Revista
Mediterránea
de Comunicación
Mediterranean Journal of Communication ISSN 1989-872X

Elena DENIA
Instituto INGENIO (CSIC-UPV). Span. elenadenia@ingenio.upv.es

Twitter as a research tool in science communication

Twitter como objeto de investigación en comunicación de la ciencia

Dates | Received: 04/04/2020 **-** Reviewed: 03/06/2020 **-** In press: 09/06/2020 - Published: 01/01/2021

Abstract

Twitter's microblogging service, employed both as an information network and as a social network, is an object of emerging research with great potential to explore the dissemination of science, but in which there exists a certain theoretical disorder. First, this article presents a variety of relevant results in communication studies emphasising Twitter. Next, the focus is on the field of science communication. Hence, a variety of illustrative works are presented to provide an overview of the different purposes, approaches and methodologies employed, providing a conceptual framework for future work. In addition, as a result of this compilation, the main functions that Twitter plays as a tool for science communication are clarified. Depending on the agents involved and their apparent objectives, these are configured in a specific and even empirically observable way. A distinction is also considered between two research approaches; one focused on information -scientific topics of public interest- and the other on dissemination agents - scientists, journalists and institutions. Some specific research lines for further study are also suggested.

Keywords

Twitter; science communication; public outreach; scientific journalism; social media; network analysis

Resumen

El servicio de microblogging Twitter, utilizado a la vez como red de información y como red social, es un objeto de investigación emergente con gran potencial para explorar la difusión de la ciencia, pero sobre el que existe cierto desorden teórico. Es por ello que en este artículo se documenta, en primer lugar, una serie de resultados relevantes en estudios de comunicación que se centran en el ecosistema Twitter. En segundo lugar, se sitúa el foco en el ámbito de la comunicación de la ciencia, para el que se exponen trabajos ilustrativos con el fin proporcionar una perspectiva de conjunto sobre los distintos propósitos, enfoques y metodologías utilizadas, en vistas a servir de marco conceptual para trabajos futuros. Además, como resultado de esta compilación, se esclarecen las principales funciones que desempeña Twitter como herramienta de comunicación científica, que dependiendo de los actores involucrados y sus objetivos aparentes se configuran de manera específica e incluso empíricamente observable. Se plantea asimismo una distinción entre dos aproximaciones de investigación; una centrada en la información -los temas científicos de interés público- y otra en los agentes difusores -científicos, periodistas e instituciones-. Por último, se sugieren algunas direcciones de investigación específicas para ulteriores estudios.

Palabras clave

Twitter; comunicación de la ciencia; periodismo científico; divulgación; redes sociales; análisis de redes

Denia, E. (2021). Twitter as a research tool in science communication. *Revista Mediterránea de Comunicación/Mediterranean Journal of Communication*, *12*(1), 289-301. https://www.doi.org/10.14198/MEDCOM000006

1. Introduction

The academic community realizes the need for a better understanding of how new virtual environments affect the practice of science communication (Brossard & Scheufele, 2013) in which access to content is often times produced without mediators. Since the current trend in science communication is to involve the public in a dialogue exchange (Nisbet & Scheufele, 2009), analysis of social media may be a useful complement to traditional surveys on social perception of science (Murphy, Hill, & Dean, 2013) that have been used to monitor citizens' interest in science and to understand the public's concerns with respect to research. In particular, the social network Twitter has been shown to actively reflect the social fabric, offering different manners of interacting, creating networks among actors, and building community (Harvey, 2014). It would therefore be a powerful tool that provides the opportunity to research science-based public debates and digital participation of laypeople in these open discussions, in addition to allowing dissemination agents to share scientific content (López Pérez & Olvera Lobo, 2019).

While it is true that science communication on Twitter has received less academic attention than, for example, the much more common marketing studies or analyses on political communication (Percastre-Mendizábal, Pont-Sorribes, & Codina, 2017), it is worth considering that various topics of scientific interest for the general population are shared using this social network, and in that sense, Twitter is an inexhaustible source of raw information related to public opinion that also supports monitoring information flow (Pérez-Rodríguez, González-Pedraz, & Alonso-Berrocal, 2018).

For researchers, businesses, and organizations interested in collecting and analyzing tweets, the platform offers an open access interface for extracting data, known as Application Programming Interface (API). Searches conducted through the API allow compilation of the data using various types of searches, including key words or user profiles, and this is how we could discern between two different approaches for academic research: (1) analyzing the content of tweets; and (2) analyzing the network of agents who operate within it. The first approach is carried out by searching for key words, and normally computational tools for processing natural language are applied. The second approach, however, is carried out by following usernames, which allows the detection of networks of actors who represent communities. Note that there is a tendency for users to participate in communities with similar interests (Java, Song, Finin, & Tseng, 2007).

This may indicate that a general trend with respect to the communicative intention of users is using Twitter to publish, to a greater extent, personal content related to their daily activities, and not as much about informative publications, around 80% and 20% respectively (Dann, 2010; Naaman, Boase, & Lai, 2010). Meanwhile, when following profiles, it is found that the social network is used based on specific information needs (Hughes & Palen, 2009). Both occurrences give some clues about the research directions that are leading the way.

On the other hand, with regard to the dissemination of information on Twitter, research on the dissemination of science has focused mainly on the process of sharing information in the second degree. This refers to how tweets are disseminated by retweeting them, while publication of original tweets—first degree of sharing—is an aspect that has received less academic attention (Veltri & Atanasova, 2015); however, it constitutes a fruitful and suitable focus for further research. Therefore, this article outlines some works using that approach in order to encourage that line of study.

2. Methodology

The overall objective of this article is to provide a theoretical system for designing new studies in science communication in which Twitter is used as a tool for analysis. The specific objectives include: (1) identifying the overall research trends on Twitter and what roles are typically assigned to the users; (2) distinguishing between two research approaches in science communication on Twitter—one focused on specific scientific topics and another on the disseminating agents of the scientific information—and showing the possibilities for analysis that each one offers; and (3) indicating Twitter's various functions as a science communication tool.

To reach these objectives, a search was first conducted using different archives such as Web of Science, Scopus, and Dialnet, combining the key words "twitter," "communication," and "science" to identify the best positioned studies available based on their citation counts. The initial search was about communication overall on Twitter, using the first two key words. Then a search was performed on science-related studies, using the three key words. This totaled 216 initial articles reviewed. The timeline of the work is marked by the birth of the platform, which allows us to elucidate what the initial functions of Twitter have been and what others it has derived. These searches have been carried out and reinforced, verifying the

links to the articles present in the bibliography of the works considered, selected under a criterion of relevance based on the diversity of research approaches, methodological resources used, and the topics of research on which the empirical studies focus. This resulted in a sample of 198 more relevant works, for a total of 414.

In this sense, it should be clarified that this is an exploratory study for illustrating the possibilities offered by the tool. With it, in addition to outlining an abundant compilation of trends in research and significant results, it also seeks to distinguish the primary functions that Twitter performs when used as a science communication tool, paying close attention to the actors involved and their apparent objectives. Thus, it aims to provide an overview of the possible approaches that the researcher may take, to inspire the design of new studies, and to facilitate the composition of the conceptual framework.

3. Twitter as an academic research tool in communication

3.1. General trends

Twitter is an emerging research tool that has inspired various types of studies in communication and led to numerous sociological analyses (Murthy, 2012). However, there is not much agreement about which methods are reliable in research using social media and what information it can reveal to us (Veltri & Atanasova, 2015), given that rigorous methodologies that allow systematic analyses have not been developed (Kahle, Sharon, & Baram-Tsabari, 2016).

Twitter is both an information network and a social network (Myers, Sharma, Gupta, & Lin, 2014). On the one hand, as a tool for disseminating information, it has demonstrated that news coverage on Twitter tends to be consistent with that in the media (Veltri, 2013; Wilkinson & Thelwall, 2012). In fact, online debates do not differ much from debates generated in the press (Gerhards & Schäfer, 2010). For example, topic modeling techniques—detection of trending topics in a text dataset—have been used in comparison with traditional media trends, like in the comparative study with news trends from *The New York Times* (Zhao et al., 2011). On the other hand, as a social network, numerous studies have been conducted on connections between agents on Twitter. Nonetheless, it is important to note that some works about agents are combined with the study of tweet content using the joint study of actor-topic networks (Haunschild, Leydesdorff, Bornmann, Hellsten, & Marx, 2019; Hellsten & Leydesdorff, 2019).

The structure of the network of users on Twitter is not the typical structure used by other social networks, given that it has low reciprocity and behaves more as a means of news dissemination (Kwak, Lee, Park, & Moon, 2010), although it is true that a certain degree of interconnection between tweets has been detected—around 25% contain mentions of other users (Huberman, Romero, & Wu, 2008). In fact, beyond the classic unidirectional model, information is disseminated in the form of conversations (Schmidt, 2014) and is aimed at an audience structured as a network whose nodes are made up of users who choose their content influencers—the profiles that they "follow." This means they get information based on their own criterion of relevance and not one established by the general media. In this research direction, there are many studies about the influence of agents on Twitter (Pérez-Rodríguez et al., 2018), a factor related to having active followers who retweet or mention the user—and not just to having more or fewer followers (Cha, Haddadi, Benevenuto, & Gummadi, 2010). In fact, measures of influence are based on the network of contacts and the publication dynamics (Congosto, 2016).

Despite the potential for dialogue and the creation of communities in the Twitter environment, it is more likely that organizations use unidirectional models (Waters & Jamal, 2011) and do not get involved in conversations often. Even so, certain organizations can be very popular on social media and have great influence on certain topics (Cha et al., 2010); for example, the NASA profile has more than 38,5 million followers.

With respect to interactions, personal profiles are the most productive profiles on Twitter and they are based on the individual commitment of the user and are not backed by a communications team (Pérez-Rodríguez et al., 2018). It is interesting that some studies identify mentions between users as a form of engagement—other times understood as the degree of user commitment—when sending significant information to the receiver (Díaz-Faes, Bowman, & Costas, 2019).

In particular, mentions are most common between users who connect internally between groups. Retweets are the typical manner in which messages are shared between communities (Grabowicz, Ramasco, Moro, Pujol, & Eguiluz, 2012). Therefore, the key to dissemination resides more in the level of intermediation—a user belonging to several communities—and not just in having more connections within one single group (Congosto, 2016). In other words, a network structure with common users in different communities substantially favors dissemination of the tweets.

In addition to the studies that look at how Twitter users form communities around their conversational connections, another essential focus is looking at the content of the tweets (Pearce, Holmberg, Hellsten, & Nerlich, 2014), an approach that has revealed that the content of tweets also affects dissemination of the information. In effect, diffusion of the messages depends on the connection between agents and is also influenced by the topics that are shared (De Choudhury et al., 2010). To demonstrate this, analyses have been done on the content of representative samples of tweets to detect trending topics (Aiello et al., 2013), as well as studies on collective attention to certain problems in the public sphere or to specific events (Sasahara, Hirata, Toyoda, Kitsuregawa, & Aihara, 2013). In this approach, research examining collective patterns of behavior regarding political topics is common (Percastre-Mendizábal et al., 2017), and attempts have been made to monitor social behavior of users on a large scale (Lin, Keegan, Margolin, & Lazer, 2014). In particular, some of the studies are done by identifying and following hashtags (Boyd, Golder, & Lotan, 2010) and the number of related retweets (Small, 2011), which even includes analyzing the evolution of topics of interest over time. In this type of study, it should be noted that dissemination of the tweets occurs mainly during the first hour after being posted (Kwak et al., 2010; Van Liere, 2010).

Given the advantage that tweets allow a semantic representation (Narr, Luca, & Albayrak, 2011), analyses on the content of tweets have often been based on Natural Language Processing (NLP). This involves automated computational methods that are generally used to analyze large quantities of tweets, although sometimes the analysis of content is also done manually using human coders to classify text, so that researchers may find subtle information that the automated methods overlook (Chew & Eysenbach, 2010; Uren & Dadzie, 2015). One way to do this is using finite lists of words—created using the researchers' judgment—to identify opinionated tweets; for example, calculating the proportion of tweets from a sample containing certain words (Zhao et al., 2011).

A common trend in this type of study is sentiment analysis, which operates by examining terms in tweets that express emotions (Liu, 2011; 2012) and therefore reflect the emotional perceptions of the users expressed in natural language (Dehkharghani, Mercan, Javeed, & Saygin, 2014). Surveys measuring user happiness are common, examining emotionally charged words present in discourse on Twitter, which are typically identified using a predetermined list with a certain number of words (Dodds, Harris, Kloumann, Bliss, & Danforth, 2011). *Affective Norms for English Words* (ANEW) (Bradley & Lang, 1999) is an available set of words that is popular among researchers. Instead of being ad hoc, the lists may also be created based on the frequency with which the terms are used (Dodds et al., 2011), or even put together at the discretion of the authors after examining the set of tweets to be investigated, applying qualitative judgment after observing the data.

One study for finding out what types articles from *The New York Times* are most frequently shared online showed that the content that evokes some emotional response has a greater likelihood of being shared and going viral (Berger & Milkman, 2012). Data related to this, based on a previous study, shows that around 27% of the topics extracted from a representative sample of tweets included personal updates (Zhao et al., 2011), something that does not occur in trending topic detection from *The New York Times* since it involves normative coverage of the media. Subsequently, a modest positive correlation was found between retweets and emotionally arousing content of the web links within the tweet (Veltri & Atanasova, 2015). With regards to links to external content, a survey of Twitter users revealed that hyperlinks play a central role that affects both information flow and the aforementioned engagement of Twitter users (Holton, Baek, Coddington, & Yaschur, 2014), for example, by seeking recommendations from users with reciprocal links.

Lastly, there have also been studies on the credibility of the news disseminated on Twitter, given the diffusion of erroneous information and false rumors. A noteworthy example is that a team of researchers performed an automatic classification of a set of tweets and detected a range of reliability around 85%, identifying those tweets as credible or not credible using a computational tool based on their dissemination (Castillo, Mendoza, & Poblete, 2011). Another study also demonstrated that having too many or too few followers instills less trustworthiness, while a user with a similar number of followers and accounts it follows is perceived as a more credible or competent user (Westerman, Spence, & Van Der Heide, 2012). It is also suggested that if an expert uses an aggressive style of language, the information shared is perceived as less credible and that, when it comes to the specific case of the debate on science issues, less is learned (König & Jucks, 2019).

3.2. User roles

Generally speaking, there are classifications based on the intention of the users that revolve around types of broadcasters according to their activity and how they operate within the network (Quercia, Ellis, Capra, & Crowcroft, 2011; Uddin, Imran, & Sajjad, 2014), while others focus on the type of tweets sent.

The first case may illustrate a typical characterization of the profiles of influencers—users with great influence on the network—obtained using the Klout tool (Harvey, 2014), and although this is currently a non-operational tool, it is still cited due to its usefulness in classification. Among the 16 types of profiles that it distinguishes, the most relevant ones are the feeder, who constantly shares information about certain topics, is participatory, and whose followers are obsessed with their updates; the thought leader, who is the opinion leader in a certain sector of the industry and whose followers trust both the trending news shared and their opinions; the specialist, who is an expert in a certain field and whose publications typically focus on a specific topic, with a concentrated and highly committed audience; and the explorer, who is characterized by "listening" to tweets impartially.

In this same approach, it may be useful to use the most generic distinction proposed by other authors who identify three types of information broadcasters: mass media, sources of media that reach massive audiences; grassroots, basic or common users, passive at the time of spreading the news but who represent 98% of the network; and evangelists, which includes opinion leaders, politicians, celebrities, and local businesses, and who reach audiences outside of the network's nucleus (Cha et al., 2010).

Using a different approach, a fairly extensive categorization based on the defined structure of the links or connections between accounts has also been proposed, which distinguishes the user roles as information source, who has a large number of followers due to the valuable nature of their updates, regardless of whether they tweet at regular intervals or infrequently—in fact, some may be automated tools that publish news; friends, who reflect friendships on Twitter that occur in the form of friends, family members, coworkers, or even between unknown users—most profiles fall into this category; and information seekers, users who utilize the network to follow other users regularly but rarely publish messages (Java et al., 2007). In reference to the latter type, it is important to clarify that an "active" social media user is one who has made at least one post in a one-week period (Kolari et al., 2007).

On the other hand, classifications that put emphasis on the content of publications also assign roles to the broadcasters, in other words, classifications of the primary types of content that take the broadcaster's intentions into consideration. One of the first and most relevant classifications proposed the following profiles: daily chatter—the most common—which offers day-to-day updates; conversations, with messages that include mentions; sharing information/URLs, tweets that contain a web address; and reporting news, those which report news or current events (Java et al., 2007). Based on the type of tweets, it was concluded that users essentially utilize social media to chat about their daily activities and to seek out or share information. This reveals that a primary characteristic of Twitter is that accounts with similar intentions connect with each other more easily, while recognizing that one single user can have multiple intentions or perform different roles.

According to another subsequent categorization by Pear Analytics, widely cited in literature, the content of most tweets is trivial, such as, "I'm eating a sandwich," (PearAnalytics, 2009). Specifically, the proposed categories of tweets and their respective percentages were pointless babble (41%), which refers to "irrelevant" content; conversational (38%), which includes mentions between users and tweets that try to involve the followers in a conversation—for example, through questions or surveys; pass along-value (9%), whose content responds to a specific interest; self-promotion (6%), such as typical corporate tweets about products, services, or promotions; news (4%), which reflects current events; and spam (4%), which refers to advertising content. Of course, some tweets would fall into multiple categories, so this categorization is not exempt from critique (Boyd, 2009; Van Dijck, 2011).

4. Twitter as a tool for science communication

While it is true that research on Twitter has been aimed greatly towards political surveys and market studies, investigating science communication to the general public also shows great potential, given that scientific news appears to be strongly linked to this social network (Brown, 2014). Broadly speaking, studies on diffusion of science on Twitter present two approaches. One approach is to identify the most influential agents in the field of science communication, who participate in networks of actors whose relationship structure can be characterized mathematically using graph theory (Pérez-Rodríguez et al., 2018). In the second approach, research is conducted by placing the spotlight on the content of the tweet about scientific topics of public interest, mostly in order to evaluate the impact on certain scientific arguments. In the following sections, both approaches will be examined using various representative works in the field of study.

The methodology in these works includes both computational techniques for massive data analysis and qualitative approaches for the classification of tweets in order to evaluate the impact of scientific information and the reactions it elicits, especially in the approach involving specific scientific questions.

4.1. Scientific topics of public interest

Topics of public interest that are manifested on Twitter and that have been given greater attention in the field of academia are, in general, those related to the perception of risk to citizens, such as discussions regarding nuclear energy, the climate debate, or topics related to nanotechnology (Li et al., 2016; Runge et al., 2013; Veltri, 2013). This approach focuses on the content of an open discussion, for which sets of tweets are collected through keyword searches and on which the emotional aspect of the users' response is sometimes analyzed.

In particular, in the debate on climate change it has been brought to light that the members of the public increasingly use social media to express themselves (Schäfer, 2012; Walter, Lörcher, & Brüggemann, 2019), and some illuminating surveys have been done by applying the aforementioned technique of sentiment analysis (Höijer, 2010). An example of this on Twitter is a case study in which three types of user communities were detected, differentiating between those who perceive the climate emergency, those who deny it, and those who are impartial, or supportive, unsupportive and neutral, respectively. It also showed that the most commonly used hashtags in the climate crisis debate are directly related to scientific content, geographical disputes, and social and technological concerns, with tweets related to political campaigns also being notable (Pearce et al., 2014).

Health-related topics are also of special interest due to their great impact on public opinion. In particular, one investigation determined that tweets about medications, chemical products, and disorders that are published by American health agencies tend to be retweeted more than the rest (Bhattacharya, Srinivasan, & Polgreen, 2014). Some measurements have also been done regarding public perception at the time of a health emergency, in principle to encourage authorities to respond appropriately to public concerns (Chew & Eysenbach, 2010). Other studies have also dealt with behaviors of skepticism and hostility towards vaccination programs by scientifically uninformed actors who are highly active on the internet (Rosselli, Martini, & Bragazzi, 2016), some of them in order to understand the emotional stance of the public (Becker et al., 2016).

Studies have been created on other topics as well, but to a lesser extent. One contribution that may be enlightening is a study that suggests that communication on Twitter about nanotechnology was, in reality, not conversational, but dominated by a few agents (Veltri, 2013). However, this is a highly complex discipline, so one may ask to what degree this condition applies if used on other less technical datasets.

Lastly, notable results came from another study in which the category "science and technology" from a sample of tweets classified under nine subjects showed a very low proportion of tweets with opinions and an average interest in comparison with the rest of the proposed categories, which included health, education and sports, among others (Zhao et al., 2011).

4.2. Agents. Who tweets about science?

Like in other areas of human interest, the growing use of social media has strengthened science communication. The actors involved in science communication include (1) science communicators (Ribas, 2012), whether they are professionals or amateurs; (2) institutions such as universities, research centers, and other organizations (Kahle et al., 2016); and (3) scientists who tweet their findings, sometimes to gain impact in the scientific community itself (Peters, Dunwoody, Allgaier, Lo, & Brossard, 2014) or even in civil society (Walter et al., 2019). The third type is the one that has inspired the largest number of studies. Of course, these proposed categories may overlap, like in the case of a scientist who is also a communications professional, an increasingly common figure.

With regards to the first category, it is worth mentioning that Twitter is the social network used most often by science journalists to report news and to establish direct contact with sources (Pont Sorribes, Cortiñas Rovira, & Di Bonito, 2013). In fact, some studies have looked at how they use Twitter to carry out their professional work (Kahle et al., 2016; Quiñónez Gómez & Sánchez Colmenares, 2017).

As for the second category, case studies have been conducted on institutional communication focused on certain accounts of popular organizations. An illustrative example is the European Organization for Nuclear Research (CERN) monitoring various social networks, including Twitter, on their outreach efforts. They found that as the audience size grows, the engagement of the user receiving the information tends to decrease although there is a greater number of total interactions with the majority of followers (Kahle et al., 2016).

As previously mentioned, in the case of scientists with Twitter accounts there is more academic attention paid to the dissemination of scientific research on Twitter and, in particular, the impact made on scientific

publication (Liang et al., 2014; Mandavilli, 2011) or sometimes on the user's intention to discuss their own academic work on social media (Rowlands, Nicholas, Russell, Canty, & Watkinson, 2011; Van Noorden, 2014). Numerous works focus on the use of Twitter among academics for dissemination of high-level scientific information (Sugimoto, Work, Larivière, & Haustein, 2017; Thelwall, Haustein, Larivière, & Sugimoto, 2013; Torres-Salinas, Cabezas-Clavijo, & Jiménez-Contreras, 2013), leading to an estimate that 21% of scientific articles are shared, at minimum, through one tweet (Haustein, Costas, & Larivière, 2015). That is why Twitter-based metrics are increasingly proposed as a potential indicator of the impact of scientific publications (Priem, Groth, & Taraborelli, 2012), and even for science's growth due to the effect that it may have on citation counts and visits to scientific articles referenced in tweets (Wasike, 2019).

These proposals are outlined in the modern concept of altmetrics, which describes a new way of measuring impact of scientific publications based on alternative indicators to the impact factor of journals, such as mentions on social media, views and downloads, and others (Priem et al., 2012). In this sense, scientists may increase citation counts of their academic work when they start discussions about them on social media such as Twitter (Liang et al., 2014). In fact, an increasing number of scientists use Twitter to discuss results of their work, to generate new research ideas, or to build up the connection between researchers (Ke, Ahn, & Sugimoto, 2017).

This is also believed to be another increasingly common practice for informal communication among scientists and it favors the merging of professional communities (Darling, Shiffman, Côté, & Drew, 2013; Shema, Bar-Ilan, & Thelwall, 2012; Weller, Bruns, Burgess, Mahrt, & Puschmann, 2013). Some studies have also suggested that the importance resides more in how users are connected than in the content of the tweets (Díaz-Faes et al., 2019; Haustein, 2019), and similarly, others have noted that the original content is rarely disseminated—often times no more than the title of the article is shared (Robinson-Garcia, Costas, Isett, Melkers, & Hicks, 2017). In this regard, an interesting proposal for measuring the engagement level of researchers who tweet their articles is to compare the similarity between the tweet's text and the title of the scientific publication, where the more they differ, the higher the level of engagement (Díaz-Faes et al., 2019; Haustein, Bowman, & Costas, 2016). Even so, it should be noted that there are case studies that reveal that dissemination patterns of scientific articles rarely go beyond the users that form a well-connected community (Alperin, Gomez, & Haustein, 2019).

While it is true that scientists interact with other scientists on Twitter, it should be noted that they also consider science communication to society to be important, and they even adjust their vocabulary with different registers, using a more neutral language towards their peers (Walter et al., 2019). According to Liang et al. (2014), «outreach activities, such as interactions with reporters and being mentioned on Twitter, can assist a scientist's career by promoting his or her scientific impact» (Liang et al., 2014: 776). Note the role of scientists on Twitter for the general public, such that reaching a broad non-scientific audience requires an online engagement effort maintained over time, and it is also a nonlinear process, given that it can only occur after a certain number of followers (Côté & Darling, 2018). Another distinct use of Twitter by scientists is carrying out collective actions aimed at social change by appealing to the importance of the public's education in science (Jahng & Lee, 2018).

As a counterpoint, some authors maintain that those scientists who use their time to foster public profiles on social media with scientific production publish less articles than those who are dedicated exclusively to research—and have even produced an index to measure it—because some believe that they should only dedicate themselves to research (Hall, 2014).

From the public's perspective, however, one study in particular on the social impact of research on Twitter stands out, showing that a sample of an audience that follows science accounts does so to stay up-to-date and feel like part of the scientific community, but does not tend to interact with the accounts broadcasting the scientific information or consider having influence on the progress of science (Álvarez-Bornstein & Montesi, 2019).

5. Conclusions

Social networks constitute an emerging field for academic research in the communications field, facilitated by the increasing power of calculation and data processing of modern computers. This article is derived from the identification and selection of different studies available in the field, with a special emphasis on science communication, whose findings are still mostly preliminary, yet still useful for practical purposes in designing future studies.

As a result of the review, it can be said that the main functions of Twitter as a tool for science communication can be summarized as: (1) informing the interested audience; (2) joining and developing

communities; (3) allowing interactions between journalists, experts, and the public; (4) increasing the impact of scientific publications; and (5) aligning science and society or even bringing them face to face. Note that depending on the actors involved and their apparent objectives, these functions are configured in a specific and empirically observable manner, outlined throughout this article. A distinction between research approaches is also made, using data extracted from the platform, one focused on the information—science topics of public interest—and another on the agents who share and/or consume the scientific information—the performance of the network actors. These drive ideas like "social media influence" or the participation and commitment of users, known as engagement.

After offering an overview of the possible approaches that researchers can adopt in this theoretical inventory, it might be possible to frame other works in a dynamic manner and discern between the most appropriate analysis resources in each case, thus facilitating the design of future studies. One method to explore is trying to determine if the growing interaction of scientists on social media is useful for purposes of advancing science and for the public's understanding of it. Another method, related to discourse on science and technology, may be finding out to what extent the scientific information the public shows interest in is related to other topics, such as politics. A third method is putting the spotlight on famous spokespersons who exercise great influence—so-called "science stars"—to examine their publication dynamics and the impact of their discourse. These are just some illustrative examples within a wide spectrum.

As a general reflection, we propose the idea that analyzing the impact of science communication on Twitter, assuming that it reflects the social fabric, may be of great interest both for governments, in order to guide scientific policies, and for academic institutions that are interested in establishing social legitimation of science and promoting the public's participation in debates on science-based matters. In particular, the use of the platform as a research tool, in comparison with macro-surveys on social perception of science, has the advantage of consuming less economic and human resources, and offers results on large datasets through computational assistance, in order to monitor information flows and user behaviors. Needless to say, in this era of big data, using Twitter in addition to traditional population surveys seems most appropriate.

6. Acknowledgements

I am grateful to the translator of this article, Elizabeth Nelsen, for her diligent work.

7. References

[1] Aiello, L. M., Petkos, G., Martin, C., Corney, D., Papadopoulos, S., Skraba, R., Jaimes, A. (2013). Sensing Trending Topics in Twitter. *IEEE Transactions on Multimedia, 15*(6), 1268-1282. http://doi.org/f5bzrz

[2] Alperin, J. P., Gomez, C. J., & Haustein, S. (2019). Identifying diffusion patterns of research articles on Twitter: A case study of online engagement with open access articles. *Public Understanding of Science, 28*(1), 2-18. http://doi.org/gdg6vs

[3] Álvarez-Bornstein, B., & Montesi, M. (2019). Who is interacting with researchers on Twitter? A survey in the field of Information Science. *2019, 10*(2), 20. http://doi.org/dw88

[4] Becker, B. F. H., Larson, H. J., Bonhoeffer, J., van Mulligen, E. M., Kors, J. A., & Sturkenboom, M. C. J. M. (2016). Evaluation of a multinational, multilingual vaccine debate on Twitter. *Vaccine, 34*(50), 6166-6171. http://doi.org/f9h2zn

[5] Berger, J., & Milkman, K. L. (2012). What makes online content viral? *Journal of marketing research, 49*(2), 192-205. http://doi.org/fxqzn7

[6] Bhattacharya, S., Srinivasan, P., & Polgreen, P. (2014). Engagement with Health Agencies on Twitter. *PLoS One, 9*(11), e112235. http://doi.org/dw89

[7] Boyd, D. (2009). Twitter:'Pointless Babble'or Peripheral Awareness+ Social Grooming. *Aphogenia, 16*, 2009. Available at: https://bit.ly/2wXAEx9

[8] Boyd, D., Golder, S., & Lotan, G. (2010, 5-8 Jan. 2010). *Tweet, Tweet, Retweet: Conversational Aspects of Retweeting on Twitter.* Paper presented at the 2010 43rd Hawaii International Conference on System Sciences.

[9] Bradley, M. M., & Lang, P. J. (1999). *Affective norms for English words (ANEW): Instruction manual and affective ratings*. University of Florida. Available at: https://bit.ly/3clEsqW

[10] Brossard, D., & Scheufele, D. A. (2013). Science, New Media, and the Public. *Science, 339*(6115), 40-41. http://doi.org/j45

[11] Brown, P. (2014). An explosion of alternatives. *EMBO reports, 15*(8), 827-832. http://doi.org/f2swhw

[12] Castillo, C., Mendoza, M., & Poblete, B. (2011). *Information credibility on twitter*. Paper presented at the Proceedings of the 20th international conference on World wide web, Hyderabad, India. http://doi.org/bm4s9p

[13] Cha, M., Haddadi, H., Benevenuto, F., & Gummadi, K. P. (2010). *Measuring user influence in twitter: The million follower fallacy.* Paper presented at the fourth international AAAI conference on weblogs and social media.

[14] Chew, C., & Eysenbach, G. (2010). Pandemics in the Age of Twitter: Content Analysis of Tweets during the 2009 H1N1 Outbreak. *PLoS One, 5*(11), e14118. http://doi.org/cz2jpx

[15] Congosto, M. L. (2016). *Caracterización de usuarios y propagación de mensajes en Twitter en el entorno de temas sociales.* (Doctoral thesis). Universidad Carlos III de Madrid, Leganés, Madrid, ES. Available at: https://bit.ly/2Mhoeo1

[16] Côté, I. M., & Darling, E. S. (2018). Scientists on Twitter: Preaching to the choir or singing from the rooftops? *FACETS, 3*(1), 682-694. http://doi.org/gdq9zt

[17] Dann, S. (2010). Twitter content classification. *First Monday, 15*(12). http://doi.org/dw9b

[18] Darling, E. S., Shiffman, D., Côté, I. M., & Drew, J. A. (2013). The role of Twitter in the life cycle of a scientific publication. *Ideas in Ecology and Evolution, 6*(1). http://doi.org/dw9c

[19] De Choudhury, M., Lin, Y.-R., Sundaram, H., Candan, K. S., Xie, L., & Kelliher, A. (2010). How does the data sampling strategy impact the discovery of information diffusion in social media? Paper presented at the Fourth International AAAI Conference on Weblogs and Social Media.

[20] Dehkharghani, R., Mercan, H., Javeed, A., & Saygin, Y. (2014). Sentimental causal rule discovery from Twitter. *Expert Systems with Applications, 41*(10), 4950-4958. http://doi.org/gghqf5

[21] Díaz-Faes, A. A., Bowman, T. D., & Costas, R. (2019). Towards a second generation of 'social media metrics': Characterizing Twitter communities of attention around science. *PLoS One, 14*(5), e0216408. http://doi.org/ggdftp

[22] Dodds, P. S., Harris, K. D., Kloumann, I. M., Bliss, C. A., & Danforth, C. M. (2011). Temporal Patterns of Happiness and Information in a Global Social Network: Hedonometrics and Twitter. *PLoS One, 6*(12), e26752. http://doi.org/b4x9cx

[23] Gerhards, J., & Schäfer, M. S. (2010). Is the internet a better public sphere? Comparing old and new media in the USA and Germany. *New Media & Society, 12*(1), 143-160. http://doi.org/bjzmbm

[24] Grabowicz, P. A., Ramasco, J. J., Moro, E., Pujol, J. M., & Eguiluz, V. M. (2012). Social Features of Online Networks: The Strength of Intermediary Ties in Online Social Media. *PLoS One, 7*(1), e29358. http://doi.org/fzs6dq

[25] Hall, N. (2014). The Kardashian index: a measure of discrepant social media profile for scientists. *Genome Biology, 15*(7), 424. http://doi.org/tw9

[26] Harvey, K. (2014). Klout Score. In K. Harvey (Ed.), *Encyclopedia of Social Media and Politics* (pp. 753-754). Thousand Oaks, California: SAGE Publications, Inc.

[27] Haunschild, R., Leydesdorff, L., Bornmann, L., Hellsten, I., & Marx, W. (2019). Does the public discuss other topics on climate change than researchers? A comparison of explorative networks based on author keywords and hashtags. *Journal of Informetrics, 13*(2), 695-707. http://doi.org/dw9d

[28] Haustein, S. (2019). Scholarly Twitter Metrics. In W. Glänzel, H. F. Moed, U. Schmoch, & M. Thelwall (Eds.), *Springer Handbook of Science and Technology Indicators* (pp. 729-760). Cham: Springer International Publishing.

[29] Haustein, S., Bowman, T. D., & Costas, R. (2016). Interpreting 'Altmetrics': Viewing Acts on Social Media through the Lens of Citation and Social Theories. In C. Sugimoto (Ed.), *Theories of Informetrics and Scholarly Communication* (pp. 372-406). Berlin, Boston: De Gruyter.

[30] Haustein, S., Costas, R., & Larivière, V. (2015). Correction: Characterizing Social Media Metrics of Scholarly Papers: The Effect of Document Properties and Collaboration Patterns. *PLoS One, 10*(5), e0127830. http://doi.org/dw9f

[31] Hellsten, I., & Leydesdorff, L. (2019). Automated analysis of actor–topic networks on twitter: New approaches to the analysis of socio-semantic networks. *Journal of the Association for Information Science and Technology, 71*(1), 3-15. http://doi.org/ggk2td

[32] Höijer, B. (2010). Emotional anchoring and objectification in the media reporting on climate change. *Public Understanding of Science, 19*(6), 717-731. http://doi.org/b7r4gv

[33] Holton, A. E., Baek, K., Coddington, M., & Yaschur, C. (2014). Seeking and Sharing: Motivations for Linking on Twitter. *Communication Research Reports, 31*(1), 33-40. http://doi.org/gfgxdk

[34] Huberman, B. A., Romero, D. M., & Wu, F. (2008). Social networks that matter: Twitter under the microscope. *First Monday, 14*(1). http://doi.org/dw9g

[35] Hughes, A. L., & Palen, L. (2009). Twitter adoption and use in mass convergence and emergency events. *International journal of emergency management, 6*(3-4), 248-260. http://doi.org/dh7cpf

[36] Jahng, M. R., & Lee, N. (2018). When Scientists Tweet for Social Changes: Dialogic Communication and Collective Mobilization Strategies by Flint Water Study Scientists on Twitter. *Science Communication, 40*(1), 89-108. http://doi.org/dw9h

[37] Java, A., Song, X., Finin, T., & Tseng, B. (2007). *Why we twitter: understanding microblogging usage and communities*. Paper presented at the Proceedings of the 9th WebKDD and 1st SNA-KDD 2007 workshop on Web mining and social network analysis, San Jose, California. http://doi.org/d3zh2r

[38] Kahle, K., Sharon, A. J., & Baram-Tsabari, A. (2016). Footprints of Fascination: Digital Traces of Public Engagement with Particle Physics on CERN's Social Media Platforms. *PLoS One, 11*(5), e0156409. http://doi.org/gbnq6h

[39] Ke, Q., Ahn, Y.-Y., & Sugimoto, C. R. (2017). A systematic identification and analysis of scientists on Twitter. *PLoS One, 12*(4), e0175368. http://doi.org/f9z4j6

[40] Kolari, P., Finin, T., Yesha, Y., Yesha, Y., Lyons, K., Perelgut, S., & Hawkins, J. (2007). *On the structure, properties and utility of internal corporate blogs.* Paper presented at the Proceedings of the International Conference on Weblogs and Social Media (ICWSM 2007).

[41] König, L., & Jucks, R. (2019). Hot topics in science communication: Aggressive language decreases trustworthiness and credibility in scientific debates. *Public Understanding of Science, 28*(4), 401-416. http://doi.org/dw9j

[42] Kwak, H., Lee, C., Park, H., & Moon, S. (2010). *What is Twitter, a social network or a news media?* Paper presented at the Proceedings of the 19th international conference on World wide web, Raleigh, North Carolina, USA. http://doi.org/c2k8cj

[43] Li, N., Akin, H., Su, L. Y.-F., Brossard, D., Xenos, M., & Scheufele, D. A. (2016). Tweeting disaster: An analysis of online discourse about nuclear power in the wake of the Fukushima Daiichi nuclear accident. *Journal of Science Communication, 15*(5), A02. http://doi.org/dw9k

[44] Liang, X., Su, L. Y.-F., Yeo, S. K., Scheufele, D. A., Brossard, D., Xenos, M., . . . Corley, E. A. (2014). Building Buzz:(Scientists) Communicating Science in New Media Environments. *Journalism & Mass Communication Quarterly, 91*(4), 772-791. http://doi.org/ggcd8d

[45] Lin, Y.-R., Keegan, B., Margolin, D., & Lazer, D. (2014). Rising Tides or Rising Stars?: Dynamics of Shared Attention on Twitter during Media Events. *PLoS One, 9*(5), e94093. http://doi.org/f56mgp

[46] López Pérez, L., & Olvera Lobo, M. D. (2019). Participación digital del público en la ciencia de excelencia española: análisis de los proyectos financiados por el European Research Council. *El profesional de la información, 28*(1), 6. http://doi.org/dw9m

[47] Mandavilli, A. (2011). Peer review: Trial by Twitter. *Nature, 469*(7330), 286-287. http://doi.org/ap2

[48] Murphy, J., Hill, C. A., & Dean, E. (2013). Social Media, Sociality, and Survey Research. In C. Hill, E. Dean, J. Murphy (Ed.), *Social Media, Sociality, and Survey Research* (pp. 1-33): John Wiley & Sons.

[49] Murthy, D. (2012). Towards a Sociological Understanding of Social Media: Theorizing Twitter. *Sociology, 46*(6), 1059-1073. http://doi.org/gfc8v9

[50] Myers, S. A., Sharma, A., Gupta, P., & Lin, J. (2014). *Information network or social network? the structure of the twitter follow graph*. Paper presented at the Proceedings of the 23rd International Conference on World Wide Web, Seoul, Korea. http://doi.org/dw9n

[51] Naaman, M., Boase, J., & Lai, C.-H. (2010). *Is it really about me? message content in social awareness streams*. Paper presented at the Proceedings of the 2010 ACM conference on Computer supported cooperative work, Savannah, Georgia, USA. http://doi.org/bqxczp

[52] Narr, S., Luca, E. W. D., & Albayrak, S. (2011). *Extracting semantic annotations from twitter*. Paper presented at the Proceedings of the fourth workshop on Exploiting semantic annotations in information retrieval, Glasgow, Scotland, UK. http://doi.org/dck8ff

[53] Nisbet, M. C., & Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany, 96*(10), 1767-1778. http://doi.org/dv4zw8

[54] PearAnalytics. (2009). *Twitter study*. San Antonio, TX. Available at: https://bit.ly/3gJyZgH

[55] Pearce, W., Holmberg, K., Hellsten, I., & Nerlich, B. (2014). Climate Change on Twitter: Topics, Communities and Conversations about the 2013 IPCC Working Group 1 Report. *PLoS One, 9*(4), e94785. http://doi.org/f5472q

[56] Percastre-Mendizábal, S., Pont-Sorribes, C., & Codina, L. (2017). A sample design proposal for the analysis of Twitter in political communication. *El profesional de la información (EPI), 26*(4), 579-588. http://doi.org/dw9p

[57] Pérez-Rodríguez, A. V., González-Pedraz, C., & Alonso-Berrocal, J. L. (2018). Twitter como herramienta de comunicación científica en España. Principales agentes y redes de comunicación [Twitter as a tool for science communication in Spain. Main agents and communication networks]. *Communication Papers, 7*(13), 95-112. http://doi.org/dw9q

[58] Peters, H. P., Dunwoody, S., Allgaier, J., Lo, Y.-Y., & Brossard, D. (2014). Public communication of science 2.0. *EMBO reports, 15*(7), 749-753. http://doi.org/s8s

[59] Pont Sorribes, C., Cortiñas Rovira, S., & Di Bonito, I. (2013). Challenges and opportunities for science journalists in adopting new technologies: the case of Spain. *Journal of Science Communication, 12*(3). http://doi.org/dw9r

[60] Priem, J., Groth, P., & Taraborelli, D. (2012). The Altmetrics Collection. *PLoS One, 7*(11), e48753. http://doi.org/gf35cr

[61] Quercia, D., Ellis, J., Capra, L., & Crowcroft, J. (2011, 9-11 Oct). *In the Mood for Being Influential on Twitter.* Paper presented at the 2011 IEEE Third International Conference on Privacy, Security, Risk and Trust and 2011 IEEE Third International Conference on Social Computing, Boston, MA, USA.

[62] Quiñónez Gómez, H. A., & Sánchez Colmenares, M. F. (2017). Uso de twitter en el Periodismo cientifico. Caso: El Nacional y El Universal en Venezuela (septiembre-octubre de 2014). *Estudios sobre el Mensaje Periodistico, 23*(1), 553-568. http://doi.org/dw9s

[63] Ribas, C. (2012). La divulgación y la comunicación de la ciencia, en la encrucijada. *Sociedad Española de Bioquímica y Biología Molecular, 173*, 10-12. Available at: https://bit.ly/2yR4ULc

[64] Robinson-Garcia, N., Costas, R., Isett, K., Melkers, J., & Hicks, D. (2017). The unbearable emptiness of tweeting—About journal articles. *PLoS One, 12*(8), e0183551. http://doi.org/gbtf8g

[65] Rosselli, R., Martini, M., & Bragazzi, N. L. (2016). The old and the new: vaccine hesitancy in the era of the Web 2.0. Challenges and opportunities. *Journal of preventive medicine and hygiene, 57*(1), E47-E50. Available at: https://bit.ly/2w7Y02V

[66] Rowlands, I., Nicholas, D., Russell, B., Canty, N., & Watkinson, A. (2011). Social media use in the research workflow. *Learned Publishing, 24*(3), 183-195. http://doi.org/c8r2bb

[67] Runge, K. K., Yeo, S. K., Cacciatore, M., Scheufele, D. A., Brossard, D., Xenos, M., . . . Su, L. Y.-F. (2013). Tweeting nano: how public discourses about nanotechnology develop in social media environments. *Journal of Nanoparticle Research, 15*(1), 1381. http://doi.org/ggxg3k

[68] Sasahara, K., Hirata, Y., Toyoda, M., Kitsuregawa, M., & Aihara, K. (2013). Quantifying Collective Attention from Tweet Stream. *PLoS One, 8*(4), e61823. http://doi.org/f43228

[69] Schäfer, M. S. (2012). Online communication on climate change and climate politics: a literature review. *WIREs Climate Change, 3*(6), 527-543. http://doi.org/f4fmqd

[70] Schmidt, J.-H. (2014). Twitter and the rise of personal publics. In K. Weller, A. Bruns, J. Burgess, M. Mahrt, & C. Puschmann (Eds.), *Twitter and society* (pp. 3-14). New York, USA.

[71] Shema, H., Bar-Ilan, J., & Thelwall, M. (2012). Research Blogs and the Discussion of Scholarly Information. *PLoS One, 7*(5), e35869. http://doi.org/hwq

[72] Small, T. A. (2011). What the hashtag? *Information, Communication & Society, 14*(6), 872-895. http://doi.org/d9hxv3

[73] Sugimoto, C. R., Work, S., Larivière, V., & Haustein, S. (2017). Scholarly use of social media and altmetrics: A review of the literature. *Journal of the Association for Information Science and Technology, 68*(9), 2037-2062. http://doi.org/gbtnkr

[74] Thelwall, M., Haustein, S., Larivière, V., & Sugimoto, C. R. (2013). Do Altmetrics Work? Twitter and Ten Other Social Web Services. *PLoS One, 8*(5), e64841. http://doi.org/q6g

[75] Torres-Salinas, D., Cabezas-Clavijo, Á., & Jiménez-Contreras, E. (2013). Altmetrics: nuevos indicadores para la comunicación científica en la Web 2.0. *Comunicar, XXI*(41), 53-60. http://doi.org/gdxxhg

[76] Uddin, M., Imran, M., & Sajjad, H. (2014). *Understanding Types of Users on Twitter*. Paper presented at the SocialCom-Stanford, California, USA. Available at: https://bit.ly/2Mi3j47

[77] Uren, V., & Dadzie, A.-S. (2015). Public science communication on Twitter: a visual analytic approach. *Aslib Journal of Information Management, 67*(3), 337-355. http://doi.org/dw9t

[78] Van Dijck, J. (2011). Tracing Twitter: The rise of a microblogging platform. *International Journal of Media & Cultural Politics, 7*(3), 333-348. http://doi.org/fxqd7v

[79] Van Liere, D. (2010). *How far does a tweet travel? Information brokers in the twitterverse*. Paper presented at the Proceedings of the International Workshop on Modeling Social Media, Toronto, Ontario, Canada. http://doi.org/b3bfc3

[80] Van Noorden, R. (2014). Online collaboration: Scientists and the social network. *Nature news, 512*(7513), 126-129. http://doi.org/t6v

[81] Veltri, G. (2013). Microblogging and nanotweets: Nanotechnology on Twitter. *Public Understanding of Science, 22*(7), 832-849. http://doi.org/dw9v

[82] Veltri, G., & Atanasova, D. (2015). Climate change on Twitter: Content, media ecology and information sharing behaviour. *Public Understanding of Science, 26*. http://doi.org/gf6dqd

[83] Walter, S., Lörcher, I., & Brüggemann, M. (2019). Scientific networks on Twitter: Analyzing scientists' interactions in the climate change debate. *Public Understanding of Science, 28*(6), 696-712. http://doi.org/gf4c58

[84] Wasike, B. (2019). Citations Gone #Social: Examining the Effect of Altmetrics on Citations and Readership in Communication Research. *Social Science Computer Review*. http://doi.org/ggdj6k

[85] Waters, R. D., & Jamal, J. Y. (2011). Tweet, tweet, tweet: A content analysis of nonprofit organizations' Twitter updates. *Public Relations Review, 37*(3), 321-324. http://doi.org/fm4ctn

[86] Weller, K., Bruns, A., Burgess, J., Mahrt, M., & Puschmann, C. (2013). *Twitter and Society*: Peter Lang.

[87] Westerman, D., Spence, P. R., & Van Der Heide, B. (2012). A social network as information: The effect of system generated reports of connectedness on credibility on Twitter. *Computers in Human Behavior, 28*(1), 199-206. http://doi.org/bnxtb6

[88] Wilkinson, D., & Thelwall, M. (2012). Trending Twitter topics in English: An international comparison. *Journal of the American Society for Information Science and Technology, 63*(8), 1631-1646. http://doi.org/f368bw

[89] Zhao, W. X., Jiang, J., Weng, J., He, J., Lim, E.-P., Yan, H., & Li, X. (2011). *Comparing Twitter and Traditional Media Using Topic Models.* Paper presented at the European Conference on Information Retrieval ECIR 2011: Advances in Information Retrieval, Berlin, Heidelberg.