New media landscapes and the science information consumer

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Individuals are increasingly turning to online environments to find information about science and to follow scientific developments. It is therefore crucial for scientists and scientific institutions to consider empirical findings from research in online science communication when thinking about science in the public sphere. After providing a snapshot of the current media landscape, this paper reviews recent major research findings related to science communication in the online environment and their implications for science in the 21st century. Particular emphasis is given to the bias introduced by search engines, the nature of scientific content encountered online, and the potential impact of the Internet on audiences' knowledge and attitudes toward science.

social media | blogs

A video on nano quadrotors generates seven millions views on YouTube, the keyword "science" produces two billion Google search results in 0.16 seconds, and the ScienceAlert Facebook page has three million "likes." Unthinkable just 10 y ago, these numbers illustrate not only the dramatic changes that have occurred in science communication during the past decade, but also the necessity of rethinking the relationships among science, media, and the public within their related communication contexts.

Science communication has traditionally been presented as a translation exercise by a mainstream media communication professional whose goal is to make complex scientific findings accessible to general audiences (1). Today's reality is very different: scientists, their institutions, and the scientific knowledge they produce are now entangled in new media environments encompassing YouTube (a video sharing platform created in 2005 and owned by Google), Facebook (a social networking platform founded in 2004), and a plethora of other new media platforms. Younger scientists support direct communication with unspecialized, "lay" audiences (2) and may discuss scientific findings outside of their specific spheres in the online realm, without any intermediary (3). And most importantly, lay audiences themselves can participate in the production of science communication content, by producing and posting videos or blog posts, or more simply by commenting on an online item. With a few clicks on one's keyboard, any individual may forward mediated information to his or her network and initiate a process of "viral" social transmission (4). And a simple Google search can give anyone access to virtually unlimited information about a specific scientific topic (5).

A growing body of research in the science communication field is documenting that the changes mentioned above are not trivial and that they may have significant impacts on public perceptions of new scientific developments and on the public's general understanding of science (6, 7). These changes also profoundly call into question the often assumed power relationship between science and the public in a science communication context (8).

This paper discusses the latest research findings in the area of science communication in online environments and their implications for science as an institution, as well as the relationship between science and the public at large. In light of existing research, I answer the following questions: What motivates individuals to seek science-related information online? What is the nature of science-related content encountered online? And, more importantly, is the Internet changing public knowledge and attitudes about science? To answer these questions, however, it is first necessary to examine the dramatic transformation of media landscapes.

Media Landscapes and New Information Environments

Mainstream media sources (i.e., print and broadcast media) have traditionally been the main source of information about science for the majority of the American public (9, 10), particularly through news outlets. However, American print journalism has been experiencing tremendous turmoil because the Internet has started to offer alternatives to audiences in terms of how they receive their news diets. Online media also have offered profitable platforms to advertisers, which were newspapers' main source of revenue (11). Over the last decade, a large number of newspapers have been cutting their news staff and reducing time spent on producing the news to adapt to the challenges posed by declining audiences and new information environments (11). Likewise, print magazines have undergone dramatic changes, with even well-established outlets having to adapt to the realities of new media environments: The iconic, American magazine *Newsweek* announced in October 2012 that it was closing down its print edition and moving to an all-digital format in January 2013. The television news business has followed the same downward trend, particularly at the local level. Ratings of 6:00 PM local television newscasts in Washington, DC, for instance, dropped 37% from 1997 to 2007 (11).

These changes do not mean that news items are not communicated anymore. They are just conveyed in new ways, with new formats and new contingencies, including hypertextuality (online connectedness via links), interactivity, and multimediality (videos, text, images, etc.) (12). "Blogs" are just one of the many types of Web 2.0 applications currently existing online that can be used to convey the news ("Web 2.0" being a term often used to refer to the interactive use of the Internet). YouTube and Twitter (a microblogging site founded in 2006) are other examples of successful, new 2.0 platforms (7). Acknowledging the growing importance of new formats for news dissemination, for the first time two prestigious Pulitzer Prizes (typically given to regional and national newspapers) were awarded in 2012 to two primarily online news outlets, the *Huffington Post* and *Politico.* In 2013, the Pulitzer for national reporting went to InsideClimate

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News, a 6-y-old nonprofit online news site with seven staff members. It should be noted that the number of blogs focusing exclusively on science issues has exponentially grown in the last 5 y. Created in 2007, the site ResearchBlogging.org alone has over 1,200 registered blogs focusing on discussions of scientific peer-reviewed research (13).

These drastic changes in media landscapes are not without consequences for science audiences for many reasons. First, unlike traditional news outlets, blogs and other online information sources often do not clearly separate "opinions" and "news." For instance, blogs can provide opinionated content in a way traditional print media outlets seldom do within their editorial columns. Because blogs nowadays are often an integral part of the online presence of a news outlet (such as in *The New York Times'* Web site), it may be difficult for readers to distinguish between news and opinions. Second, online news is no longer consumed in isolation and is almost always accompanied by numbers representing volumes of Facebook "likes," Twitter mentions, readers' comments, and other Web 2.0 types of attributes that could all have the potential to affect readers' interpretations of the news (14). Furthermore, online news can now be accessed from multiple sources and not solely through the media organization producing it. For example, social network users can access news through links provided on their social networking sites or through news aggregators independent from the original producer. These automated news aggregators, such as Google News or Yahoo News, try to foresee the interests of online audiences through frequently updated algorithms. Audiences' browsing patterns provide data for these algorithms, as do their preferences expressed through tools such as the "like" button on Facebook, the "+1" button on Google+, or "retweeting" on Twitter. At the aggregated level, these data provide metrics that allow automated services such as Google News to spot the most popular stories on the web and to feature them in a prominent fashion on their own aggregators (15).

The extent to which information environments' new features impact audiences' attitudes and knowledge related to science is an empirical question that will be discussed later. What is clear is that information consumers have embraced the digital revolution. In 2012, four in five Americans reported regularly using the Internet, with their most popular online activities being e-mailing and using search engines to find information online (16). On a typical day, these two activities alone were performed by 59% of adult Internet users. Getting news online is ranked fourth on the list of typical online daily activity (46% of Internet users) after using social networking sites such as Facebook, Linkedln, or Google+ (48%). And the use of video sharing sites such as YouTube is no longer restricted to teens, with 71% of online American adults acknowledging their use of such sites in 2012 (16).

Digital access to news through multiple formats is only one aspect of new media environments. In 2011, the digital revolution entered a new phase, the "age of mobile." More than 20% of adults in the United States now own a tablet computer. Four out of 10 American adults own a smartphone that allows them to connect to the Web no matter where they are. New cars are starting to have built-in Internet connections (17). This constant connectivity is exaggerating the tendency for individuals to actively (and frequently) surf the Web for information about any topic and to interact with others online. Ironically, this evolution has proven to be positive for the struggling news business, with mobile owners reporting an increased consumption of news through mobile platforms (17).

To recapitulate, Americans routinely go online to look for information, where they also generate content, share it with others, and connect with people with common interests (7). Through new media platforms, individuals can access massive amounts of information about virtually anything, from anywhere, and without much cognitive effort. Online users can interact with others through Web 2.0 tools and make sense of information they are exposed to using contextual cues (e.g., Facebook "likes," blogs comments, etc.) they encounter. This online revolution has not been without consequences for science information consumers, who, as pointed out earlier, have always relied on traditional journalistic sources like newspapers and television news to keep up with scientific developments. Indeed, data suggest that science information consumers are migrating online.

The Science Information Consumer

As noted in *Science and Engineering Indicators* [a report produced every 2 y by the National Science Foundation (NSF)], it was becoming clear by 2004 that the Internet was displacing traditional sources for information about science in the United States. Although television was still listed as the most prominent medium in terms of overall time spent interacting with science content, the Internet had become the primary resource for those seeking information about science (18). These trends were confirmed in subsequent *Science and Engineering Indicators* reports (19, 20). However, for the first time, in 2012, television and the Internet were both put forward as the primary source of information about science and technology by roughly the same proportion of individuals, respectively, 34% and 35% (21, 22). One could argue that the individuals citing the Internet as their primary source of information about science were turning to online versions of mainstream newspapers and thus were still relying on journalistic sources. However, the 2012 NSF report challenges this view, particularly for information related to specific scientific topics. Among respondents citing the Internet as their primary source of information about distinct scientific topics (60%), almost half (48%) reported relying on online sources other than journalistic ones to do so. In other words, these individuals relied on blogs, social networks, Internet search tools, and other nonjournalistic online sources to find out more about science (21).

In short, American lay audiences are increasingly using Internet sources outside of mainstream journalistic channels for science-related information. Although still scant, data suggest that scientists themselves are starting to rely on these alternative channels to stay up-to-date with scientific developments in their own field or others. One in five American neuroscientists in 2010, for instance, reported using blogs to follow news about scientific issues (23) whereas one in four physicians used social media one or more times a day to stay up-to-date on medical information and innovations (24).

Some demographic patterns concerning online science information audiences are worth noting. Although those individuals who pay attention to science primarily on the Internet are diverse in terms of age (and slightly more diverse racially) than those who rely on other media, overall they tend to be more knowledgeable about science, more educated, and primarily male (25). In other words, the online science information consumer is far from representative of the general population. One may therefore wonder whether the Internet is contributing to gaps in science knowledge and to differences in science attitudes between online and offline audiences—an empirical question I will later address.

Finding and Evaluating Science Information Online: Insights from Science Communication Research

So how is the online environment impacting processes related to science communication? Science communication research has begun to address several questions that are extremely relevant to those interested in the potential of the Internet for increasing public interest and engagement with science. Below, I summarize key findings and outline major research needs for some of the questions often asked in scientific circles.

Question 1: What Motivates Individuals to Seek Science-Related Information Online? As early as 2006, the majority of Americans were using the Internet to look up science information, either to "look up the meaning of a particular scientific term or concept" (70%), to "look for an answer to a question [they had] about a scientific concept or theory" (68%), or to "learn more about a science story or scientific discovery [they had] first heard or read about offline" (65%) (26). More recent data are scant (21) although search patterns for specific scientific terms can easily be determined with the help of the Google Insights tool: for instance, in 2008, biotechnology and climate change generated roughly the same volume of online searches in the United States (25).

An emerging area of research is exploring individuals' motivations for seeking science information online, for learning more about scientific issues, and for exposing themselves to certain types of content. Notably, through Google data mining, one study examined the relationship between the time in the calendar year, the volume of Google news media coverage, and the volume of science-related searches over a certain time period. Results showed that educational activities, and to some degree media attention to news events, were driving science-related searches. Other potential influential factors (e.g., interpersonal exchanges through social networks) were mentioned but not included in the analysis (27).

Others have argued that information exposure does not happen in a vacuum. The conditions under which individuals search for and encounter information online may also serve as motivators and determine the type of information individuals look for. For instance, it is clear that attitudes toward a specific scientific issue seem to be the main motivators for further learning—contrary to common assumptions, individuals supportive of a technology are more likely to seek information about it than others are (28). Anticipating a discussion with people who held views opposite to their own regarding nanotechnology also encouraged individuals to seek out information about nanotechnology issues. In this context, individuals tended to choose information provided by online editorials (or opinion pieces) rather than by online news stories. Interestingly, accessing this information did not necessarily make these individuals learn about the issue (28). Because the motivation was to prepare for a discussion rather than to find out more about the issue, learning did not systematically take place.

In sum, empirical research suggests that lay audiences search for information about specific scientific issues based on different motivations and with different learning and attitudinal outcomes. Empirically explored motivators include feeling strongly about a scientific issue, expecting to have to talk about it, having to address it in an educational setting, or having noticed it covered in the media. In other words, it is clear that motivational processes behind online information seeking for scientific issues, and the potential outcomes of these searches, are complex and that research is only beginning to shed light on them.

Question 2: What is the Nature of the Science Content Encountered Online? Assessing the nature of online science content raises a number of challenges, the most obvious ones being the numerous disciplines that may fall within the "science" umbrella and the massive volume of data that needs to be collected and analyzed. Research has therefore focused on understanding online portrayals of specific scientific innovations, rather than on attempting to draw general conclusions about the nature of online science. To make the volume of online content manageable, scholars often restrict their analysis to content suggested by online search engines and compare it with traditional media content. This approach makes sense because, as I discussed earlier, online searching is often the first step taken by those who want to find out more about science.

Using the approach described above, top Web sites' content and major print newspapers' content in the United States and Germany were found to cover genomic research in a similar way. In other words, there were no significant differences between the online and offline coverage of genomic research, in terms of frames used, evaluations provided, and actors mentioned (29). This result does not hold across scientific issues, however. Specifically, offline and online news coverage of nanotechnology was shown to differ significantly, with online news users more likely to be exposed to environmental dimensions of nanotechnology than American print newspapers' readers. The extent to which online users (or print newspapers' users for that matter) are getting skewed views of nanotechnology is therefore worth raising (30).

Other novel and promising approaches for the analysis of online science content include sophisticated methods involving computational linguistic software. This software can be used to analyze all blog posts, tweets, and other types of online content related to a specific scientific issue or theme. These types of methods eliminate most of the limitations posed by more traditional media content analysis techniques, such as sampled online content, human coding, or simple computer analyses. Discussions related to nanotechnology—nano—on Twitter, for instance, were assessed with this novel type of intelligent algorithm, revealing that 55% of all nano-related tweets (or Twitter posts) written over a year expressed certainty whereas 45% expressed uncertainty. Twenty-seven percent of tweets expressed optimism, 32% were neutral, and 41% expressed pessimism (31), thus indicating that discussions about nanotechnology on the microblogging site Twitter were overall positive. The extent to which these discussions represent the views of the population at large is an empirical question, but these results do reflect the views of individuals likely to shape public opinion about an emerging technology by expressing them on the highly influential platform Twitter.

However, studies such as the ones summarized above are of limited use if the goal is to understand how online content might be impacting public opinion about science. First, these studies are based on analyses of aggregated content that may not represent what most individuals are actually encountering in the online world (in other words, they have low ecological validity). Instead of assessing the nature of aggregated online content for a specific scientific issue, it is therefore important to focus on analyzing what type of search terms individuals are more likely to use to find information about that issue, and on the type of content they are likely to encounter while doing so. Paying particular attention to Google as the most popular search engine, with 64% of all searches (14), recent research has produced interesting results and has raised a number of practical and ethical questions. For instance, a Google search for "nanotechnology," "nanotechnology + risk(s)," and "nanotechnology + benefit(s)" (the most-used search terms for nanotechnology) brings up mainly nonnanotechnology-related Web sites (e.g., www.sciencedaily.com). Over a third of the links suggested by Google are nano-specific Web sites (e.g., www.nanowerk.com), and a small proportion are government Web sites and Wikipedia (32). Interestingly, the nonnano Web sites focus primarily on environment and health dimensions related to nanotechnology, rather than on business or economic dimensions. Consequently, audiences may perceive that nanotechnology pertains primarily to the areas of the environment and health. Google search specific results (and the order in which they are presented to audiences) are creating a latent bias through an overarching frame that may lead information seekers to infer that environmental and health dimensions are more important than others when thinking about nanotechnology (32).

Media giving weight to specific aspects of an issue (or to a specific issue over others) is not a new phenomenon, of course, and the potential effects this weighing can have on audiences' attitudes and understanding of issues are well-documented in communication research literature (33). It could therefore be argued that the processes at play in the online environment are not much different from those pointed out in traditional media effects literature. Indeed, it is reasonable to assume that individuals may give more importance to the dimensions they see covered more often in online media, a process, called agenda setting, that has been extensively explored in traditional media contexts. Empirical data, however, suggest that online processes involve more layers than in traditional media settings (in which an editor or a group of editors choose what topic/issue to cover). As discussed earlier, online users are often actively seeking information about a specific topic. Adding to the literature on the latent bias introduced by Google algorithms, a recent study analyzed what terms individuals used most frequently to search for information related to nanotechnology (as tracked by Nielsen online), what search terms were suggested by Google (based on Google-suggested data), and the nature of the content these keywords retrieved (based on a content analysis of the top ranked search results in Google) (5). Results showed a discrepancy between what individuals searched for online, the search terms Google pointed them to, and the content individuals were exposed to in the end. In other words, a "self-reinforcing informational spiral" seems to be at play, in which automated Google suggestions drive the searches, the traffic, the page ranks, and ultimately the content encountered by the information seeker (5). The latent bias introduced by the Google algorithm (which is obviously not driven by conscious editorial choices as is the case in mainstream media) leads to an important question: is public opinion ultimately related to scientific topics based on how Google results are presented, rather than on what individuals are searching for and the information available?

A question that also needs to be addressed is to what extent information encountered online is accurate and provided by trustworthy sources. Empirical evidence seems to suggest that inaccurate accounts of scientific phenomena are present in the online world although exact proportions have yet to be quantified across the multitude of online platforms. For instance, negative (and inaccurate) portrayals of science are documented in YouTube videos although online video-sharing practices for this type of content are far from being understood systematically by empirical communication researchers (34). However, the online landscape for science is not as grim as it may initially seem. Motivated individuals are not passive when selecting which science stories to pay attention to online and have a tendency to choose those written by blog writers perceived as having greater expertise (35). Likewise, when motivated to learn about a specific issue, these information-seeking individuals tend to prefer messages presenting two sides of an argument (i.e., not opinionated) over one-sided messages (35). In other words, individuals are not passively processing skewed or false information about science but may be assessing the trustworthiness of the information encountered, depending on the context.

It is also important to keep in mind that, although accuracy and trustworthiness are important concepts to consider when thinking about scientific information online, one should not assume that the presence of these concepts will guarantee that lay individuals will develop a positive attitude toward science. In fact, scientific knowledge is not the unique (or even the primary) determinant of how individuals perceive complex scientific issues (36). However, the extent to which online environments increase public knowledge about science (and influence attitudes) is worth pondering from a normative point of view.

Question 3. Is the Internet Changing Public Knowledge and Attitudes About Science? It is clear that online environments have the potential to increase public knowledge levels about a wide range of topics by providing easier access to information than what was possible 20 y ago (when online media were just starting to develop at a larger scale). As noted earlier, however, those who tend to pay attention to science content online tend to be more knowledgeable about science and to be more educated (25). It could therefore be argued that Internet access is favoring knowledge acquisition among this particular group, therefore reinforcing knowledge differentials between the highly educated and other groups. Results of a longitudinal study seem to counter this argument and paint a brighter picture. Internet use (along with television use) appears to be reducing gaps in science knowledge that have been documented between groups with different levels of education, by helping the less-educated online users gain comparatively more knowledge about science (37).

The processes by which these knowledge gains occur are less understood. According to a 2010 survey of a representative sample of the American population, the number of hours spent online is indeed positively related to an increase in scientific knowledge, taking into account the effect of education, age, and several other explanatory variables (22). And the more heterogeneous an individual's information sources about a specific scientific issue, the higher this individual's knowledge levels about the topic (36). It may therefore not be the time spent on the Internet that makes a difference in terms of knowledge acquisition, but rather exposure to different types of content through different online information sources. Audiences may also be taking advantage of additional information, potentially hyperlinked in the article or provided by discussion groups and other types of online expertise.

According to research in different scientific contexts, specific online modalities can help knowledge acquisition about science. For instance, a linear Web site design tends to promote factual learning whereas a nonlinear design (i.e., allowing for viewing in multiple orders) tends to promote an understanding of the interconnectedness of the health information related to three separate topics presented online (cancer treatments, nicotine addiction, and asthma) (38). Levels of potential interactivity on a Web site also matter for learning, according to a study that used ecogenomics as a case study; interestingly, low levels of interactivity generated more knowledge about the issue of ecogenomics than medium or high levels of online interactivity. And, as we noted earlier, an individual's predispositions toward a specific issue (such as a positive attitude) can also lead to increased knowledge when one is exposed to information about a scientific topic online (28).

The online environment can therefore boost learning about science although this learning will be dependent on individual characteristics and online modalities, as well as on the conditions under which the information exposure occurs. The extent to which this environment changes public attitudes toward science is another question.

Research has been examining the relationship between media use and attitudes toward science from a wide range of theoretical perspectives (see Eveland's paper in this PNAS issue) (39). It is clearly established that mediated information can influence individuals' attitudes toward science through different routes (10). As mentioned earlier, two individuals are likely to react differently to the same information while relying on their value systems, existing knowledge, and other mental shortcuts to make sense of the information (40). I have argued elsewhere, however, that new media environments introduce additional challenges and that processes not yet fully understood are at play when individuals find information online. For instance, online newspaper articles are not consumed in isolated fashion as they used to be and are now contextualized by readers' comments, Facebook posts, and "likes" or short commentaries in Twitter posts (6).

This online contextualization of science-related information matters as far as attitudes toward science are concerned. Notably, a recent study concluded that the level of civility of the comments following an objective online news item on potential risks related to a technology impacted readers' perceptions of such risks. Among those supportive of nanotechnology, those exposed to uncivil comments after the news item perceived more risks in the technology than those exposed to civil comments. This pattern held true among the highly religious individuals (14). Results get even more disturbing: those exposed to uncivil comments were more likely to see bias in the news story than those exposed to civil comments, even though all subjects saw the same news story (41). In short, a well-written, balanced news story about a scientific topic may be interpreted differently because of the comments that follow it. Obviously, these results have important implications for science communication online and point to the importance of carefully evaluating how scientific information is presented, under which format, and with what type of contextualization.

Looking Forward

Science communication is being redefined as online environments gain prominence and traditional science reporting shrinks in volume. Science sections in mainstream news outlets are disappearing, and science communication is increasingly taking place through blogs and other online-only forums managed by former journalists, scientists, and lay individuals alike (30). Throughout this paper, I have discussed and outlined major research findings related to the potential impact of online science contexts on science information seeking and exposure, as well as the effects of diverse online modalities on attitudes and knowledge levels among lay audiences. It is clear that we are only beginning to grasp the consequences of the online revolution on public attitudes and knowledge related to science.

A major conclusion of this review is that, although research examining general communication processes on the Internet is fertile—peer-reviewed journals such as the *Journal of Computer Mediated Communication* or *New Media and Society* are devoting many pages to these types of studies—empirical research examining specifically online science communication processes and outcomes is still scant. Ironically, as the well-attended 2013 ScienceOnline conference demonstrated (42), 21st-century science communicators (including a number of scientists themselves) have enthusiastically embraced the social Web as a powerful tool for communicating science at a speed greater than that at which empirical research on these processes has been conducted and published. As a result, many of the "best practices" of online science communication currently exchanged among practitioners are based on experiential evidence rather than on an empirical understanding of the broad outcomes that could be expected from current efforts. For instance, although it is clear that one of the best ways to reach a large number of individuals beyond an established network (such as the regular readers of a particular science blog) is through an online item that goes viral, the notion of virality for science stories has seldom been empirically investigated. The influential microblog Twitter has yet to be explored empirically as a science communication platform from an audience perspective. The effect of specific wording choices on Twitter, for example, may not only prime readers to process the information in a certain way, but may also encourage further dissemination. And the potential of social networks for science communication has yet to be explored empirically, a puzzling circumstance considering that two-thirds of online American adults are now Facebook users and that numerous groups are using this social network to communicate their views about a wide range of scientific issues, impacting public opinion in the process. Because social networking sites such as Facebook clearly provide good opportunities for individuals to be exposed to information they would otherwise not encounter or look for (42), online science communication researchers should make investigating these settings a priority.

The impact of the online revolution on science communication processes does, obviously, go beyond the few questions explored in this review. I examined empirical findings related to some questions that are at the core of the relationship among science, media, and the public and that are often raised in science circles. Of course, new information environments are transforming science far beyond the few questions addressed in this paper. Traditional peer review is radically transformed by extensive discussions of published research in blogs and other platforms. Both the meaning and reach of scientific publishing are being reconfigured as new options such as open access and online reference managers are changing the rules of the game. And the profession of the scientist itself is being redefined as some young researchers consider embracing public communication in the online world, without clear indication that it will help their careers within traditional academic structures. All these aspects of science 2.0 are in need of empirical research. However, if among the goals of science as an institution is broad engagement with science across all cross-sections of the public, advancing the science of online science communication should be a priority. The good news is that we do not need to reinvent the wheel and can build on empirical findings not only from other areas of communication research, but also in other fields such as marketing research and computer science.

Science as an institution is, more than ever, in need of public support as federal funding is shrinking and scientific issues become more and more entangled with social and ethical considerations. A theoretical understanding of the processes at play in online environments will have to be achieved at a faster rate if science wants to leverage the online revolution for successful public engagement.

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