

Down to a r/science:

Integrating Computational Approaches to the Study of Credibility on Reddit

Keywords: Content analysis; Internet research; Observational research methods; Textual analysis; Science communication

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Abstract

Digital trace data enable researchers to study communication processes at a scale previously impossible. We combine social network analysis and automated content analysis to examine source and message factors' impact on ratings of user-shared content. We found that the expertise of the author, the network position that the author occupies, and characteristics of the content the author creates have a significant impact on how others respond to that content. By observationally examining a large-scale online community, we provide a real-world test of how message consumers react to source and message characteristics. Our results show that it is important to think of online communication as occurring interactively between networks of individuals, and that the network positions people inhabit may inform their behavior.

Keywords: social network analysis, source credibility, science communication, social media, expertise

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Social media is an important part of American life as seven-in-ten Americans use at least one form of social media to communicate with others (Pew Research Center, 2019). Beyond communication, two-thirds of U.S. adults report receiving news through social media (Shearer & Gottfried, 2017), including news about science. People increasingly use online sources to seek science information in general and follow specific developments in science (Su, Akin, Brossard, Scheufele, & Xenos, 2015).

The interactive nature of social media makes it possible to engage with information related to science in more profound ways than previously possible (e.g., Cody, Reagan, Mitchell, Dodds, & Danforth, 2015). Scientists recognize that social media offer new opportunities to engage with the public¹ about science (Liang et al., 2014). With scientists sharing more information about science through social media and members of the public increasingly using social media sites to engage with science information, investigating how the public responds to science content is vital to understanding the modern information environment surrounding science. Specifically, we investigate how individuals react to credibility cues on social media.

The study of source credibility has a rich history dating back to Carl Hovland's propaganda research in the 1950s (Pornpitakpan, 2006). Experimental work has since illustrated the influence of source and message factors on evaluations of perceived credibility (Pornpitakpan, 2006; Wathen & Burkell, 2002). While these studies have developed our understanding of the influence of source and message dimensions on credibility evaluations, recently scholars have argued for re-evaluating the role of credibility in today's information

¹ When we refer to the "public" in this paper, we are referencing scientifically-interested individuals, thus constituting a subset of the population.

environment (Metzger & Flanagin, 2013; Metzger, Flanagin, & Medders, 2010). In the past, traditional “gatekeepers” often served to evaluate information and pass it along to members of the public (e.g., doctors, journalists). Today, however, individuals often identify credible information themselves. Therefore, there is an open question of whether individuals still rely on traditional source cues to determine the credibility of information. To address this question, scholars have conducted experiments where individuals select information (Metzger & Flanagin, 2013) and conducted focus groups to understand how individuals evaluate the credibility of a website (Metzger et al., 2010). We build on this research by exploring whether traditional source cues predict credibility-related outcomes on a large, observational, and externally valid scale. As the divide between experts and the public becomes more fluid and as rapid access to new scientific studies increases, it is often left to the public to assess the credibility of online content (Brossard, 2013; Mason, Boldrin, & Ariasi, 2010), which may inhibit a full understanding of the scientific process and the implications of science for the public.

Recent changes in the media environment might significantly influence how the public understands science topics and perceive new scientific developments (Brossard, 2013; Winter & Krämer, 2012). Despite the importance of this question, studying online systems is difficult due to their size and complexity. Social scientists, therefore, have begun to use computational methods, such as network analysis, to aid in their study of these complex systems (Lazer et al., 2009; Mahmoodi, Leckelt, van Zalk, Geukes, & Back, 2017). In the current study, we introduce an integrative approach to the study of science communication, combining network- and content-analytic methods to study the communication of science information in the Reddit community r/science.

As of 2019, Reddit is the sixteenth most popular website worldwide and the fifth most

popular in the U.S. (Alexa, 2019). Further, about 78% of Reddit users report Reddit as their primary source of news (Barthel, Stocking, Holcomb, & Mitchell, 2016b). Reddit exemplifies a new way that people obtain and understand information: through discussion with others outside the boundaries of their physically-mediated networks (Barthel, Mitchell, & Holcomb, 2016a). Scholars have studied several topics on Reddit such as health-related discussions (Sharma, Wigginton, Meurk, Ford, & Gartner, 2016) and communication during crises (Suran & Kilgo, 2017). One area that has not been sufficiently studied, however, is conversations surrounding scientific information. This is noteworthy because as of 2016, Reddit's dedicated science subreddit (r/science) has more than 12 million members and more than 20 million users contribute to the largest science-related subreddits (Cenci, 2016). Given the attention to science information on the site, is important to examine the ways individuals react to credibility cues on the site.

Beyond studying whether traditional credibility cues behave the same way in online communities, Reddit offers an opportunity for examining organic interactions between scientists and members of the public. For the past decade science communication scholars have urged scientists to abandon their traditional top-down approach for communicating with the public (i.e., lectures or opinion pieces) and should engage the public with dialogue. Although researchers have examined scientists' attitudes towards the public, few studies have captured what such dialogues look like in practice. Reddit is a platform where scientists directly communicate daily with the public. Therefore, it is vital that we study this interaction to understand effective science communication on social media.

This study advances the literature in the following ways. First, this study examines a science-related subreddit holistically, as we analyze the network of posts and comments on one

of the most popular science forums on the internet over a year-long period. Previous studies examining social media dealt with the difficulty of analyzing hundreds of thousands of posts by selecting only a small sample to analyze. We overcome this difficulty by combining social network and automated content analyses to address examine our research questions at scale. This method enables the unobtrusive observational study of interactions between users in an organic environment. Second, this study introduces a computational approach for understanding communication about science.

Reddit Overview

Reddit is an online messaging community where users post and comment on content. The website has over 234 million users, also called “redditors”, and receives over eight billion-page views per month (Cenci, 2016). In general, redditors are young (64% are between the ages of 18 and 29) and around two-thirds are male (Sattelberg, 2019). Furthermore, the majority of redditors have either some college education or a college degree (Sattelberg, 2019).

Any user can initiate a new community, called a subreddit, about a subject of their choosing, or participate in an existing subreddit. For example, a redditor can share a news story or a research article, and other redditors can respond to that post. As opposed to information shared through traditional news sources, where content provided by source is primary and comments are secondary, discussion between users is typically the main function on Reddit (Barthel et al., 2016a).

After a redditor has created a post, other users can upvote or downvote it. This voting process not only allows users to express their approval or disapproval– it also determines the positioning of posts within on the site. Within the comment thread of given post, voting determines the presentation order of comments. Upvotes are generally considered good and

downvotes are typically considered bad. There are likely nuanced meanings for upvotes and downvotes in the Reddit community, perhaps signaling attributes such as interestingness or content quality to other users. Although it is likely that in the r/science Reddit community that upvotes are substantially related to credibility, other aspects of message quality are likely to be related to the score that a post receives.

Credibility Cues on Reddit

According to dual processing models of communication, people process messages either heuristically or systematically (Chaiken, 1980; Petty & Cacioppo, 1986). Systematic processing is more cognitively taxing than heuristic processing. Individuals typically process a message heuristically when they have neither the motivation to apply cognitive resources nor sufficient background knowledge. Since many science topics are unfamiliar to the public, individuals may rely on heuristics in order to form judgements (Anderson, Brossard, Scheufele, Xenos, & Ladwig, 2014). Individuals tend to scan their social environment for clues about what is typical or normative and might attend to social cues such as votes or user comments to identify credible content (Spartz, Su, Griffin, Brossard, & Dunwoody, 2017).

Perceived credibility can also be thought of as the person or message's "believability" (Fogg, 1999; Hovland, Janis, & Kelley, 1953). There are typically three dimensions that interact in order to affect a message or person's perceived credibility. First is source characteristics, such as expertise or trustworthiness (Eastin, 2006; Pornpitakpan, 2006). Second is message characteristics, such as language complexity or accuracy (Pornpitakpan, 2006). Third is the receiver's characteristics, such as personal beliefs or prior knowledge (Pornpitakpan, 2006). Our focus is on source and message factors.

Source Factors

When people evaluate unfamiliar information, they often judge the information's credibility based on the message's source (Eastin, 2006). Source credibility typically encompasses two dimensions: expertise and trustworthiness (Wathen & Burkell, 2002). Expertise is often determined by evaluating the source's related professional experience (Weiner & Mowen, 1985). Trustworthiness is often established through multiple interactions where a source displays dependability (McGinnies & Ward, 1980). Source factors are especially relevant in the context of science communication, as people may not have knowledge or experience with science and instead rely on heuristic cues (Bromme, Kienhues, & Porsch, 2010; Winter & Krämer, 2012).

Of the two dimensions of source credibility, source expertise on a given topic is relatively straightforward. According to Eysenbach and Köhler (2003), individuals report that when determining the credibility of an online source, they initially examine the author. Specifically, people evaluate if the individual, or source, has professional experience. People tend to assign more credibility to those perceived as a primary source (Hilligoss & Rieh, 2008). For example, if an individual with a PhD in biochemistry shares a research article related to biochemistry social media, she might be perceived as a primary source on the subject and to have relevant professional experience.

Within r/science, redditors can obtain "author flair" which indicates their education or professional experience. Author flair is displayed prominently, next to or above the author's username. Author flair typically specifies whether the user has earned a degree or gained professional experience in a particular field, which likely serves as a heuristic for individuals to determine if the redditor has expertise on the subject being discussed. As upvoting might be seen as a type of "social endorsement", redditors who have author flair will be more likely to receive

“upvotes” than individuals without author flair.

H1a: Redditors who use author flair will receive higher scores on their comment submissions than redditors who do not use author flair.

It is intuitive that as a source’s stated degree level increases (i.e., an individual with a Ph.D. versus an M.A.), so should their perceived expertise in that field. Therefore, we also hypothesize the following:

H1b: As a redditor’s author flair signals a higher level of expertise, their comment submissions will receive higher scores.

Trustworthiness is another important dimension of perceived source credibility in online communities. A source’s trustworthiness can be established through multiple interactions with other users where the individual consistently provides quality information (Galegher, Sproull, & Kiesler, 1998; Mou, Miller, & Fu, 2015). It is difficult to measure trustworthiness within a community as the researchers are often outsiders of the group, therefore this dimension has not received as much attention.

However, within a social network, an individual’s trustworthiness might be measured using a concept called “centrality.” Conceptually, centrality is how important an individual is to the network (Freeman, 1978). The concept has been used as a measure of the credibility of webpages. For example, Google’s algorithm ranks search results based on how many hyperlinks are directed at a site, implicitly assuming that sites with more hyperlinks directed at it are more credible (Brin & Page, 1998)². It is still an open question, however, whether the same centrality principles apply to credibility online.

On Reddit, there is reason to believe that users occupy central positions in the network of

² Although the current Google ranking algorithm relies upon many proprietary factors, the original published ranking algorithm relies only on network structure. In this way, the method assumes that network structure will reveal which nodes in the network provide valuable information.

comments because they have provided useful comments previously. This is due to the way that information is shown to users. On a thread with many comments, comments that have (a) a higher score and (b) have received many previous comments, are presented to users at the top of the comment tree. Because of this, the previously highly-rated and highly-commented on comments are likely to be viewed receive more positive feedback. This drives these users toward the center of the network related to a given post. As users create many comments that receive high scores and receive many comments across posts, they will be more central to the overall network.

We use eigenvector centrality to measure centrality for all users across the full network. Redditors are considered more central to the network when they receive more comments on their submissions from other redditors who have also received a high number of comments on their own submissions. We expect that the scores of comments from central individuals to be higher on average than those of more peripheral individuals.

H2: Redditors who are more central to the network will receive higher scores on the comments they create than those who are peripheral to the network.

Message factors, in this case directly produced by sources, are another heuristic for establishing credibility. While many message factors of scientific information have been studied (i.e., “scientificness” of the message, see Thomm & Bromme, 2011), we focus on language complexity. Language complexity has been defined and operationalized in multiple ways, but the overarching theme between these studies is that message complexity increases if processing it demands high cognitive resources (Haard, Slater, & Long, 2004; See, Petty, & Evans, 2009). When information presented is complex, individuals use the complexity as a heuristic cue that the source has expertise on the matter (Cooper, Bennett, & Sukel, 1996). In other words, novice readers tend to view sources of information as more credible when they use more syntactically-

challenging phrasing to convey a message.

Language complexity has been shown to differentially affect metacognitive processes regarding message reception, making judgements about messages more difficult (Bullock, Amill, Shulman, & Dixon, 2019; Oppenheimer, 2006; Sweitzer & Shulman, 2018) and may promote the use of heuristic processing. Language complexity is not necessarily detrimental to the explanatory potential of the text, as it may be correlated with positive evaluations of arguments and explanations (Zemla, Sloman, Bechlivanidis, & Lagnado, 2017). This is particularly the case when the “academic” qualities of the phrasing are used as heuristic cues for expertise. We expect that Reddit users will differentially evaluate comments based on the complexity of the language in much the same way as they differentially evaluate comments from users with varying levels of explicitly-stated expertise (i.e., flair; see H1a and H1b). That is, we expect the message factor of language complexity to operate as a credibility cue. Therefore, we hypothesize the following:

H3: Comments with more complex language will receive more upvotes than comments that do not use complex language.

The scientific information found in r/science is valuable because it explains scientific findings to non-experts with academic rigor (Cenci, 2016). Writing style, particularly for those steeped in the academy, has been the subject of several investigations both in scientific texts (e.g., Arya, Hiebert, & Pearson, 2011) and in online forums (Hartley & Cabanac, 2016). The writing of scientific experts reflects community norms, such as the use of the scientific method and the description of complex research methodologies (Thomm & Bromme, 2011). While H3 tests whether the complexity of language is evaluated in much the same manner as explicit cues of a user’s expertise (H1a and H1b), it is nonetheless important to ascertain whether the use of language complexity as a heuristic expertise cue is justifiable. Previous research on the subject of expertise and language complexity has found that experts often use more complex language than

novices (e.g., Tolochko & Boomgaarden, 2018). We thus expect that experts on r/science will use more complex language in their comments:

H4a: Users with author flair will use more complex language than those who do not use author flair.

H4b: Language complexity will increase as the user's level of expertise increases.

Method

We examine the structure and content of comment forum networks using social network analysis and automated content analysis. Social network analysis enables us to understand how the topology of the network influences voting patterns on comments and posts. Automated content analysis enables us to study the content of messages at scale.

Data Collection

To study how network position and content affect the likelihood that a submission receives positive feedback, we use the archive of Reddit that is hosted by Google's BigQuery. We select all posts and comments from r/science between January 1, 2016 to December 31, 2016. There are 1,450 moderators who enforce the rules on r/science (see Table 1 for a description of the basic rules). While we use top-level posts to create the network of comments—the initial post—top-level posts on r/science only contain links to external sources (i.e., a link to a science news article). Therefore, the content we analyze comes from comments following the post, which is a set of 556,535 comments made by 159,535 unique users.

[Insert Table 1 Here]

Network Analysis

Using the structure of the posts and comments, we created a weighted network of the connections between users. We consider two users to have a directed tie that goes from the author of a comment to the author of the post or comment that the comment is replying to. We

weight the ties between users by the number of times a given user has commented on another user's submission. The decisions to use both weighted and directed network is an important one, as it reflects both the varying strength and potential for either symmetrical or asymmetrical relationships in discussion networks (Faraj & Johnson, 2011; Monge & Contractor, 2001, 2003, pp. 35). Figure 1 shows an example of a post and subsequent comments and how this would be translated into a network. We used the *igraph* package (Csárdi, 2019) in R for all network analyses.

[Insert Figure 1 Here]

Measurement

Independent variables.

Author flair used measured whether the author used “flair” when making the comment. Within the r/science subreddit, redditors can obtain “flair” from moderators if they provide documentation that they have expertise in a scientific area. This is typically accomplished by sending a photo of their diploma, academic course registration, business card, or by providing a verifiable email address to the moderators (Reddit, *n.d.*). The general format of the display of author flair is: “Level of Education | Field | Specialty or Subfield”. For example, “Professor | Biochemistry” or “Graduate Student | Physics | Quantum Mechanics”. Relatively few users ($n = 2,385$) used author flair and the vast majority have not ($n = 157,150$). Authors who use flair are relatively prolific. Authors who use flair have created more comments ($M = 19.74$, $SD = 82.55$) than those who do not ($M = 3.24$, $SD = 30.74$), receive higher scores on their comments ($M = 13.02$, $SD = 90.51$) than those who do not ($M = 9.20$, $SD = 80.26$), and have received a larger total number of comments from others on prior submissions ($M = 256.25$, $SD = 509.90$) than those who do not ($M = 15.46$, $SD = 179.92$). These descriptive statistics show the substantial role

that users who use flair play on the forum.

Author expertise was measured categorically using the academic credentials present in the authors' flair. We used the *stringr* package (Wickham, 2019) in R to separate components of the flair text that are denoted by the "|" separator. Each component was further refined by converting all text to lower case, removing punctuation characters (e.g., both "Ph.D." and "PHD" become "phd"), and removing space characters at the beginning or end of components to account for variations in formatting. We dissected components into individual words to search for words which correspond to levels of educational achievement. The levels observed in the data are: No degree information ($n = 157,327$), Bachelor's degrees (e.g., "ba" or "bs"; $n = 637$), Master's degrees (e.g., "ma" or "ms"; $n = 606$), Doctorate degrees (e.g., "phd" or "professor"; $n = 660$), and some graduate school (e.g., "ms" or "phd" *along with* "student" in the same component; $n = 299$). These were coded such that information which would indicate multiple levels of educational attainment (or "student") would override the prior classification. For example, if an author's flair contains both "ms" and "phd", the author is categorized as having completed a doctorate.

Network characteristics were assessed using igraph. We calculated node-level network characteristics in a time dynamic way, including in-degree, out-degree, and eigenvector centrality. Because an author's position in the network varies across time, we calculate the network measures dynamically at the precise time that a new comment is made. That is, when a comment is made we calculate the in-degree, out-degree, and eigenvector centrality of the author at the precise moment the comment is posted to the site. In that way, the behavior of future commenters or the author themselves will not affect these measures. *In-degree* measures the number of times that a submission a user created was commented on by others ($M = 35.24$, $SD =$

235.47). *Out-degree* measures the number of times that a user had commented on a submission by another user ($M = 117.08$, $SD = 674.56$), and is therefore a count of the number of comments a user has previously made. *Eigenvector centrality* is a network measure of how central a node is based on the centrality of the nodes that node is directly tied to. This variable is measured as a percentile rank of the full set of centrality scores, as the raw centrality measures are highly skewed ($M = 0.50$, $SD = 0.29$; raw $M = 0.001$, raw $SD = 0.031$).

Days between measured the number of days between when a submission was created and when it was archived ($M = 26.92$, $SD = 8.44$). Including this measure in the analyses accounts for differences in the score that a comment receives over time. Scores on comments tend to change more rapidly soon after appearing on the site, so by including the age of the comment we account for differences that depend on when data were collected relative to when a comment was submitted.

Reply to post is an indicator variable for whether a comment is a direct reply to a top-level post (1) or is a reply to a comment further down the comment tree (0). Of all comments, 137,680 (24.7%) were replies to top-level posts.

Dependent variables.

Score measured the score a comment received from other users. Once a submission is made, other users may either “upvote” or “downvote” the submission. The score of a comment is the number of upvotes minus the number of downvotes ($M = 9.51$, $SD = 81.16$)³.

Language complexity was measured using the Flesch (1948) Reading Ease scale⁴ ($M =$

³ Although the distribution of scores for posts is highly skewed, we use the raw score rather than the transformed score for ease of interpretability. Models using a log-transformed version of the dependent variable show substantively similar results.

⁴ We note that all analyses using language complexity were also conducted using the Flesch-Kincaid (Kincaid, Fishburne, Rogers, & Chissom, 1975) Grade Level scale, which produced substantively similar results.

67.17, $SD = 24.68$). We used the *koRpus* package (Michalke, 2018) in R to “tokenize” the text from comments. Tokenizing delimits words and sentences using punctuation and grammatical structures. We then generated the language complexity statistics. Note that this variable is also used as an independent variable in some analyses. Higher scores indicate that a submission is easier to read (i.e., less complex language).

Analytic framework.

To account for multiple observations from an author, we use generalized estimating equations (GEE) to cluster standard errors on the author, which accounts for multiple observations of the same author (Liang & Zeger, 1986). We include in our regression analyses the measures for *days between*, *reply to post*, *in-degree*, and *out-degree* as control variables. Submissions receive more votes over time and scores tend to settle to a relatively stable value after 1-2 weeks. By controlling for the number of days between a post being created and when the data was collected, we account for differences in the score a post receives that are due to differences in the amount of time between post creation and data collection rather than from the theoretical processes under study. Similarly, direct comments on posts tend to receive higher scores than those that are replies to comments on posts (comments on comments). By controlling for a comment’s position in the comment tree, we account for differences in the score a post receives that are due to the comment’s position⁵.

The measures for in-degree and out-degree quantify the local level of interaction patterns between a user and immediate contacts. By controlling for these factors, centrality should indicate the influence of network position that is less in control of the focal individual. Put another way, by including the measures of direct connection, the measures of network centrality

⁵ We note that models that exclude these control variables produce substantively similar results, but by including them the estimates of our key independent variables are more efficient.

should be net of pure “popularity” (*in-degree*) or activity on the site (*out-degree*).

Results

We first examined the relationship between user-generated signals of expertise and our network-based measure. We found significant positive associations between *author flair used* and *eigenvector centrality* ($r = .024, p = 0.01$), and *author expertise* and *eigenvector centrality* ($r = .020, p < 0.01$). The low correlation values are due, at least in part, to the rarity with which author flair is used on the site. To test H1a, H2, and H3, we performed two regression analyses, presented in Table 2. In Model 1, the *score* a post received is predicted by *author flair used*, *reading ease*, *reply to post*, and *days between*. In Model 2, the *score* a post received is predicted by *author flair used*, *reading ease*, *reply to post*, *days between*, *eigenvector centrality*, *in-degree*, and *out-degree*.

[Insert Table 2 Here]

As shown in Model 1, there is a significant positive relationship between *author flair used* and the *score* a post receives ($\beta = 0.011, p < 0.01$), supporting H1a⁶. As shown in Model 2, there is a significant negative relationship between a redditor’s *eigenvector centrality* and the *score* a comment receives ($\beta = -0.009, p < 0.001$), which does not support H2. Importantly, in this model *author flair used* continues to be a significant predictor of the *score* a comment receives. This suggests that network centrality and author flair do not account for the same variance in the *score* a comment receives. Finally, in both Model 1 ($\beta = -0.009, p < 0.001$) and Model 2 ($\beta = -0.010, p < 0.001$) *reading ease* is negatively associated with the *score* a comment

⁶ We note that the coefficient estimates for the effects of our independent variables on comment scores are often small. However, it is important to note that most of the comments have scores near zero. Indeed, 50.1% of comments have a score of -1, 0, or 1. Further, 80.7% of comment scores are between -5 and 5. As such, even a small coefficient estimate suggests that a comment’s likelihood of receiving an extra vote is substantial.

receives, supporting H3.

To test H1b and to further test H2, we performed two regression analyses, presented in Table 3. Separate regression models were used because the measures for *author flair used* and *author expertise* are highly correlated ($r = 0.81, p < 0.001$). Conducting separate analyses avoids problems with multicollinearity. In Model 3, the *score* a post received is predicted by *author expertise*, *reading ease*, *reply to post*, and *days between*. In Model 4, the *score* a post received is predicted by *author expertise*, *reading ease*, *reply to post*, *days between*, *eigenvector centrality*, *in-degree*, and *out-degree*.

[Insert Table 3 Here]

As shown in Model 3, there is a significant positive relationship between *author expertise* and the *score* a comment receives ($\beta = 0.012, p = 0.009$), which supports H1b. As shown in Model 4, there is a significant negative relationship between a redditor's *eigenvector centrality* and the *score* a comment receives ($\beta = -0.009, p < 0.001$), which contradicts H2. In the model accounting for network position, *author expertise* remains a significant predictor of the *score* a comment receives. This suggests that the variance explained by author expertise is separate from the variance accounted for by network centrality. Finally, in both Model 3 ($\beta = -0.009, p < 0.001$) and Model 4 ($\beta = -0.010, p < 0.001$) *reading ease* is negatively associated with the *score* a comment receives, supporting H3.

To further examine the relationship between *author expertise* and the *score* a comment receives, we conducted parallel analyses to those presented in Table 3, except only include authors who used author flair. In this way, we are examining whether the same relationships hold among the relatively small set of authors ($n = 2,385$) who used author flair. The results of these regression analyses are presented in Table 4.

[Insert Table 4 Here]

In these models, we find that *author expertise* is a positive predictor for the score a comment receives in both models but is only significant in Model 6 ($\beta = 0.020, p < 0.01$). However, we note that in Model 5, the coefficient is similar to the coefficient in Model 3. The lack of a significant relationship may owe to the reduced power from reduced sample size. We also note that in Model 6 the relationship between *in-degree* and the score a post receives is also positive and significant ($\beta = 0.057, p < 0.001$), suggesting that among authors who use author flair receiving more comments is associated with higher comment scores. Together, these results further support H3.

To test H4a we performed two regression analyses, presented in Table 5. In Model 7, the dependent variable is the *reading ease* for a comment as predicted by *author flair used*, while controlling for *days between*. In Model 8, the dependent variable is the *reading ease* for a comment as predicted by *author flair used*, while controlling for *days between*, *eigenvector centrality*, *in-degree*, and *out-degree*.

[Insert Table 5 Here]

As shown in Model 7, there is a significant negative relationship between *author flair used* and *reading ease* ($\beta = -0.094, p < 0.001$). Similarly, in Model 8 there is a significant negative relationship between *author flair used* and *reading ease* ($\beta = -0.077, p < 0.001$). Together these results support H4a. These results suggest that the use of author flair is associated with writing comments using more complex language, after accounting for network position.

To test H4b, we performed two regression analyses presented in Table 6. In Model 9, the dependent variable is the *reading ease* for a comment as predicted by *author expertise*, while controlling for *days between*. In Model 10, the dependent variable is the *reading ease* for a

comment as predicted by *author expertise*, while controlling for *days between*, *eigenvector centrality*, *in-degree*, and *out-degree*.

[Insert Table 5 Here]

As shown in Model 9, there is a significant negative relationship between *author expertise* and the *reading ease* with which a comment is written ($\beta = -0.085, p < 0.001$).

Similarly, in Model 10 there is a significant negative relationship between *author expertise* and the reading ease at which a comment is written ($\beta = -0.069, p < 0.001$). Together these results support H4b. Again, these results suggest that the use of author flair to signal expertise is associated with writing comments in more complex language net of network position.

Discussion

We brought new data and methods to investigate important questions concerning whether traditional source and message cues predict credibility-related ratings on a large social media platform. Although the hypotheses tested here are derived from well-established theories of expertise in the science communication literature, to our knowledge the dynamics of social structure and expertise have not been previously tested at the scale investigated here. We may have expected, for example, that the effects of the characteristics or network position of a single user would be overwhelmed at scale by the presence of non-experts (Ruths & Pfeffer, 2014, pp. 1063). Instead, we found evidence that credibility indicators, such as expertise and message complexity, work in similar ways on r/science as they do in smaller-scale interactions. Further, we find that an author's expertise and content characteristics have a significant impact on how the content is assessed by others. Interestingly, we also found that it was an individual's centrality score prior to submitting a comment was negatively associated with the score that comment would eventually receive. This finding contradicted our expectations, and we elaborate

on some potential explanations of this result below. This illustrates the significance of previously tested source and message factors in an externally valid manner.

We found that redditors who make claims to expertise through the use of author flair create submissions that receive higher scores. This finding is promising for science communication as it shows that expertise might play an important role in an individual's evaluation of science content online. Because this study is observational in nature, we cannot definitively rule out other factors that might have impacted content voting. Indeed, our results showed that prior network position is related to the score that a comment receives, but that relatively peripheral users received higher scores on their posts. While this goes against our original hypothesis that redditors who are more central to the network will receive higher scores on the comments they create than those who are peripheral to the network (H2), it is not unsurprising. Peripheral users who contribute to a conversation may bring new perspectives. Further, although we do not have direct measures of this, it is possible that relatively peripheral users only contribute to conversations high up a thread's chain of comments when they have particularly pertinent information. If there is selective posting of this kind, these peripheral users may be likely to post information that is likely to receive a high score from others. Furthermore, posting quality information might increase one's trustworthiness within the network which might relate to receiving higher scores on a given comment. This finding is supported by Morrison and Hayes (2013) who found that there is a group of "casual commenters"—individuals who infrequently post on various subreddits—who are generally well-received by the Reddit community (e.g., receive feedback via upvotes and comments). Given our findings, in conjunction with previous work, future research should investigate whether centrality scores are a good measure of trustworthiness in online communities, or if other measurements, such as

average upvotes, might be a better proxy. It is important to note that we also found that a source's expertise predicted their centrality within the network, thus illustrating that the effects of trustworthiness and expertise are difficult to disentangle when examining source characteristics in an observational manner.

We also examined message characteristics, specifically the effects of message complexity on credibility ratings. Comments with more complex language were rated more highly. This finding supports previous credibility research where message complexity serves as a heuristic cue for credibility. However, science communication scholars recommend that scientists use simple language when communicating with the public (Mogull, 2017). Our research suggests this may negatively impact perceptions of scientist credibility. Further research is needed to assess whether simple messages provided by expert individuals are perceived as equally credible as complex messages in order to better guide scientists on best practices when communicating with the public.

We also assessed the extent to which redditors who used author flair and who indicated they had scientific expertise use more complex language than those who did not. First, those who use author flair write comments with significantly more complex language. Second, we found that authors who indicate a higher level of education in their author flair use more complex language than those who indicate a lower level of education. These results suggest that users with more training use more sophisticated syntax to communicate on Reddit. While this relationship justifies the use of language complexity as a heuristic credibility cue, it may also hinder the flow of scientific information. Future research should consider the public's reception of countervailing cues of credibility and complexity.

Taken together, these findings suggest that experts use more complex language when

discussing science information on Reddit compared to laypeople. Importantly, the mean reading ease across all users indicates that comments and comments on r/science are written in “plain English” that is “easily understood” (Flesch, 1948). Normatively, it is encouraging that much of the information presented in r/science is written in an accessible way.

This study has several limitations worthy of note. First, the nature of the data on a website, such as Reddit, are – to some degree – unverifiable. For some measures, such as the characteristics of the content, this is not much of an issue. However, for author expertise we are only able to measure expertise through the information that users present. Although r/science administrators attempt verification, and this should give us confidence that our measures are meaningful outside the context of the website, we note that the results related to expertise should be interpreted with some caution. That said, the way in which redditors present themselves online is important. Even if their self-presentation is not genuine, it may impact how others evaluate content they create. Additionally, we assume that author flair indicates expertise. It is also possible that author flair is perceived as an in-group cue. When a user considers a message author or source as part of their in-group this can lead to strong persuasive effects (Edwards, Edwards, Qing, & Wahl, 2007). Further, author flair could also serve as evidence that the user is a human rather than a bot which could also lead to credibility-relevant outcomes. Further research is needed to determine the ways in which author flair is interpreted. A related limitation is our use of upvoting as a proxy for perceived credibility. While Leavitt and Robinson (2017) found that upvoting is a mechanism that redditors use to endorse the quality and credibility of crowd-sourced breaking news information on Reddit and Hayes and colleagues (2016) focus groups on upvoting and other endorsement behavior on social media revealed that upvoting is a form of social currency on reddit. More research is needed in order to understand the meaning of

upvoting on the r/science platform specifically and whether upvoting can indeed be used as proxy for perceived credibility.

Another substantial tradeoff in using large-scale, digital trace data like the data employed in this study is that the nature of causal relationships is difficult to discern. Although we include control variables in our models to attempt to reduce the impact of likely confounds, accounting for all of the possible omitted variables is a fool's errand. Of particular concern in our study, comment authors who present credentials may also be more likely to present information in a compelling way. If that is the case, distinguishing between the causal effect of a credential and a convincing argument is quite difficult. Future research may wish to examine the processes we have investigated here using experiments to better identify causal relationships.

It would be preferable to have a host of other measures about the users, such as age, gender, employment status, and so on, to better understand how various types of users interact with one another. Although we do not have demographics about the users of r/science, we do know that 64% of overall Reddit users are between the ages of 18-29 and are predominately male (Barthel, et al., 2016b). Future work should investigate r/science users through other means to better understand who such redditors are and their motivations for using the site. We are not making claims that the interactions between scientists and members of the public are generalizable to other forms of public engagement (e.g., speaking at a scientific pub or participating in a town hall meeting). The Reddit community is atypical in many ways, including being relatively highly educated (Barthel et al., 2016b).

Likewise, future research may wish to investigate dimensions of language other than complexity to understand how they may impact how those comments are received. For instance, the use of language that evokes particular cognitive processes, such as language related to

causality or certainty, may impact how scientific information is perceived (Jenson, 2008).

Although we had strong a priori expectations surrounding the relationship between language complexity and how information would be assessed, future work should endeavor to examine other dimensions of language.

Due to the size and complexity of the data, we had to make some decisions to simplify the analysis. First, we calculate the centrality of users dynamically. However, we do not have access to data on user behavior prior to the observation period, so user flair usage or centrality prior to the posts we observe cannot be included. While we attempt here to account for dynamic network centrality processes, future research should endeavor to further examine how network structure is affected by user-generated content. Although we used time dependent measures for our network variables, we cannot control for all possible processes through which network position may impact the evaluations of other users and thus the score that a comment receives. In the research reported here we have attempted to control for as many processes as were practical given the available data, regardless, there are likely omitted variables that may cause high-scoring comments to be negatively associated with centrality.

As the use of the internet for science communication continues to increase, and as the records of such communication become more readily available (Lazer et al., 2009), it is critical to develop and test theories in large-scale data. In this study we apply a number of tools to the study of science communication to investigate a popular social media site through which discussion of recent scientific findings is common. Our results show how communication occurs interactively, and how the network positions people inhabit may inform the behaviors they engage in. There is a growing literature on science communication and the interactions between experts and non-experts through media and public forums (e.g., Epstein, 1995; Liang et al.,

2014). This study advances our understanding of how scientists and members of the public engaging in a dialogue. We hope that our study can inform future research that concerns large-scale patterns of interaction and how science communication occurs online.

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Table 1

Forum Rules for r/science Subreddit

Submission Requirements	Comment Rules
Directly link to published peer-reviewed research articles or a brief media summary	On-topic. No memes/jokes/etc.
No summaries of summaries, re-hosted press releases, reviews or popular reposts (over 100 upvotes)	No abusive/offensive/spam comments.
Research must be less than 6-months old	Non-professional personal anecdotes may be removed
No sensationalized titles, all titles must include the model where applicable	Arguments dismissing established scientific theories must contain substantial, peer-reviewed evidence
No blogspam, images, videos, infographics	No medical advice!
All submissions must be flaired and contain a link to the published article, either in the submission link or as a standalone comment.	Repeat or flagrant offenders may be banned.

Table 2

Comment Score as a Function of Author Flair Use, Comment-Level, and Network Variables

	Model 1			Model 2		
	β	<i>SE</i>	<i>p</i>	β	<i>SE</i>	<i>p</i>
Intercept	5×10^{-18}	0.004	1.000	-4×10^{-17}	0.002	1.000
Author flair used	0.011	0.004	0.006	0.013	0.004	0.001
Reading ease	-0.009	0.002	<0.001	-0.010	0.001	<0.001
Reply to post	0.031	0.006	<0.001	0.037	0.003	<0.001
Days between	-0.005	0.001	<0.001	-0.006	0.001	<0.001
Eigenvector centrality	--	--	--	-0.009	0.002	<0.001
In-degree	--	--	--	0.004	0.003	0.150
Out-degree	--	--	--	-0.024	0.004	<0.001
<i>N</i>	159,535			159,535		

Note. Standard errors are clustered on the author of the comment.

Table 3

Comment Score as a Function of Author Expertise, Comment-Level, and Network Variables

	Model 3			Model 4		
	β	SE	p	β	SE	p
Intercept	4×10^{-17}	0.004	1.000	9×10^{-17}	0.002	1.000
Author expertise	0.012	0.005	0.008	0.014	0.004	0.001
Reading ease	-0.009	0.002	<0.001	-0.010	0.001	<0.001
Reply to post	0.031	0.006	<0.001	0.036	0.003	<0.001
Days between	-0.005	0.001	<0.001	-0.006	0.001	<0.001
Eigenvector centrality				-0.009	0.002	<0.001
In-degree				0.005	0.002	0.053
Out-degree				-0.024	0.004	<0.001
N	159,535			159,535		

Note. Standard errors are clustered on the author of the comment.

Table 4

Comment Score as a Function of Author Expertise, Comment-Level, and Network Variables

	Model 5			Model 6		
	β	<i>SE</i>	<i>p</i>	β	<i>SE</i>	<i>p</i>
Intercept	3×10^{-17}	0.013	1.000	3×10^{-18}	0.009	1.000
Author expertise	0.019	0.011	0.090	0.020	0.007	0.003
Reading ease	0.012	0.008	0.117	0.014	0.008	0.071
Reply to post	0.024	0.018	0.166	0.048	0.014	0.001
Days between	0.004	0.007	0.541	0.001	0.007	0.932
Eigenvector centrality				0.005	0.010	0.617
In-degree				0.057	0.012	<0.001
Out-degree				-0.075	0.011	<0.001
<i>N</i>	2,385			2,385		

Note. Standard errors are clustered on the author of the comment.

Table 5

Reading Ease as a Function of Author Flair Used, Days Between, and Network Variables

	Model 7			Model 8		
	β	SE	p	β	SE	p
Intercept	3×10^{-16}	0.009	1.000	3×10^{-16}	0.005	1.000
Author flair used	-0.094	0.008	<0.001	-0.077	0.008	<0.001
Days between	0.005	0.002	0.010	0.003	0.002	0.079
Eigenvector centrality				-0.035	0.006	<0.001
In-degree				-0.016	0.008	0.038
Out-degree				-0.049	0.014	<0.001
N	159,535			159,535		

Note. Standard errors are clustered on the author of the comment.

Table 6

Reading Ease as a Function of Author Flair Used, Days Between, and Network Variables

	Model 9			Model 10		
	β	SE	p	β	SE	p
Intercept	3×10^{-16}	0.009	1.000	3×10^{-16}	0.005	1.000
Author expertise	-0.085	0.008	<0.001	-0.069	0.008	<0.001
Days between	0.006	0.002	0.006	0.004	0.002	0.055
Eigenvector centrality				-0.038	0.006	<0.001
In-degree				-0.025	0.009	0.005
Out-degree				-0.048	0.014	<0.001
N	159,535			159,535		

Note. Standard errors are clustered on the author of the comment.