable measurements and conclusions that do not accurately answer the set research questions. More research is needed about the differences in the motivations to write and publish original tweets and to retweet content that someone else has created earlier. Understanding such differences may open up new avenues to investigate new forms of online scholarly communication.

The findings also raise some concern over the use and credibility of composite metrics where tweets and retweets are treated as one measure or an indicator of online attention. Such aggregated metrics may not accurately reflect true engagement with or attention towards scientific articles and the underlying diversity in motivations for the online activity surrounding scientific articles can obstruct or skew reasoning about the changes or conclusions drawn from statistical analyses and associations. Researchers must consider the possible different levels of engagement and different types of actions tweets and retweets represent when conducting future research using data from X. On the other hand, if analysed separately original tweets and retweets may provide research opportunities to study new aspects of online scholarly communication and how scientific content is shared and discussed online. Clearly, more research is needed to better understand the detailed dynamics of distinct forms of social media interactions and their implications for scholarly communication.

6. Conclusion

While peer-review may not be without its considerations, the prospect of using X for research evaluation bears even more complexity due to potential for misinterpretation of attention or popularity over quality. Overall, original tweets, retweets, and the total volume of all tweets, each contribute differently to the perceived attention the shared or mentioned research has gained on X, and therefore, to the validity of the research assessment, should X be used for that purpose. Original tweets require some engagement and are therefore likely to represent a more engaged and meaningful interaction with research and its outputs. Retweets, on the other hand, may require less effort and engagement from the user and they may contain more affordances that better catch readers' attention and attract them to retweet. Retweets are likely to fill an important function to disseminate scientific articles to wider online audiences. The aggregated metric of all tweets offers a broad view of visibility or attention but may obscure the quality or level of engagement. Future research could identify diversity in the underlying activity across other altmetric platforms, beyond Twitter, and expand on our understanding of quality and popularity of research metrics. The weak correlation between these social media metrics and traditional citations underscores the complexity of using altmetrics for research evaluation, suggesting that they should be interpreted as a supplementary indicator of impact or attention rather than a direct measure of academic influence. While social media continues to evolve and the ways in which we use the online platforms become increasingly diverse, so too will the ways in which we assess research impact become more diversified and complex. There are more lessons to learn about how different social media metrics may contribute and refine altmetric models in research evaluation and lead to better understanding of how to use them to capture the complex dynamics of modern online scholarly communications.

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Conflict of Interest

The authors declare that they have no known competing interests.

Note

1. https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/1297.0

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