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A Pilot Qualitative Case Study of Agricultural and Natural Resources Scientists' Twitter Usage for Engaging Public Audiences

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Abstract

Scientists are frequently asked to broadly share their expertise and research with a variety of audiences, beyond typical academic circles in their home disciplines. That could include developing community engagement programs, school outreach, leveraging online social networks, and other activities. The purpose of this study was to examine U.S. agricultural and natural resources (ANR) scientists' typical science communication channels, their experiences utilizing Twitter for sharing their knowledge, research, and engaging in online public science discussion. Diffusion of Innovations theory and the model of science in-reach versus outreach guided this study. Researchers used a qualitative case study design. Data collection included ANR scientist interviews (n = 8) and application of Internet-based research methods for observing scientists' Twitter activities. Four themes emerged from the data: 1) academic journals and conferences as scientists' typical communication channels, yet Extension efforts help to broaden audiences, 2) scientists expected research to be peer-reviewed before public dissemination to combat misinformation and spreading of 'junk science', 3) scientists balanced professionalism, personalization, promotion, and Twitter hashtags for engagement, and 4) scientist-identified barriers to using Twitter included lack of time and avoiding heated discussions. Recommendations include revisiting scientists' job descriptions and expectations for online science engagement. Also, there should be continual development and implementation of science communication training for scientists targeting best Twitter practices, growing followers for outreach beyond academic colleagues and groups, using visuals for online engagement, intentional scheduling for social media, and how to effectively navigate heated online discussions.

Keywords

science communication, public science engagement, outreach, Twitter, diffusion of innovation, Internet-based research, qualitative

Cover Page Footnote/Acknowledgements

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Introduction

Social media offers easily accessible tools and platforms for scientists to directly reach public audiences for information sharing and scientific engagement (McClain, 2017; Mojarad, 2017). The use of social media for public engagement fits well with the land grant university mission to extend academic research and knowledge to the public (Kellogg, 2000). The latest research and innovation from scientists and educators are often shared at the university institutional level, while many scientists and educators themselves often do not share their work with online audiences at the individual level because they view it as unprofessional (Van Eperen and Marincola, 2011).

Bik and Goldstein (2013) described that scientists often view social media as a poor use of their time. However, the researchers recommended that scientists should view social media favorably and establish an online presence "to boost their professional profile and act as a public voice for science," in order to move science beyond academic journals to online engagement (p. 1). This comes at a time when some political and religious groups have shown declining trust in science (Gauchat, 2012). Therefore, an opportunity exists to utilize social media for providing an inside look at real-life scientific efforts and processes for providing science transparency to public audiences. The authors of this study aimed to qualitatively explore U.S. agricultural and natural resources (ANR) scientists' social media use for public engagement. Research data included interviews with ANR scientists at a land grant university about their Twitter experiences and perceptions and online observations of the scientists' tweets.

Literature Review

Scientists and Science Engagement

There is a prevailing notion that the public is illiterate when it comes to science and that providing facts and information will solve the science knowledge gap. However, simply relaying information with hopes to increase literacy has proven to be ineffective (Nisbet and Scheufele, 2009; NASEM, 2017). Science literacy has been described as communities' and citizens' knowledge and understanding of scientific concepts, how science works, and application of scientific knowledge for making everyday decisions (NASEM, 2016; Maienschein, 1998). Educational efforts and national science education standards are in place to systematically engage students in science (NRC, 1996), yet there is a need to employ informal science education and communication efforts to engage the public in science outside of educational institutions (Falk, Storksdieck, & Dierking, 2007; NRC, 2009).

Public engagement is described as a dialogue, sharing of ideas, or back and forth communication processes for positively impacting attitudes, perceptions, and behaviors about organizations and societal issues (Dhanesh, 2017). Wooden (2006) outlined the following steps for public engagement: 1) raising general awareness, 2) developing a sense of urgency to act and find solutions, 3) identifying trade-offs and experts' opinions, 4) examining the trade-offs, 5) making decisions by weighing pros and cons, 6) taking an intellectual stand, and 7) resolution and behavior change. In science education and communication, the aim is to engage audiences in scientific concepts for increasing the understanding and use of science in everyday decision-making (Hu, Zhengfeng, Zhang, & Ahu, 2018; Leshner, 2003).

As public audiences grapple with understanding and applying scientific advances, trust in science, and a feeling of disconnect from scientists, professional scientific organizations and scientists are searching for ways to better communicate scientific processes, results, and everyday applications, as well as increase scientist interactions with community members via public engagement efforts in-person and online (AAAS, 2016; Peterman, Evia, Cloyd, and Besley, 2017).

Science research funding organizations such as the National Institutes of Health (NIH) and the National Science Foundation (NSF) require scientists to demonstrate broader societal impacts for disseminating their work to expand public understanding of critical scientific developments (Lok, 2010). Since the late 1990s, NSF has required scientists to include broader impacts in their grant proposals (Holbrook, 2005). In addition to expanding scientific projects beyond research publications and presentations to public engagement initiatives, scientists are called upon more frequently to improve their communication skills and to potentially engage in online public interactions.

National training efforts such as The American Institute of Biological Sciences 'Communication Boot Camp for Scientists' (AIBS, 2018), the Alan Alda Center for Communicating Science (AACCS, 2018), and National Public Radio's (NPR) Friends of Joe Palca's Big Idea (FJOBIs, 2018) are underway for training scientists, educators, staff, and graduate students to develop 21st century communication skills for conversationally explaining complicated scientific topics in a variety of formats. These programs introduce scientists to techniques for explaining technical research with less jargon, scientific processes in conversational terms, as well as bigger picture societal impacts of research studies.

Burchell, Franklin, and Holden (2009) interviewed scientists from a variety of disciplines (n = 30) and found the interviewees viewed public engagement as important, yet overwhelming and time consuming. Scientists also shared concern for strained and potentially negative social interactions with the public and a need for employers and funders to provide adequate time and resources for scientists to intentionally incorporate public engagement efforts into their already demanding workloads. Poliakoff and Webb (2007) applied the theory of planned behavior as a predictor of scientists' intentions to participate in public engagement. The researchers surveyed scientists at the University of Manchester (n = 169) and found most scientists had a positive attitude toward participating in public engagement activities, that fear of engaging was low, and that most scientists had previously participated in a public engagement activity or planned to in the near future.

In addition to developing and facilitating in-person workshops and events, scientists are also called upon to have an online presence for sharing science via websites, blogs, podcasts, social media, etc. A chemistry professor and communications manager at the California Institute of Technology developed new college courses for training scientists and engineers to craft online messages, utilize web tools, and grow audiences (Martinez, 2016). Dudo and Besley (2016) surveyed members of the American Association for the Advancement of Science (AAAS) about their perceptions of online communication. Results showed scientists' personal priorities for communicating online were to defend science, inform, excite, build trust, and tailor messages. Hence, scientists generally appeared to be interested in and valued using the internet for dispelling myths about their work, as well as intentionally raising awareness of research for informing public audiences.

In the field of internet marketing, research shows digital content can impact audiences' cognitive, emotional, and behavioral engagement with various messages (Hollebeek and Macky, 2019). In online public engagement, audiences make their own choices of when to log in and interact with content versus messaging that interrupts their time. Hence, there is opportunity to grow and foster trust through online engagement with audiences who seek out specific information. While scientists are encouraged to establish an online presence, McClain (2017) pointed out that research funders may not see the impacts of or value scientists' posting content via individual online channels. However, as social media analytics become more refined, there

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does appear to be a sizeable contingency of scientists utilizing the specific social media platform of Twitter to establish online identities to have their voices heard (Côté and Darling, 2018; Ke, Ahn, and Sugimoto, 2017).

Tweeting Science

It is estimated that Twitter has "321 million monthly active users," and the most followed accounts include popular celebrity figures such as singer Katy Perry (107 million followers) and singer Justin Bieber (105 million followers) (Statista, 2019.; Twittaholic, 2019). While still in the millions, scientists appear to have far fewer followers on Twitter than celebrities and politicians. Widely known astrophysicist Neil deGrasse Tyson from the public television show Nova Science Now and podcast Star Talk has 13.1 million followers (@neiltyson, 2019). Bill Nye, often referred to as 'The Science Guy' from his past public television show, has 5.8 million followers (@BillNye, 2019).

Ke, Ahn, and Sugimoto (2017) examined Twitter lists and memberships using a snowballing technique to find users with identifying information fitting the U.S. Bureau of Labor Statistic's definition of scientist occupations, as well as Wikipedia lists of scientist careers. The researchers found 45,867 scientists using Twitter, with mathematical and physical scientists underrepresented and social scientists overrepresented on the platform (Ke, Ahn, & Sugimoto, 2017). They also found that more male than female scientists used the platform (Ke, Ahn, & Sugimoto, 2017).

Kevin Folta, University of Florida professor and genomics scientist in the Horticultural Sciences Department, is a well-known example of an academic scientist utilizing online platforms for public science engagement (Goodwin, 2016; Scott, 2018). He developed the 'Talking Biotech Podcast' and had 21.2 thousand followers on Twitter (@kevinfolta, 2019). Folta is known for his genetically modified research in strawberries and his widespread efforts to have transparent exchanges with public audiences about biotechnology with the goal of building trust (Goodwin, 2016). Folta leveraged online and in-person channels for science communication and admitted to receiving backlash for his GMO research and stance, yet he remained committed to public biotechnology engagement (Scott, 2018).

Similar to Folta's social media strategy for transparent science communication, agricultural communication researchers have recommended farmers and producers use Twitter to shed light on production practices and everyday farming and ranching life. Allen, Abrams, Meyers, and Shultz (2010) stated "The information provided by agriculturalists could help others gain a better understanding of how food and fiber is produced, dispel myths about agricultural practices, and combat negative publicity in the event of an agricultural crisis" (pg. 5). Allen et al. pointed out practical tips for establishing a Twitter presence such as increasing followers, using proper hashtags, and tracking engagement via analytics software.

Wagler and Cannon (2015) found Twitter served as an effective public platform for disseminating and sharing information to public audiences during times of drought (n = 2,804 tweets). The researchers noted users turned to Twitter as a news source for the latest drought information, agricultural and environmental impacts, and disaster recovery information. They recommended academic institutions personalize social media use via strategies such as utilizing faculty experts to serve as "genuine opinion leaders who may provide more authentic perspectives and aid in personalizing online conversations" (p. 14). Their recommendation is in line with aforementioned literature suggesting scientists could individualize and lead online science engagement.

Building upon the review of literature, this study specifically aimed to utilize a qualitative case-based approach for in-depth examination of ANR scientists' adoption of Twitter and their experiences using the platform for sharing scientific information.

Conceptual Framework

At the intersection of science communication, public engagement, and technology adoption, a combination of an emerging conceptual framework and longstanding and tested theory informed this study. The Diffusion of Innovations theory (Rogers, 2003) guided the examination of participants' various stages of Twitter adoption and usage. Twitter was selected as the technology to study due to prior research that has shown several scientists are indeed using the social media platform (Ke, Ahn, & Sugimoto, 2017; Côté and Darling, 2018). Additionally, the conceptual framework of 'Preaching to the Choir vs. Singing from the Rooftops' (Côté and Darling, 2018) provided an important lens for this study. Both are expanded upon in the following sub-sections.

Diffusion of Twitter for Scientist - Public Communication and Engagement

The Diffusion of Innovations theory served as a lens to examine how Twitter usage has diffused across participating ANR scientists. The Diffusion of Innovations theory outlines how society adapts to new innovations, as they become mainstream (Rogers, 2003). The diffusion curve includes categories to organize the way different members of society fall into an equally distributed curve for adopting new innovations over time. From left to right on the adoption curve the categories are; innovators, early adopters, early majority, late majority and laggards (Mahajan, Muller, and Srivastava, 1990). Those that fit into the farthest category on the left are the early adopters, those that are most willing to use the new innovations. Individuals who fit into the category farthest to the right are those not interested in adopting, the laggards. Occasionally, there is a sixth category called non-adopters. Katz (1957) is attributed for introducing the idea of opinion leaders and followers. Opinion leaders are the innovators and early adopters who help influence the masses. The new idea or product continues to spread through different audiences until it becomes saturated. The Diffusion of Innovations theory could potentially be conceptually applied to scientists' Twitter usage for public engagement as a continuum of scientists who frequently use the social media platform for science engagement, to those who sometimes tweet, to those who do not use the platform.

Scientist Twitter Inreach vs. Outreach

Côté and Darling (2018) investigated the reach of ecologists and evolutionary biologists (n = 110) across 11 countries who have adopted and use Twitter. The researchers aimed to find out if the scientists were engaging public audiences and policy decision-makers versus simply tweeting at fellow science colleagues. Côté and Darling conceptualized scientists' Twitter via the inreach versus outreach model in Figure 1.

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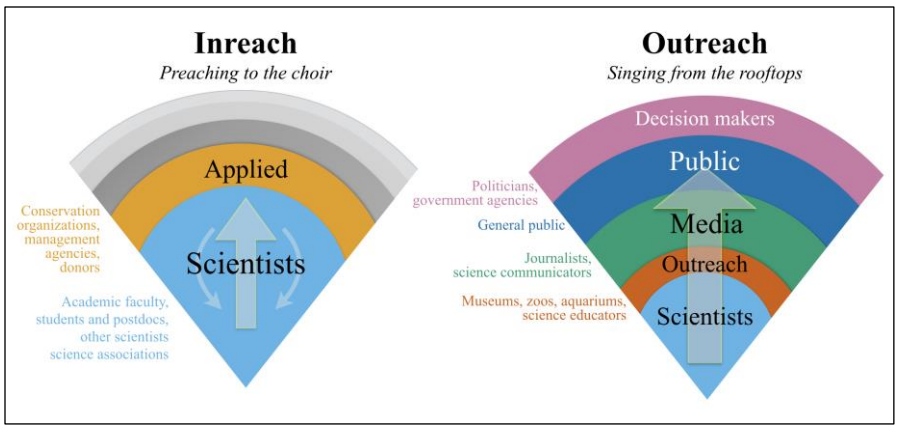

Figure 1. Conceptual model of scientist' Twitter usage and potential to reach public audiences and decision-makers. Copied with permission from Côté and Darling (2018).

Results showed that scientists who have more than 1,000 followers on Twitter have the potential for external outreach and engagement with non-scientists. Scientists with fewer followers were typically tweeting to fellow scientists, which created an echo chamber effect. Hence, there is capacity for scientists to leverage Twitter for public engagement, once they surpass the 1,000 followers threshold. Côté and Darling also noted a very small number of decision-makers followed scientists who had high 'popularity' levels with more than 2,200 followers. Hence, scientists should ideally establish Twitter strategies and usage habits for expanding their reach to a larger range of followers for effective public engagement encouraging science-based decision-making and behavior change. The diffusion of innovations adoption curve and conceptual model of Twitter for public science engagement informed the study's interview questions and data analysis for examining ANR scientists' Twitter practices and experiences.

Purpose and Research Questions

Previous literature provided insight into the potential for scientists to act as opinion leaders and personal voices in public science engagement for increasing transparency, trust, and public science literacy. Additionally, scientists are called upon to utilize online communication and education tools for engaging the public. Some scientists have taken to Twitter for engagement, and some have not. What is not known is how and why scientists in ANR are using or choosing not use Twitter for public science engagement, as well as their perceptions and experiences with tweeting. The purpose of this pilot qualitative case study was to examine twitter use of a sample of ANR scientists in each of the diffusion of innovations curve adoption categories, as well as how the scientists use Twitter for public science communication and engagement. Research questions included:

- RQ 1. What channels do ANR scientists typically use to communicate their research to public audiences?
- RQ 2. What are ANR scientists' perceptions of their role in communicating science to public audiences?
- RQ 3. What do ANR scientist participants describe as successful Twitter practices?
- RQ 4. What barriers do scientists identify that prevent them from utilizing Twitter for public science engagement?

Methods

Case Study and Online Inquiry Design

This study followed a case study design utilizing qualitative and online inquiry methods for investigating University of Nebraska-Lincoln's ANR scientists' perspectives and experiences with Twitter for science communication. A case study design was appropriate, as it allows for deep exploration of elements such as the who, how, and why of an issue within a specific context (Yin, 2018). Qualitative methods of online ethnography were utilized in this study to gain new and direct knowledge of ANR scientists' Twitter practices and experiences. Online ethnography is the study of Internet-based learning spaces, cultures, communities, conversations, individuals' online engagement and behaviors, and more (Gerber, Abrams, Curwood, and Manifico, 2017; Schwandt, 2015). Qualitative methods such as observation and interviews can be applied to examining online spaces (Gerber et al., 2017). Researchers utilizing these methods straddle virtual and in-person worlds to make sense of online and physical presences, as well as online engagement and behaviors (Sade-Beck, 2004). This study utilized online qualitative inquiry methods for observing scientists' Twitter usage, as well as in-person interviews for scientists' first-person, non-technology mediated discussion and insight about their online presences and experiences.

Participants

Researchers used a snowball sampling technique for identifying and recruiting participants. The sampling strategy includes consulting specific information sources to find participants that meet study criteria and then adding more participants who are interconnected to the originally identified participants and case (Yin, 2018). In this study, researchers consulted with a lead social media staff member in the Institute of Agriculture and Natural Resources to develop a list of College Agricultural Sciences and Natural Resources scientists based on the diffusion of innovations curve of frequent, moderate, and non-Twitter users. Researchers then recruited from the list of suggested ANR scientists. Researchers and the lead social media staff member evaluated the list through a diffusion and in-reach versus outreach lens and categorized scientists into the different adoption categories. For instance, scientists who frequently tweeted and had more than 1,000 followers were considered early adopters, while scientists who consistently tweeted but had less than 1,000 followers were considered the early majority, and so on. While the diffusion of innovations curve includes time as a measure for early to late adoptions, the researchers took this into consideration as the early adopting scientists had higher number of followers potentially as a result of using Twitter longer than late adoption scientists with fewer followers. Eight ANR scientists voluntarily consented to participate.

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Table 1.

Participants

Pseudonym	ANR Scientists	Tweets	Followers	Likes
Aftab	Associate Professor of Biological Systems Engineering	953	334	3,090
Joe	Administrator of Entrepreneurship Program Professor of Animal Science	0	40	0
Kevin	Soil Scientist and Adjunct Professor	0	0	0
Matt	Professor of Agricultural Education	1,995	351	5,104
Ricardo	Assistant Professor of Agronomy and Horticulture	1,330	1,134	777
Rob	Assistant Professor of Agronomy and Horticulture, Extension Turfgrass Specialist	2,069	3,515	1,456
Tina	Assistant Extension Educator, Master Gardener Program	1,055	487	1,426
Trisha	Professor of Entomology	567	533	59

Case studies often do not require a large number of participants (Yin, 2018). A small number of participants in a qualitative study can provide deep, rich data for gaining insight into perspectives and experiences. The point of saturation also exists when interviews can produce redundant information (Fusch & Ness, 2015). In this study, researchers believed a point of saturation was reached, specifically in regards to scientists' discussion of their Twitter usage and engagement experiences, as well as barriers for utilizing the technology.

Conceptualization of participating ANR scientists' Twitter diffusion and adoption

Researchers conceptually mapped participating scientists' Twitter adoption and frequency and level of usage to the diffusion of innovations curve (Figure 2). To develop the conceptual curve and place scientists into the different adoption categories, researchers specifically worked with social media staff in the college to identify which scientists had the most/least followers, used Twitter frequently/sometimes/rarely, and which scientists social media staff believed currently did not use Twitter but would benefit from a presence on the platform. After data collection, researchers reviewed the initial conceptual curve and determined data sources supported scientists' placement.

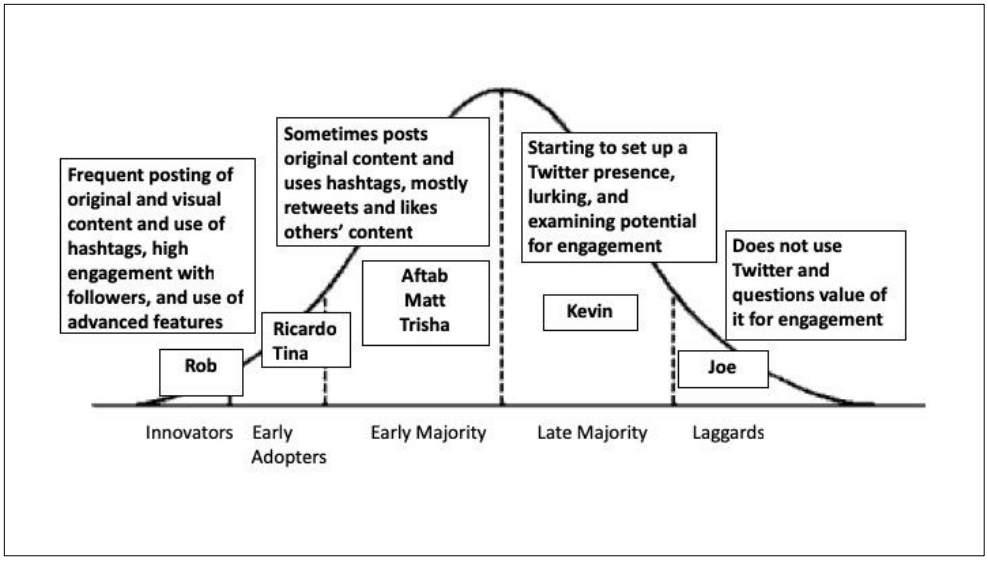

Figure 2. Participants' Twitter usage conceptually mapped to the diffusion of innovations curve.

Researchers placed scientists into the diffusion categories that conceptually matched scientists' descriptions of their Twitter usage, as well as their number of tweets, followers, and likes. The scientists were categorized accordingly:

- Innovators and early adopters - Rob, Ricardo, and Tina were placed in the innovators and early adopters categories due to their frequent usage of Twitter for science engagement, posting original self-generated research content, and for using advanced Twitter features. Rob described being highly innovative in his usage with attempting viral videos and polls, as well as investigating Twitter features for capturing public engagement research data to show impact. He also had the most tweets, followers, and likes (see participant table 1).
- Early majority – Aftab, Matt, and Trisha also valued Twitter for public engagement, viewed Twitter daily, and frequently posted content, shared articles, and retweets. They did not necessarily have a detailed communication plan and rarely tried advanced Twitter features, yet they utilized visuals and hashtags to increase interest in their posts.
- Late majority - Kevin had created a Twitter account, but he was not utilizing it with any frequency. He questioned the quality of interaction via tweets, but he was open-minded and investigating his options and considering Twitter for sharing science.
- Laggards - Joe deeply questioned the value of tweeting for science engagement. He held onto a Twitter account, but he did not tweet. He believed richer interactions occur via direct newsletters and other means of possibly more personal communication than tweets. He was a laggard by choice with Twitter, while he continued to use and expand other communication channels.

Data Collection and Analysis

Data collection methods included video-recorded interviews (approximately 20-30 minutes in length across a one-month period) and Twitter screen captures/observations. Prior qualitative researchers have noted the importance of collecting online and offline data to develop a full picture understanding of the research context and participants' experiences, as well as ethical issues such as attaining proper participant consent when studying online environments and communities

(Eysenback & Till, 2001; Sade-Beck, 2004). The University of Nebraska-Lincoln's Institutional Review Board approved the study. Participants voluntarily consented and selected their level of permission for showing/blurring their faces or only using text quotes in research presentations and publications. The second and third researcher of this paper recorded one-on-one video interviews with participants via iPad kits in university offices and classrooms. The interviews consisted of categories of questions such as participants' typical pathways for sharing scientific information, their views of Twitter, Twitter usage and strategies, as well as examples of public interactions via Twitter (Table 2).

Table 2.

Interview question guide samples.

Topic Area	Interview Question Samples
Typical communication patterns	• What are your major ways of communicating your findings? • Do you publish your research results? In what types of journals? Who reads your work in those journals? • Have you ever taken a class or seminar on science communication? about how to post on social media?
Public engagement perceptions	• What are some of the successes you've had with communicating your research? • Could you share times when you were not successful and wish you could have reached a larger audience with your results? • Does social media have a role in public science discussions and education? And what should that role be?
Twitter usage	• How active are you on Twitter? What is your Twitter handle/name? • What is your profile photo of? You profile description? • How often do you tweet a day? What Twitter pages do you follow? • Who do your Twitter followers consist of?
Twitter barriers	• What do you see as the value / lack of value in using Twitter? • What prevents you from using Twitter? • Have you ever had a heated exchange or feedback on Twitter? If yes, how did you handle it?

The researchers then transcribed the interviews, in order to become intimately involved with the data. Interview transcriptions were uploaded to the cloud-computing qualitative analysis software Dedoose and inductively coded for emergent categories and themes (Saldaña, 2016). Researchers open-coded the interviews and compared codes to arrive at categories such as

'audiences' and 'Twitter usage' with child codes such as 'hashtags' and 'retweets.' Then, researchers independently chunked categories into themes, compared themes, and ultimately arrived at overarching themes described in the results section.

In addition to the interviews, researchers also utilized online observation screen capture methods within Internet-based research for exploring participants' Twitter activity (Gerber et al., 2017). Specifically, researchers took screen captures of participants' Twitter activity during the week of November 14-21, 2016 with their consent, which coincided with the month-long timeframe throughout which interviews were conducted. Criteria for the selected screen captures included two of the participants' original, self-generated content tweets with high engagement such as retweets and likes and two of the participants' re-tweets with high engagement such as retweets and likes. Researchers then compared the participants' Twitter activity and interview explanations about handles, tweets, re-tweets, followers, and posting strategies. Overarching themes were then sent to research participants for member-checking to insure they agreed the findings were accurate (Schwandt, 2015).

Results

The results of this study include four themes. Table 3 outlines each of the study's research questions and resulting themes.

Table 3.

Results.

Research Question	Theme
1. What channels do ANR scientists typically use to communicate their research to public audiences?	Academic journals and conferences are typical outreach channels, yet Extension efforts help to broaden audiences.
2. What are ANR scientists' perceptions of their role in communicating science to public audiences?	The importance of peer-review before public dissemination to combat misinformation and spreading of 'junk science'
3. What do participating ANR scientists' describe as successful Twitter practices?	The balance of professionalism, personalization, frequency, promotion, and Twitter hashtags for engagement.
4. What barriers do scientists identify that prevent them from utilizing Twitter for public science engagement?	Social media takes too much time and can lead to unwanted public discussions.

The themes are presented in the below sub-sections with supporting interview quotes and screen captures of scientists' Twitter activities and explanations.

Theme One (RQ 1): Academic journals and conferences are typical outreach channels, yet Extension efforts help to broaden audiences

Scientists in this study reported predominantly communicating their research through academic communication channels such as peer-reviewed journal publications and scholarly conferences. Scientists stated that the first audience for sharing their work is usually made up of their academic peers. Kevin said, "I publish results in professional journals, make presentations at

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professional meetings and through professional societies that I'm a member of." Similarly, Trisha described, "So, number one is through your scientific journals. Your peer-reviewed publications, that's part of presenting your scholarship. But that only reaches a certain audience group. And so that's my peers at other institutions, that are working in this realm that I'm working in." Aftab mentioned the importance of including graduate students in academic publications and presentations. He said, "I encourage my graduate students to do the presentation, and it's only when they're not available or graduated that I present. I like to encourage my graduate students to do the presentations because really, they're the ones who do a lot of the leg work, right?"

Some of the scientists discussed their efforts to expand their communication of research results to also reach public audiences. Public communication channels such as news releases, newsletters, magazines, video, and online were often discussed secondarily for research dissemination. Rob described, "I go around the country giving about 23 talks a year, talking about our research and then, we have traditional web logs and articles in magazines." Kevin leveraged Extension to engage public groups in his work, "We do work with the Extension educators here at the University of Nebraska-Lincoln to make presentations at field days and workshops that they organize. So that's where producers and crop consultants would get the information." Aftab mentioned outreach for youth via Extension programming and online mobile applications as another communication channel, "I also kind of in tangentially got involved in some youth outreach activities. So, for example, last year, I worked with somebody in Extension, was the subject matter expert to build an app towards youth, and I think it was middle school students." Only one scientist discussed working with mainstream media for sharing research with the public. Kevin said he occasionally worked with university communication staff for news releases and radio interviews. While some of the scientists mentioned working with university communication staff to disseminate research results, none of them discussed receiving science communication training.

Theme Two (RQ 2): The importance of peer-review before public dissemination to combat misinformation and spreading of 'junk science'

Most of the scientists tended to agree that it is important to engage the public in science topics, with the caveat that the science was ethically conducted and peer-reviewed for accurate and factual discussion. Aftab said, "I do believe in general we need to have, scientists need to be, engaged with society at large." Kevin described the need for science to undergo peer-review, before taking it to social media for the public:

> It's more of an ethics issue where the individual [scientist] has to be able to support what they're putting out with things that are brought in through the peer review process - that's something that's very important to science. It's kind of the backbone that everything we do be reviewed. I mean nobody reviews Twitter. You don't have to support what you say on there with documented research.

While scientists considered the need to engage public audiences in scientific information and decision-making, they also described the challenges of navigating public beliefs and mis-information from false science sources. Matt said:

> The danger in my mind is that people believe what they read. Which means, you know, I'm [the public] going to going to find those on Twitter, the blogs, the social commentaries,

> the news outlets, that align with my belief systems, and I'm going to follow them. Now the other side of that is, I know there is a great deal of junk science that's out there. There's a lot of misinformation, and I've stumbled into enough blogs and chat rooms to realize there are people who are posting things that have absolutely no idea what they're talking about when it comes to food production, agriculture, the areas that we deal with.

Tina also described public engagement challenges, yet she indicated a motivation to dispel misinformation about science and scientists by using the same social tools used by the public. She stated, "I think we really need to be where people are. There is so much misinformation on the Internet, on blogs, on Facebook, on Twitter. I really think we need to be out there to actually give everybody the correct information." Rob said scientists are constantly at a disadvantage in the face of bogus scientific claims and emotional pleas shared online, but he remained optimistic and encouraged scientists to continue to share accurate information:

> We can't sit here and just say social media is the reason for science illiteracy in this country and this world. We're just letting people with one agenda, which more often or not, anti-what the science says, dominate the conversation. So, we need to have professors, researchers, and people that will view both sides, present it in a factual way, and use the same emotion that the science illiterate or people with a different agenda are trying to push.

Rob also encouraged fellow scientists to share their passion for their work and findings with public audiences, in order to present all sides of an issue for making informed decisions.

Theme Three (RQ 3): The balance of professionalism, personalization, frequency, promotion, and Twitter hashtags for engagement

The researchers asked participating scientists to describe their approaches for how they present themselves online via Twitter and their strategies and typical usage patterns on the social media platform. As for selecting a profile photo, scientists gave mixed responses including selecting headshots to convey a sense professionalism versus photos of themselves in the field and interacting with students versus more informal humorous photos. Rob said, "I think it's really important. You're trying to differentiate yourself so you have to show you're an expert at something. I don't really have a professional photo, but a photo of me is me out doing research on turf grass." Matt discussed taking a personalized approach to his profile presence, "The picture I have on there is a headshot of my wife and I. Probably in trying to be personal, I wanted people to know what was important to me." Aftab said he finds himself blurring some of his professional and personal life on Twitter, "I have a goofy picture on my Twitter profile. I mean, it's fine. It's not inappropriate, but it's just funny. So, I'm not one to have those clear distinctions. I feel like we tend in our world to compartmentalize things too much as it is, so I don't really see the need to compartmentalize things on Twitter as well." Trisha chose to keep her profile photo professional, yet more of an action shot interacting with students, than a headshot. She said, "My Twitter profile is me with a group of students doing a honey bee experiment, and that was really important to me just because I love interacting with students, and I thought first impression, that's something that I wanted them to know about."

Scientists who frequently used Twitter described posting and retweeting multiple times throughout the week, while those who minimally logged in described only tweeting and re-tweeting when they shared information about graduate student dissertation defenses or attended

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research conferences. Trisha stated the importance of tweeting intentionally, "I want it to be tweets that come across that are impactful and so people want to read your tweets versus: 'Oh, this person just tweets 20 things out each day, and it's what's going on in their life, or that type of thing." The scientists considered to be active on Twitter said they posted on average once a day, and those in the middle of the adoption curve tweeted every two to three days. On the other end of the spectrum, Joe never tweeted, but he did secure a Twitter account and page for his entrepreneurship center, in case he ever found value in tweeting in the future.

Visuals appeared to be a driving force in many of the scientists' tweets. Scientists often posted a photo from their classes or conferences they attended. For instance, Trisha shared photos of class presentations from an international program (Figure 2).

Figure 2. Screen capture of Trisha's visual class presentation tweet.

Similarly, Ricardo discussed trying to be creative with sharing photos about his weed research plots to give his followers an inside look at his fieldwork (Figure 3).

Figure 3. Screen capture of Ricardo's fieldwork tweet.

Ricardo also described a publishing company working with him to promote his latest research via online video, "They want to give me the opportunity of recording a five-minute video, and I'm sharing some slides of the research findings, and they're going to put that out on the web and then, they let you share that on Twitter." Rob also mentioned the power of tweeting videos about newly published research articles:

> We did one video this year, and it was viewed like 30,000 times, and it was just a very controversial topic in the turf industry, and we showed a video and said, 'Hey guys, this doesn't work the way you think it works.' It just spread like wildfire. If you can have some type of content in addition to some text, that really increases the odds of getting it seen. People are lazy, they want to watch a two-minute video, not read a 20-page manuscript.

Scientists who were frequent Twitter users appeared to understand how to use hashtags and tags for networking and connecting back to their universities and colleges. They used hashtags while and attending research conferences to keep up with the backchannel of communication occurring at the conferences. For instance, Rob posted about that he was on his way to a prominent conference in his discipline (Figure 4).

Figure 4. Screen capture of Rob's conference travel tweet.

Matt said, "I've been to some conferences, and as the head of the conference, I've initiated some hashtags and then, have the projectors going where people are using the hashtag and then, you see this scroll of tweets that are going out to me." Aftab used hashtags to refer back to and promote his department and college, "In the professional realm, I use university hashtag and for example, we have a science literacy effort in institute and they have a institute hashtag." Tina often used the Extension hashtag for sharing and engaging audiences in information about the Master Gardener program. She also tried to use hashtags for engaging with the university, but she mentioned that can be challenging to keep up with, as universities are often re-branding and developing new hashtags, "I think sometimes we all don't know what those changes are, so they don't get filtered down through the system as well as they probably should."

Theme Four (RQ 4): Social media takes too much time and can lead to unwanted public discussions

For the scientists hesitant to adopt Twitter for public engagement, two barriers were repeated across interviews: lack of time and heated discussions. Joe oversaw an entrepreneurship center in the college and discussed that Twitter did not have the return on investment the center hoped to achieve for rich, interactive public engagement and education. He said, "We've chosen not to play the Twitter game because there's X amount of time for our staff. Will we in the future? If we can figure out how to tie it to something meaningful like podcasts, blogs, deeper, stronger messaging." Kevin talked about the time commitment of building a consistent Twitter presence,

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which can be overwhelming in addition to a scientist's research and teaching responsibilities. He said, "I don't have the time to commit to maintaining, I mean if people are following you on Twitter there going to want to see something on a regular basis so you have to have the time to do that and I think it should be done with high quality and I just don't have the time to do it right now." Ricardo described simply not having enough time for wordsmithing engaging tweets, "Sometimes it takes me 10 minutes to get those short sentences because I don't know which words to eliminate. So, I don't really have a good strategy there."

Encountering and navigating heated discussions with public audiences also appeared to be a downfall of Twitter from the scientists' views. Aftab described the challenges of scientists and their research being misunderstood online, "I do not feel like social media is the place to play out some of those arguments. I try to avoid getting into any kind of situations like that. It's just difficult today, it's difficult to actually resolve. I prefer if I have to have conversations that might get heated. Do it in person." Ricardo said, "If someone tries to start a heated conversation or message, I don't think it's appropriate. So, I avoid it." Rob recommended that scientists keep check of their emotions in online engagement and instead, approach heated discussions with facts. He said:

> It's really easy to get caught up in feuds on Twitter. Its challenging, if someone starts calling out your research, it's really easy to get caught up because you're so emotional and invested in your research. But you really just have to supply the info and let other people realize that person may be misinterpreting the data or misunderstanding what they're saying.

Many of the scientists considered early adopters and majority of Twitter users in this study had personal stories and/or stories of a colleague experiencing a heated online discussion about their research and expressed tweeting with caution when it comes to terms, data, figures, and images shown.

Limitations

Limitations of this study include the small sample size, lack of duration of time monitoring scientists' social media activities, and that the findings may not be generalizable to larger scientist groups. Due to the nature of the undergraduate researcher funding for the study, there was a time deadline to conduct the research within one semester. However, scientist interviews did have overlapping responses and discussion points, researchers had a rich case study data set including triangulation of interviews and screen captures, and member-checking was conducted to confirm the findings with scientist participants. It is possible the same methods could be used with a larger scientist population from a broader variety of disciplines.

Discussion, Recommendations, and Conclusions

This study aimed to qualitatively examine ANR scientists' perceptions and experiences engaging public audiences in science topics via Twitter. Oftentimes, social media research involves quantitative analytics, without an investigation of first-person accounts of Twitter users' intentions and usages (Ke, Ahn, and Sugimoto, 2017). This study showed ANR scientists tend to somewhat follow the typical diffusion of innovations curve in their adoption and attitudes toward Twitter for public science engagement. Universities and research funders are calling on scientists to establish online public personas and engage more with different audiences to provide transparency in scientific research (McClain, 2017). However, as found in this study and others, some scientists

are hesitant to tweet their science due to time commitment to effectively do so, potentially encountering heated debates about their work, viewing Twitter as an ineffective tool for disseminating scientific information, and lack of recognition for public online engagement efforts in the tenure and promotion process (Bik and Goldstein, 2013; Burchell, Franklin, and Holden, 2009; Dudo and Besley, 2016). One recommendation for increasing scientists' efforts to reach public audiences with their research online is for university administrations to review current faculty job descriptions and promotion requirements to include parameters for recognition of scientists' efforts for public online outreach, education, and research dissemination.

Five out of eight of the scientists in the study fell into the innovator, early adopter, and majority categories. They were actively using Twitter, posting original content including visuals and research data, and even trying advanced features such as polling the public. The participating group of scientists viewed Twitter as a valuable tool for expanding the reach of their research beyond traditional academic publications and presentations to engage public groups. However, only two of the scientists (Rob and Ricardo) had more than 1,000 Twitter followers. According to the results of Côté and Darling's (2018) study, in order for scientists to 'sing from the rooftops' to a broader audience, scientists must grower their Twitter followers beyond their inner academic circles to establish outreach to museums, public groups, the media, and decision-makers. While it appeared several of the participating ANR scientists in this study valued Twitter for public engagement, they had not yet reached a large enough follower threshold to achieve true outreach.

To scale-up and advance this research from a pilot case study approach, future studies could more systematically examine a larger population of ANR scientists' online public science engagement via a case study with a larger number of participants, survey, social media analytics, focus groups, and observations. Specifically, researchers could have ANR scientists with more than 1,000 Twitter followers catalog time spent creating and replying to social media posts versus audience reach to establish scientist time commitments versus online cognitive, emotional, and behavioral engagement levels. Additionally, researchers could conduct a content analysis of scientists' heated social media exchanges and conduct a focus group or survey those scientists about their experiences and strategies for navigating heated discussions to arrive at tangible steps rooted in real-world examples for a science communication guide focused on fostering transparent social media practices.

Results of this study also confirmed previous research that pointed to a need for science communication training to prepare scientists for leveraging social engagement tools for broader impacts in their work (Bik et al., 2015; Lok, 2010). None of the scientists in this study described receiving science communication or social media training, yet they had questions about Twitter features, strategies for online public engagement, and welcomed the support. It is recommended that ANR science communication professionals continue to track the Twitter usage patterns of their college scientists and reach out to scientists in the late majority and laggard categories for discussions about public science engagement and how to share their research via the college's social media channels, if they do not want to start their own Twitter account. Science communicators should also continue efforts or begin new ones to provide social media training that is focused on: 1) time management and posting tools for ease of establishing and maintaining a Twitter presence, 2) messaging strategies for sharing peer-reviewed scientific articles and conference proceedings for public audiences, 3) how to increase Twitter followers and reach beyond academic circles, 4) best practices for using mobile multimedia tools for creating original content, 5) developing transparency in science by using visuals and audio, 6) navigating heated online discussions, and 7) how to foster solutions-focused, positive public engagement for

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encouraging critical thinking and informed decision-making. There is an opportunity for future mixed-methods research studies to include development, implementation, and assessment of science communication training for ANR scientists focused on the above outlined objectives.

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