Science Gets Social: Why Scientists Use Social Media to Communicate

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Acknowledgements

Though an argument that can undoubtedly be made for any age, we are living in the midst of unprecedented change to our global village, from the questions we ask to the answers we seek, from the air we breathe to the media through which we speak. Science and research are helping us better understand these changes and how to best navigate the shift to successfully propel society forward into our shared future. The ability to engage in the challenge of higher learning surrounding the communication of this change is both an honour and a privilege, and I am fortunate enough to not only have studied at but to also have built my career at one of Canada's finest universities. It is the University of Alberta's commitment to the public good, in particular the scientists and researchers in the Faculty of Science and their dedication to pursuing answers to some of society's most challenging questions, that drove me back to the books and inspired the focus for my research.

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Abstract

Disruptions to the global sociopolitical and technological landscape are expanding the need, challenge, opportunity, and capacity for science communication. Though adoption is slow, scientists are steadily increasing their use of social media for science communication. While this is an emerging field of research, there are few qualitative studies exploring why scientists are using social media. Drawing on the uses and gratifications theory, this study explored the following research questions:

> **RQ1:** What are the factors and conditions motivating individual academic research scientists to use social media for science communication?
>
> **RQ2:** How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

The study adopted an exploratory design using semi-structured interviews with five academic research scientists at a Canadian university who were identified as active social media users. Through a thematic analysis, the study found that these scientists were motivated to use social media to remain current with changes and opportunities in science, to connect with a global community of scientists, to share the findings of their publicly funded research beyond the scientific community, and to contextualize science to build support in society. The findings suggest future qualitative research that considers audience engagement as well as implications for not only professional practice but also policy development. In contrast to the extant literature, the study also suggests that—given shifts in the political climate and communication platforms through which science is now being communicated—there may be a decrease in a historic tension in science communication.

Keywords: science communication, social media, Twitter, public understanding of science, knowledge mobilization, knowledge translation

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Introduction

Political, social, and technological changes in today's world are affecting the practice of science communication, both an increased need for scientists to communicate and also the platforms through which they are able to do so. In a political climate that questions scientific truths, not only are there fewer science journalists translating scientific findings for a general audience, but funding agencies are also increasing pressure on scientists to communicate findings to policymakers and the general public. Concurrent with changes to news consumption—with citizens increasingly turning to online sources for science information—there is skepticism about the veracity of the science information online. As science continues to be politicized yet becomes ever more critical in addressing society's most pressing needs, it is vitally important for scientists to communicate about science to in turn increase public support.

Scientists are slowly but increasingly adopting social media as a tool to communicate both within and beyond the scientific community. Social media represents a sea change in science communication, democratizing "outreach," an activity traditionally practiced by a small percentage of scientists to increase the public understanding of science. This practice, previously dominated by "celebrity scientists," has also been subjected to a professional stigma, which suggests that more media exposure means less scientific significance. While science communication has historically functioned in a deficit model of one-way information dissemination through mass communication channels such as television, books, radio, and newspapers, social media now presents the possibility for two-way engagement with the audience. A tool for outreach, social media is also a popular avenue for "inreach," or communication within the scholarly community, therefore representing an intersection of audiences with drastically different information needs.

Purpose of this Study

While the current literature presents a broad picture of the practice of science communication via social media, it lacks insight into the motivations of individual scientists. An exploration of these motivations and subsequent satisfaction with the use of social media for science communication may provide realistic expectations for scientists who have not yet adopted the practice and may help improve not only the efficacy of science communication via social media but also the way it is discussed, prioritized, and supported by academic institutions, policy makers, and funding agencies.

With these considerations, I embarked on a research project to address the gap of qualitative exploration pertaining to individual academic research scientists' use of social media. Given the study's exploratory nature and limited sample size (focused on academic research scientists at one Canadian university) there are limitations. Due to the resource restrictions of the capstone format, I was unable to explore the depth and efficacy of audience engagement through a content analysis of corresponding communication, an important consideration moving forward in the research field of science communication and social media.

Preview of the Related Literature

Exploring science communication via social media requires examining several viewpoints in the current scholarly and grey literature—including mainstream media and trade publications—representing scientists and science organizations, science communication scholars, and broader studies related to academics' use of social media.

A brief review of the literature addressing the larger field of science communication and the push for the public understanding of science (Brossard & Lewenstein, 2009; Burns,

O'Connor, & Stocklmayer, 2003; Ecklund, James, & Lincoln, 2012) reveals the tension of the professional stigma known as the Sagan effect, suggesting an inverse relationship between media exposure and scientific ability (Ecklund et al., 2012; Hornig Priest, 2009; Jensen, Rouquier, Kreimers, & Croissant, 2008; Liang et al., 2014; Russo, 2010). Contrasting this potential for peer reproach—lingering in spite of recognition of the need for science communication (Carr, Grand, & Sullivan, 2017; Griggs, 2014; Hall, 2014; Martinez-Conde, 2016)—is not only the call for scientists to speak out to combat the "war on science" (Hunter, 2016; Krauss, 2014; Liang et al., 2014; Mojarad, 2017; Nature, 2017) but also an increased emphasis by funding agencies for scientists to share their findings (European Research Council, n.d.; Government of Canada, 2015).

With scientists using social media for both outreach to a public beyond the scientific community and inreach with peers for scholarly communication, the literature reveals an intersection of audiences (Bombaci et al., 2016; Côté & Drew, 2018), presenting both opportunities and challenges for the practice. While the use of social media for science communication is an ever-expanding area of focus in the literature, the dominance of quantitative studies demonstrates a discipline-specific understanding (Bik et al., 2015; Hwong, Oliver, Van Kranendonk, Sammut, & Seroussi, 2017; Kahle, Sharon, & Baram-Tsubari, 2016; Pavlov et al., 2018; Spencer, Gunderson, Hoiland & Schleiffarth, 2017) with a lack of depth and little understanding of the motivation of individual scientists. The focus on quantitative research in the extant literature therefore necessitates the exploration of qualitative studies in adjacent literature pertaining to academics' use of social media (Grand, Holliman, Collins, & Adams, 2016; Smith, 2016) to root this qualitative exploration.

This study is informed by the uses and gratifications theory, an individualistic theory which helps us to understand the link between motivations for use of a particular media and subsequent satisfaction realized through use (Lindgren, 2015; Whiting & Williams, 2013). It is additionally influenced by the Canadian context, where government funding agencies are pushing for broad sharing of publicly funded science (Government of Canada, 2015). As much that exists in the current literature pertains to science organizations and broad groups of scientists primarily anonymized to their discipline and based in an American context, I was influenced by the work of Quan-Haase, Martin, and McCay-Peet (2015), Canadian researchers whose qualitative work explores how digital humanities scholars are using social media, with the uses and gratifications theory informing their thematic analysis.

Preview of Research Design and Methodology

To build upon the exploration of science communication via social media as a way to deepen an understanding of the phenomenon, I engaged an exploratory research design framed through the theory of uses and gratifications. I purposively sampled academic research scientists who are actively using social media for science communication, exploring their individual practices via semi-structured interviews, which were then analyzed via a qualitative content analysis. This approach allowed an in-depth analysis of the motivations guiding these scientists' use of social media, providing the opportunity to set expectations for those who have not yet adopted the practice.

While there are many potential methodologies through which to approach this research, a qualitative exploration guided by semi-structured interviews presented the best opportunity to build upon and deepen the understanding beyond that which is presented in the extant literature,

allowing the population in question to illustrate important considerations rather than looking to confirm a pre-existing hypothesis.

A mixed-methods approach combined with a content analysis may have provided audience considerations yet would have taken this study beyond the focus on the motivations of the scientists. While a survey may have been engaged to sample a larger population, it would have narrowed the depth of understanding of individual scientists. Though an exploration of non-users may have aided in the understanding of the barriers perceived as prohibiting adoption, the approach of studying active users was instead engaged as a way to positively present the reasons why scientists are using social media in an effort to set realistic expectations for potential users and help guide communication surrounding the practice by government funding agencies, policy makers, and academic institutions.

Summary and Introduction of Research Questions

The following are the resultant research questions guiding this capstone project:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media to communicate science?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

A qualitative exploration of this phenomenon serves several purposes: a deepening of the understanding as presented in the current literature; an opportunity to increase efficacy of the practice; an opportunity to influence future adoption by potential users; and the opportunity to

help guide academic administrators, policy makers, and funding agencies in their communication surrounding the practice of science communication via social media.

This research study is presented as follows: an overview of the current literature surrounding science communication via social media; an outline of the design and methodology guiding the research; a presentation of the findings with subsequent discussion; and a conclusion detailing how the study and the subsequent deepening of the understanding of the phenomenon adds to the current literature with suggested areas of exploration to build upon for future research into the use of social media for science communication.

The literature review that follows in the next chapter presents a grounding for this capstone project and establishes a case for this particular research study examining the factors and conditions motivating individual academic research scientists to use social media for science communication. The literature review unites several areas of interest and importance as it pertains to the study: the purposes of science communication; the tensions affecting science communication from within and beyond the scientific community; the ways in which social media is changing science communication as well as the associated opportunities and challenges; a consideration of the audiences for science communication; and an overview of current practices in science and academia as a broader consideration. The core academic research explored in the literature review is enhanced through supporting grey literature—mainstream media as well as trade publications and funding agency documents—to paint a picture of the landscape in which this study is situated.

Literature Review

> A world in which one in seven people actively use Facebook (*11*), and more than 340 million tweets are being posted everyday (*12*) is not the future of science communication any more [sic]. It is today's reality. (Brossard & Scheufele, 2013, p. 41)

Changes to the traditional media landscape, increased pressure from funding agencies to share scientific findings, a public who is increasingly turning to social media for science information, a political climate that is creating mistrust surrounding science, and disruption to the academic publishing process mean that scientists must embrace social media as a professional communication platform.

The current literature reveals a mixture of both optimism and opportunity as well as challenge and skepticism as it relates to science communication via social media. While on the one hand, social media may provide an avenue to facilitate the democratization of science, do messages get lost in translation when science is distilled into soundbites? On another hand, by opening conversations that were previously closed to scholarly journals and conferences, is there confusion about who the audience is for science communication on social media? And is recognition of the importance of science communication and the opportunity social media provides translating into action for individual academic research scientists?

This chapter provides an overview of the field of science communication, contrasting the challenges associated with the practice with the increased need—given the pressure from funding agencies in a contentious climate affecting the communication of science—as well as the opportunity social media provides as a tool to advance the practice. It then situates social media as a tool within the larger field of science communication, exploring the opportunities and challenges social media provides as a platform. It then presents a broad perspective of how

scientists are currently using these tools to communicate. Finally, it considers how the mass media theory of uses and gratifications may be engaged to understand the factors and conditions motivating individual scientists to use social media and how an understanding of those motivations may be used to set expectations for scientists considering adoption of the practice.

Here I detail what science communication is and why it is important, with a brief historical perspective. I then touch upon the possibility social media presents for disruption to science communication, representing the opportunity to shift from a deficit model of one-way information dissemination toward dialogue, shifting from what Benkler (2003; 2006) describes as the industrial information economy to the networked information economy. I explore how scientists are currently using social media to communicate, presenting discipline-specific findings and suggestions primarily presented by science organizations and research collectives. My analysis of academic journal articles as well as popular media and trade publications reveals a broad discussion of the practice dominated by quantitative information, yet expresses a lack of qualitative depth exploring the motivations of individual scientists. Finally, I detail how the uses and gratifications theory can be used to help address some of the gaps in knowledge of the depth in the perspective of individual academic research scientists reflected in the current literature.

Overview of the Field of Study / Methodology of Literature Review Process

To approach the question of how scientists are using social media to communicate, I first establish the larger field of science communication, tracing the tradition of the practice as well as its challenges and finally situating the practice within the current global context.

From this perspective, it is possible to contextualize the use of social media as a tool used for science communication. Science communication via social media has been considered by

practitioners from multiple disciplines including scientists, science communication scholars, and communications researchers. It is therefore important to critically consider all of these perspectives holistically in this literature review.

Reviewing the literature allowed me to critically assess gaps in knowledge surrounding scientists' use of social media and how I might structure a research design to best address these gaps.

Systematic library search. I undertook a review of the literature to explore the question of how scientists are using social media to communicate. I approached the search from multiple disciplines (Booth, Papaioannou & Sutton, 2016) considering the perspective not only of scientists but also communication practitioners and science communication researchers.

It is important to note that, though communication by its nature includes an intended audience, focus has been concentrated on the perspective of scientists rather than the audience to focus the scope of the literature reviewed.

As this question sits at the intersection of multiple disciplines, I employed Boolean logic to narrow and expand the scope of my search with key terms outlined below. It was important to consider the nuance in meaning of both science communication as well as social media and to include related terms. I included key social media platforms, based on Pew Research Findings (Greenwood, Perrin & Duggan, 2016), which identify Facebook, Instagram, and Twitter as the first, second, and fifth most popular platforms used by Americans. (The third and fourth most popular platforms—Pinterest and LinkedIn—were not included as they extend beyond the scope of my consideration of science communication.) Unfortunately, I could not find comparable Canadian data and so used U.S.-based Pew Research Findings.

Key term	**Related terms**
Science communication	Science information Science literacy Knowledge translation Knowledge mobilization Public understanding of science Public outreach Public engagement Community engagement
Online engagement	Online communication Digital engagement Digital communication Digital literacy
Social media	Social network Facebook Twitter Instagram
Scholarly communication	Altmetrics Inreach Research impact Scientific impact

Table 1. Literature review search terms. Key terms and related terms used in systematic library search.

After identifying key search terms (above), I engaged the University of Alberta Libraries' access to both the EBSCO database and Google Scholar. Based on discussions with librarians, I explored the following databases in greater detail: Communication and Mass Media Complete; Nature Publishing; PubMed; ScienceDirect; Science Journals (AAAS); Scopus; and Web of Science. The first and last proved most useful from the communication and science perspectives respectively. Because this topic is constantly evolving, I also set Google Scholar alerts with key search terms to stay abreast of new findings following the initial search. Additionally, I set Google Scholar alerts for articles both published by and citing the authors of key articles.

Eligibility criteria. Though no longer in its infancy, science communication via social media is still a burgeoning field of research and practice. Therefore, the bulk of the literature

reviewed was primarily from the last five to seven years with some older supporting materials serving to situate the use of the social media within the larger umbrella of science communication.

Additional eligibility criteria favoured peer-reviewed publications as well as citation record, though the latter proved challenging given the recency of this body of knowledge. Though the majority of the literature reviewed was published in peer-reviewed academic journals, it was important to also contextualize the larger global climate and social context in which scientists are communicating via social media. This literature review therefore includes some grey literature by way of editorials, opinion pieces, and practical guides or "how-to's" from trade publications, blogs, and mainstream media such as the New Yorker, CBC, and the Scientific American, for example.

Where possible, focus was given to scientists representing a variety of disciplines in the physical and natural sciences, though there is some inclusion of broader academia in adjacent literature including the health and social sciences.

Consideration was given to methodology when possible, though this presented an early discovery that much of the current literature is dominated by quantitative studies. The majority of literature was found to consist of quantitative research from a variety of scientific disciplines—representing a broad rather than deep overview of the field—with calls for further applied research as the practice continues to evolve. Only a small minority of studies were qualitative in nature, presenting a limited depth in perspective of individual scientists' motivations for the use of social media for science communication.

Search results. My initial search yielded roughly 100 potential sources, which were organized alphabetically by authors into a source matrix consisting of the following categories:

title; date; author; publisher; category/theme; APA citation; in-text citation; argument; methodology; population/participants; notes; quotes; link; effectiveness of methodology; relevance of theory; and possible biases.

With the objective of looking ahead to create conversations and connections between sources (Oliver, 2012), I refined the initial sources based on a focus on themes and disciplines, identifying similarities and differences in key arguments and conclusions to provide a coherent narrative review of the literature. Coding at this stage included particular emphasis on key terms identified prior to and emerging with the systematic library search. Developing brief summaries of each source as it was relevant to my research helped identify which would be most useful moving forward. During this consideration, I noted key passages and pertinent quotes. I eventually fully annotated the ~50 most relevant sources, keeping record of the other ~50 for future consideration, some of which proved useful for this literature review.

The review of the literature is organized as follows: a consideration of the overarching field of science communication; the opportunities and challenges social media presents as a tool for science communication; how scientists are currently using social media to communicate; and finally, how the theory of uses and gratifications may be used to help deepen our understanding of why scientists are using social media.

Review of the Literature

The push for public understanding of science. Science communication, often referred to as "outreach" (Burns et al., 2003), is loosely defined as "any activity in which scientists translate their research or broader scientific concepts to those outside of the academy" (Ecklund et al., 2012). One of the ideas behind science communication is improving the public

understanding of science or increasing science literacy to, amongst other aims, improve not only public support but also increase research funding and positively influence public policy (Brossard & Lewenstein, 2009; Pavlov et al., 2018; Royal Society, 2006). Science communication has often been viewed in terms of a deficit model of communication, presuming that there is a gap of knowledge to be filled in a linear fashion, transmitting information from experts to the public (Brossard & Lewenstein, 2009; Stilgoe & Wilson, 2009).

Surveys in the last decade in the United States and Europe (Ecklund et al., 2012; Jensen et al., 2008) indicate that roughly half of academic scientists engage in outreach, or science communication, with roughly half of the activity generated by a much smaller percentage of scientists, approximately five percent. (Comparable Canadian statistics are not available.) Carr, Grand, and Sullivan (2017) demonstrate that scientists believe they have a duty to communicate and engage with the public, yet are not necessarily actively doing so. Reasons for lack of engagement stemmed from lack of time, incentive, training, and not knowing the appropriate level at which to communicate. These barriers to engagement echo throughout the literature (Bik & Goldstein, 2013; Collins, Shiffman, & Rock, 2016; Grand et al., 2016; Mojarad, 2017; Nature, 2017; Pavlov et al., 2018; Prabhune, 2017; Royal Society, 2006; Wilkinson & Weitkamp, 2013).

The tension of the Sagan effect. Interestingly, beyond these reasons for non-engagement, there is an additional tension in the scientific community related to the merits of communicating scientific findings beyond academia. The stigma of the so-called Sagan effect—referring to Carl Sagan, the astronomer behind the popular PBS program *Cosmos*—(Ecklund et al., 2012; Hornig Priest, 2009; Jensen et al., 2008; Liang et al., 2014; Royal Society, 2006) suggests those who popularize science are viewed by peers to be less scientifically important. The perception is described as a “professional stigma attached to spending too much time

translating one's research to the broader public" (Ecklund et al., 2012), which "suggests that frequency of media interaction might be inversely proportional to scientific ability" (Russo, 2010). Standing in contrast to this critique, however, research also points to a positive correlation between engagement, including science communication, and academic output (Jensen et al., 2008).

Though it is argued that the Sagan effect is still plaguing contemporary academia (Martinez-Conde, 2016), so too is communicating science beyond academia seen to be becoming a key stage of the research cycle (Wilkinson & Weitkamp, 2013). This growing consensus within the scientific community that it is important to communicate with the public is perhaps influenced by the emphasis by funding agencies to share scientific findings (Andrews, Weaver, Hanley, Shamatha & Melton, 2005; Baron, 2010, Government of Canada, 2015).

The science of sharing. The Government of Canada's "open access" policy for research is described as such:

> Making research results as widely available and accessible as possible is an essential part of advancing knowledge and maximizing the impact of publicly-funded research for Canadians. Increased access to the results of publicly-funded research can spur scientific discovery, enable better international collaboration and coordination of research, enhance the engagement of society and support the economy. (Government of Canada, 2015, n.p.)

In addition, the Government of Canada's Public Communications Policy of the Federal Research Funding Organizations (2016) states that "Institutions and Agencies both benefit from positive public awareness of federally funded research and research training, and from promoting the value of this investment for Canadians," (n.p.).

The European Research Council (n.d.) takes an even stronger stance, providing strategic suggestions for grant holders in order to "Prove to citizens, decision-makers and industry that investing in curiosity-driven frontier science is vital to us all…. Let European citizens know how the EU spends public money: investing in scientific projects with potential impact on their lives and on society," (n.p.)

Beyond government funding requirements, there are additional considerations for academic research scientists, who, working as part of public institutions like universities, must consider part of the larger institutional mandate to communicate findings beyond the academy. Consider for example, the vision of the University of Alberta, one of Canada's top five universities (Goldberg, 2017) located in Edmonton, Canada: "...knowledge shall not be the concern of scholars alone. The uplifting of the whole people shall be its final goal," (University of Alberta, 2018, n.p.). The university additionally describes the mission of the academy as "...discover[ing], disseminat[ing], and appl[ying] new knowledge…" (University of Alberta, 2018), wherein dissemination is expressed as a way to share findings with society.

The war on science. This increased emphasis to share science is undoubtedly influenced by our current global political climate, rife with disruptions affecting the communication of science (Anderson, Brossard, & Scheufele, 2010; Cagle & Tillery, 2017; Holliman, Whitelegg, Scanlon, Smidt, & Thomas, 2009). The optimism surrounding the "unmuzzling" of Canadian scientists following the end of the Harper-era federal government (Abedi, 2015; Proudfoot, 2017; Waters, 2015) is overshadowed by the sharp contrast of the state of science for our neighbours to the south, where American scientists are increasingly raising alarm bells about the need for their peers to speak up.

In a so-called "war on science" casting shadows of doubt on the scientific certainty of issues such as climate change (Hunter, 2016; Krauss, 2014; Liang et al., 2014; Nature, 2017), the Trump administration is instituting "gag orders," where some scientists are "no longer allowed to communicate with the public about taxpayer-funded research," (Chen, 2017).

Simultaneous to this influential global superpower creating suspicion surrounding science (Hunter, 2016; Krauss, 2016; Nature, 2017), there are fewer professional science journalists translating scientific findings for public consumption (Nature, 2009; White, 2011) and an increase in non-experts wading into the fray with opinions on science. While the increase in the latter is viewed optimistically by some (Galetti & Costa-Pereira, 2017), others caution that ill-informed influencers may be steering the public discourse about science in dangerous directions (Bucchi, 2017; Fletcher, 2016; Mojarad, 2017).

In this shift in the communication landscape, two-thirds of Americans report getting at least some news on social media (Bialik & Matsa, 2017); yet disconcertingly, "about twice as many social media users distrust science posts on social media as trust them (52% compared with 26%)," (Bialik & Matsa, 2017, para. 8). (Comparable Canadian data was not available). It is within this contentious context that we consider scientists' use of social media as a tool for science communication.

The shift from few to many. Historically, science communication has been disseminated to a passive audience through mass communication tools such as television and radio, part of what Benkler refers to as the industrial information economy (2006). "Celebrity scientists" spoke to society on a weekly basis on popular radio and television programs like Carl Sagan's *Cosmos* in the 1980s, *Bill Nye the Science Guy* in 1990s, David Suzuki's *The Nature of Things* on CBC since the 1960s, CBC's *Quirks and Quarks* (with Suzuki, then Jay Ingram, and now science

communicator Bob McDonald), and *The Daily Planet* with Jay Ingram and Dan Riskin in the aughts and current decade. Magazines and books provided additional platforms for science communication. The commonality in all of these mass communication platforms—television, radio, magazine, and books—was the high cost to entry, restricting access to a few privileged scientists.

Additionally, science journalists were viewed as a gateway between scientists and the public, helping distill difficult scientific concepts and translate them for public consumption (Dunwoody, 2014; Lucibella, 2009; Rehman, 2013). Yet, as discussed earlier, there are now fewer science journalists, meaning fewer trusted sources as intermediaries between scientists and the public (Nature, 2009; White, 2011).

Though published near the end of the last decade, the conclusions of an important editorial in Nature (2009) reflect this disintermediation, encouraging scientists to embrace new technology as a way to keep science in the collective consciousness in the absence of journalists as intermediaries:

> In principle, anyone with an internet connection now has access to more, and better, scientific coverage than ever before. In practice, however, this sort of information reaches only those who seek it out…. And as mass media sheds its scientific expertise, science's mass-market presence will become harder to maintain…. [Scientists] should encourage any and all experiments that could help science better penetrate the news cycle…. Scientists are poised to reach more people than ever, but only if they can embrace the very technology that they have developed [the Internet]. (p. 458)

Society is still in the midst of the transition from the disintermediation of the dominant communication modes in the industrial information economy to the networked information era,

where, with the advent and increasing popularity of the internet, audiences have moved from passive to active with lower barriers to entry presenting a democratizing effect on media with the possibility to connect with more people than ever (Benkler, 2003; Shirky, 2008). The ability to reach the masses is now in the hands of potentially everyone rather than restricted to those able to access the previously dominant (and costly) modes of communication.

This evolution of communication has been disrupted most notably by social media. (Luckett & Casey, 2016; Shirky, 2008). Barriers to entry have lowered, and costs of production—beyond investment of time—have virtually disappeared. As a result of this disintermediation, any scientist can now potentially reach a global audience.

The opportunities and challenges of social media. In a world where scientists are increasingly pressured to share their findings with the public, social media presents both opportunities and challenges (Allgaier, Dunwoody, Brossard, Lo, & Peters, 2013). Despite the fact that scientists perceive advantages to using social media for science communication, adoption of the practice is slow (Collins et al., 2016; You, 2014). (This reflects the earlier discussion of the recognition among scientists of the importance of science communication not necessarily translating into action.)

There are several factors working against scientists using social media including peer criticism (Griggs, 2014; Hall, 2014; Jia, Wang, Miao, & Zhu, 2017), lack of trust on the part of the public reading science (Bialik & Matsa, 2017), lack of academic recognition or training (Carr et al., 2017; Grand et al., 2016; Nature, 2017), discrepancy in the tools used by the public and scientists that may lead to audience confusion (Bombaci et al., 2016; Collins et al., 2016), and the challenge of simplifying science into soundbites (Brossard & Scheufele, 2013, Darling, Shiffman, Côté, & Drew, 2013; Goulet & Lamontagne, 2018).

Just as there is an acknowledged debate surrounding science communication, so too is there debate surrounding the value of social media as a tool for science communication. While there are those who argue that scientists must embrace social media as a powerful path to engage the public (Griggs, 2014; Pavlov et al., 2018; Sandu & Christensen, 2011; Tachibana, 2014; Van Eperen & Marincola, 2011), others are skeptical (Farr, 2017; Hall, 2014).

And in this age of the "democratization" of science (Bucchi, 2017; Jia et al., 2017; Prabhune, 2017; Weiland, 2017), where any scientist can arguably communicate with anyone, anywhere, any time, celebrity scientists still dominate a large share of the conversation. Today's most popular celebrity scientists are Sagan's *Cosmos* successor Neil deGrasse Tyson and Bill Nye—a holdover from the industrial information era. While both are still using some of the more dominant modes of science communication including television, books, and magazines, as well as Netflix for a new era of media consumption, deGrasse Tyson and Nye's arguably cheapest, fastest, and most accessible platforms for science communication are social media. Together, the two scientists amass nearly 19 million Twitter followers (Twitter, 2018a; Twitter, 2018b) and more than three million Instagram followers (Instagram, 2018a; Instagram, 2018b), a number that grows by exponential amounts each year.

All told, deGrasse Tyson and Nye present some serious science star power or social media clout, for which they have been both praised (Eichenlaub, 2017; Shorty Awards, 2017) and criticized (Atkin, 2017; Cornellusen, 2014; Villaluz, 2017). This critique is perhaps reflective of the hangover of the Sagan effect in the social media era, which Martinez-Conde (2016) has recently documented.

Much as there is disagreement about the veracity of science popularization being equated with scientific relevance, so too is there disagreement whether non-celebrity scientists should

pursue social media for science communication. Hall (2014) investigated what he dubbed "the k-index," in homage to both the famous/infamous Kim Kardashian and the h-index, or "Hirsch" index, a common measure of scientific impact. In his playful yet highly cited study, Hall demonstrated that the more Twitter followers a scientist has, the lower his/her scientific impact, when compared with citation metrics through Web of Science.

(For context, Hirsch [2005] created the h-index—still the dominant method to assessing scientific importance—as a method to "quantify the cumulative impact and relevance of an individual's scientific research output," [p. 1]. Kardashian, the reality television personality most noted as "famous for being famous" (Zaslove, 2017), boasts more than 60 million Twitter followers [Twitter, 2018c] and more than 113 million Instagram followers [Instagram, 2018c].)

Reminiscent of the discounting of the Sagan effect, Hall's (2014) findings have also been challenged, most notably in the prestigious peer-reviewed journal Science (You, 2014) with the exploration of the top "science stars" of Twitter, which demonstrated that top tweeters—including deGrasse Tyson—are also highly academically cited.

The intersection of peers and the public. Interestingly, much of the literature in the discussion of scientists' use of social media speaks to the scholarly possibilities social media provides. Social media has been hailed as an "international water cooler for scientists" (Wolf, 2017, p. 78), with scholarly motivations such as curiosity, research discussion, peer communication, and metrics (Van Noorden, 2014). Weiland (2017) posits, "We can ask if we are approaching the point when the scale of participation in social media means that scholars and scientists wishing to keep pace with their field and colleagues can afford <u>not</u> to use digital networks to advance their work," (p. 420). In other words, social media for scholarly

communication has passed the point of being viewed as a frivolity and now merits serious consideration.

While not the exploration of this study, which focuses primarily on public communication rather than peer-to-peer, it is important to note that the literature is dominated by the discussion of disruption to the academic publishing schedule and the opportunity that social media provides for alternative measures of scientific impact (Eysenbach, 2011; Liang et al., 2014; Priem & Costello, 2010; Shuai, Pepe, & Bollen, 2012). The growing movement of scientists using social media is both necessitating the need for and leading the way toward the development of new non-traditional indications of impact, termed "altmetrics" (Priem, Taraborelli, Groth & Neylong, 2010; Haustein, Bowman, Holmberg, Peters & Lariviere, 2014; Shuai et al., 2012).

Focusing in on the scholarly discussion with more relevance to my study, the use of social media in the research cycle is argued to be leading to greater transparency of the scientific process and increased accuracy of the scientific record, providing access to a broader audience with conversations across disciplinary boundaries and beyond academia including the public, politicians, policy makers, and journalists (Baron, 2010; Darling et al., 2013; Faulkes, 2014; Haustein et al., 2014; Ke, Yong-Yeol, & Sugimoto, 2017; Murthy & Lewis, 2015; Pavlov et al., 2018; Rowlands, Nicholas, Russell, Canty & Watkinson, 2011; Shuai et al., 2012; White, 2011). However, though digital scholarly communication offers a potential bridge between researchers and the public, a recent review of the altmetrics literature (Sugimoto, Work, Lariviere, & Haustein, 2017) suggests that social media is still being used predominantly for scholarly communication.

The actual audience. This is perhaps indicative of a larger challenge with scientists using social media for science communication: that they are not always aware who they are communicating with when they use social media, representing a missed opportunity for effective audience engagement and understanding. Bombaci et al. (2016) found discrepancy between intended and actual audiences in their quantitative analysis of tweets from conservation science conference attendees. While scientists believed they were communicating to policy makers, government agencies, NGOs, and the public, in reality, their messages were more often reaching members of the media as well as other academics. As further evidence of audience discrepancy, Collins et al. (2016) noted discrepancies between social media platforms used by scientists versus those used by the general public. In an examination of the followers of more than 100 ecology and evolutionary biology academic scientists, Côté and Drew (2018) found that followers were primarily other scientists, at roughly 55 percent, with a following that diversified to research and educational organizations, media, members of the public, and "decision makers" once the scientists surpassed 1000 Twitter followers. These blurred lines of scholarly and science communication pose challenges in terms of creating audience-appropriate messaging.

Creating audience-appropriate messaging also raises additional concerns about distilling or simplifying complex scientific ideas into soundbites (Brossard & Scheufele, 2013; Darling et al., 2013; Grand et al., 2016). Optimistically however, the literature suggests that increased training and social media policies highlighting use and advantages will lead to a better understanding of how to use the tools (Bik & Goldstein, 2013; Collins et al., 2016; Holliman, 2011; Jia et al., 2017; Pavlov et al., 2018).

The current practice of science communication on social media. With that consideration, it is important to consider how scientists are currently using the tools. In spite of

noted challenges, understanding how scientists are currently using social media may help further contextualize expectations for those who have not yet adopted the practice.

Martinez (2016) notes, "Scientists these days don't just need to be good at putting their ideas into writing; they need to know how to post them on Twitter and Facebook," (para. 1). Science communication researcher Mojarad (2017) echoes and argues that scientists have a responsibility to communicate: "It is time for us to acknowledge that the job of a scientist in the social media age includes not only researching and teaching but also championing the messages of science," (p. 1363). Yet how do scientists translate these maxims into practice?

In terms of training or advice for best-practice implementation, there appears to be a gap in the literature written from the perspective of and for individual scientists. Though there are examples from grey literature including academic blogs with suggestions for academics' use of social media (Miah, 2016; Mollett, Brumley, Gilson, & Williams, 2017), it has been acknowledged that scientists need more than "anecdotal evidence" to be motivated to use social media (Bik & Goldstein, 2013; Brossard & Scheufele, 2013). Yet existing research-based studies—detailed in the subsequent section—focus on science organizations and online science collectives rather than individual scientists, representing a gap in knowledge and understanding.

Bik et al. (2015) present best practices to minimize time investment and maximize outcomes based on a decade of experience with online science outreach through the Deep Sea News collective: linking outreach with research; defining goals for online engagement; defining target audience; developing public intellectual brand; focusing on storytelling; conveying not just science content but also passion and personality; leveraging multiple tools to engage different audiences; and measuring effectiveness by assessing data.

The scientists behind another online science collective—the TravelingGeologist—select certain platforms for peer-to-peer engagement versus others for public engagement (Spencer et al., 2017). While recommending Twitter for links to papers, Facebook for controversial discussions, and Instagram for field photos, the TravelingGeologist collective recommends that rather than viewing social media platforms as distinct entities, all should be considered as an integrated social media platform with distinctions among the tools for audiences and engagement levels (Spencer et al., 2017).

Representative of the Arctic science initiative at the Norwegian Polar Institute, Pavlov et al. (2018) argue that their work with the @oceanseaicenpi has not only improved altmetric scores, it has also helped the researchers associated with the project become better communicators. They choose multiple platforms—Facebook, Twitter, and Instagram—to reach a wide audience and work through teamwork as a collective to lessen the individual workload. And in the absence of formal training, they choose platforms based on personal comfort level. They distinguish posts as fieldwork, educational, publication, portrait, history, and meetings, focusing all through a storytelling lens. Their most popular posts are heavily influenced by photography, and they diversify and tailor their content based on platform-specific performance metrics.

Several empirical studies identify distinct features of engaging science posts, the understanding of which may help scientists craft effective communication. By applying machine learning and psychometrics to more than 100 space science accounts on Facebook and Twitter, Hwong et al. (2017) found the messages that elicited the most audience engagement were brief and used links, hashtags, emotive words, question marks, and visual elements. In their study examining the European Organization for Nuclear Research (CERN) communication of particle

physics across multiple social media platforms—including Twitter, Instagram, and Facebook—Kahle et al. (2016) concluded that, though different platforms lend themselves better to different types of engagement, "awe-inspiring" imagery universally elicited the strongest engagement. In an analysis of the Monterey Bay Aquarium Research Institute's Facebook page, Fauville, Dupont, von Thun, and Lundin (2015) noted dialogue as a way to foster an atmosphere of trust, necessary to foster engagement.

Lee and VanDyke (2015) found, however, that science organizations are using Facebook and Twitter primarily for one-way information dissemination. In a follow up study, Lee, VanDyke, and Cummins (2017) suggested encouraging engagement by posting questions to the audience and responding to questions and comments, something scientists are uniquely positioned to do. Interestingly, in their analysis of Twitter comments related to scholarly articles, Charland, Huang, Li, and Li (2017) found that emotional comments were most likely to receive response.

On the whole, the literature suggests that science communication on social media is primarily being used for one-way information dissemination (Su, Scheufele, Bell, Brossard, & Xenos, 2017), missing an opportunity to move away from the linear deficit model of science communication toward dialogue as a way to encourage engagement and deepen trust (Su et al, 2017).

The exploration of qualitative engagement. This discussion of engagement leads into a limited discussion of qualitative exploration of academics' use of social media. (While the focus of this study is academic research scientists, the limited qualitative literature necessitated expanding out beyond science into adjacent literature related to broader academia.) In three studies that qualitatively explored the use of social media in academia, the authors arrive at a

similar conclusion: that in spite of the possibilities social media provides for dialogue, it is still being used primarily for one-way information dissemination.

In their study of Chinese scientists' perception of the role of social media in science communication, Jia et al. (2017) found that scientists are reluctant to engage in dialogue because of a perceived lack of control as well as fear of reproach by peers—harkening back to the Sagan effect. Similarly, though the scientists Smith (2016) interviewed in the UK and USA noted recognition of the power of social media for dialogic communication as an opportunity to break barriers between scientists and their audience, participants were reticent to engage in dialogue without the assurance of a sympathetic audience.

This discussion of the need to move beyond the deficit model of science communication as a way to foster trust surrounding science in society contrasts with the reality of the recognition that social media is not yet being used to its full dialogue potential. In a qualitative case study from the Open University (UK), Grand et al. (2016) found that academics who engaged digitally did so primarily in a one-way approach. The authors argued that in order to foster engagement in a truly dialogic fashion, academia must foster a culture—including support, which includes training, time, and recognition or incentives—to encourage engagement with research.

Analysis of Findings from the Literature Review

In terms of the review of the current literature exploring how scientists are using social media to communicate, I note several key observations and a gap for further exploration.

While there is a broad overview of the field and increase in research into this evolving practice, there is a lack of depth in understanding of the motivations of individuals scientists engaging social media for science communication. While there is recognition of value in the

practice of science communication on social media and the increased importance of science communication in our current global climate, so too is there recognition that adoption is slow as well as the overtone that lack of time, incentive, and training is possibly prohibiting scientists from taking on further responsibilities. The Sagan effect still persists (Hall, 2014; Martinez-Conde, 2016), presenting the ongoing tension of the recognized need for science communication yet the reluctance to do so based on poor peer perception.

In spite of the barriers to adoption, there is a broad understanding of how scientists are using social media. However, this evidence tends to be discipline-specific, such as marine science, particle physics, nanotechnology, geology or earth science, space physics, etcetera. While there are increasing numbers of studies and contributions from science organizations and research collectives who are successfully using social media for science communication, there is minimal evidence from the perspective of individual scientists. (And there was no literature representing Canadian scientists.)

Additionally, there is a noted gap in qualitative research, with the recognition that the scant extant qualitative research is generally presented from broader academia rather than science-specific. Therefore, it is important to address this gap by exploring the motivations of individual scientists currently using social media as an opportunity to better set expectations for those considering adoption of social media for science communication.

Uses and Gratifications Theory

To frame my study of why scientists are using social media for communication, I will be looking through the lens of the uses and gratifications theory, which originated in the 1970s as a

way to explore people's motivations for using particular mass media as well as the satisfaction they received in doing so (University of Twente, n.d.).

Uses and gratifications theory is individualistic in nature (Lindgren, 2015). The theory asserts that individuals have unique needs and will seek media to satisfy those needs based on personal goals (Whiting & Williams, 2013; Zolkepli & Kamarulzaman, 2015). The three main objectives underlying the development of the theory relate to how people are using mass communication, what motivates them to do so, and the consequences—both positive and negative—that occur as a result (University of Twente, n.d.).

Over the decades, the theory has been applied to new technological innovations, moving from roots in radio and television (Blumler, 1979; Blumler & Katz, 1974; Katz, Blumler, & Gurevitch, 1973; Rubin, 1983) to include new developments such as the internet (Eighmey & McCord, 1998; Stafford, Stafford, & Schkade, 2004), mobile telephones (Leung & Wei, 2000), and text messaging (Grellhesl & Punyanunt-Carter, 2012; Thurlow & Brown, 2013). Recent studies have examined the use of social media with respect to uses and gratifications (Correa, Hinsley, & De Zuniga, 2010; Hsu, Chang, Lin & Lin, 2015; Liu, Cheung, & Lee, 2010; Mull & Lee, 2014; Park, Kee & Valenzuala, 2009; Quan-Haase et al., 2015; Quan-Haase & Young, 2010; Whiting & Williams, 2013; Zolkepli & Kamarulzaman, 2015).

In this subsection of the literature, researchers have identified several major categories for the uses and subsequent gratifications of social media (Lindgren, 2015; Whiting & Williams, 2013; Zolkepli & Kamarulzaman, 2015): to generate peer support or in response to peer pressure; to socialize or facilitate a sense of belonging; as a form of entertainment or relaxation; as a habit or a way to pass time; to build identity or reputation; and to conveniently seek and share information. Though not specific to scientists or science communication, these categories

will be used in combination with the review of the literature to help frame the inquiry for this study and in the development of my research instrument, described in detail in the research design and methodology section that follows.

Drawing back to the review of the literature pertaining to scientists' use of social media for communication, uses and gratifications theory has been used to frame what we do with information on social media as "...an expressive form of information, we find information, but we do something with it. We link it. We share it with others and recirculate it," (Lindgren, 2015, n.p.). This suggests engagement with an audience, which the preceding literature review notes as lacking as it pertains to science communication.

Whiting and Williams (2013) advocate that the uses and gratifications theory should be given more prominence in the social media literature as a critical pathway that "helps explain the many and varied reasons why consumers use social media," (p. 362). Though they examined consumer behaviour, their tenets make a strong case, and their categories (information seeking; expression of opinions; communicatory utility; convenience utility; information sharing; and surveillance/watching of others) and research method (exploratory research with interviews focused on why—rather than how—people use social media) were key considerations in the design of my study. Additionally, similar to my approach, the researchers did not focus on any particular social media platform but examined the broad category of social media as a whole.

Localizing more closely to my research focused on academics, Quan-Haase et al. (2015) examined digital humanities scholars' uses and gratifications with Twitter. Though my research question and design looks broadly at social media, based on a survey in the fall of 2016, the majority of our scientists are using Twitter as their primary platform, making this study particularly relevant. Again, their design (thematic analysis of semi-structured interviews

wherein the uses and gratifications framework "informed the coding process" [p. 4, 2015]) along with research questions and interview guide are particularly useful in informing the direction of my design. The authors' argument—that "what is needed is a more holistic understanding of [digital humanities] scholars' motivations behind Twitter use," (2015, p. 3)—draws key parallels to my investigation of the motivations behind our scientists' use of social media, as illustrated through my research questions.

Summary of Literature Review

The purpose of this literature review was to provide a grounding for my study situated in the current discussion of science communication via social media. As such, I established the larger field of science communication, contrasting the challenges with the increased need, before focusing in on social media as a tool for science communication. To present a more holistic consideration of the phenomenon, I explored literature from scientists, science communication scholars, and communications researchers in addition to grey literature including mainstream media, trade publications, and academic blogs.

The key findings and noted gaps as well as a consideration of the theory of uses and gratifications detailed in this review of the literature will help shape my research design and inform my research questions. With consideration rooted in the extant literature with the goal of addressing gaps in understanding presented therein, the research questions that guide my study are as follows:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media to communicate science?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

The following section on research design and methodology will detail how I will use this literature review as a springboard to set out to explore this area of inquiry.

Research Design and Methodology

Disruptions to the traditional media landscape, with fewer science journalists and more people turning to online sources for science information—concurrent with a global climate creating mistrust surrounding science—have created conditions where science communication is possibly more important than ever in modern history. The advent and increasing use of social media as a communication tool by scientists is providing opportunities to reduce the barriers to access for science communication. A review of the current literature illustrates the breadth of discussion of the practice. However, the majority of studies are quantitative in nature, presenting limited depth in understanding motivations as to why scientists are using social media to communicate, as well as assessing their satisfaction with the tools.

Additionally, much of the literature is focused either on science communication with the public or scholarly communication amongst peers; there is little context for understanding the motivations of individual scientists. Generally, there is a discipline-specific approach; nanotechnology, particle physics, space physics, marine science, and geology for example, representing multiple scientists from multiple institutions (primarily in the United States, Europe, or Asia, with a noticeable gap in Canadian data). In the resulting findings in the extant literature, there is a noticeable lack of qualitative data and an abundance of quantitative data. Schutt (2011) eloquently explains the contrast of the two approaches, with qualitative representing "many data on a few cases rather than few data on many cases" (p. 324). As a consequence, the existing literature presents data generalized to sub-disciplines of science with a lack of depth in understanding individual practices.

To deepen the understanding provided by the current literature and to present a rich description of these phenomena rooted in the theory of uses and gratifications—not previously considered in the extant literature—my research design took a qualitative approach.

As discussed in the preceding literature review chapter, my study focused on the following research questions:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media to communicate science?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

By using purposive sampling to purposefully select participants for my study—drawn from the tenure-track faculty members of the University of Alberta Faculty of Science in Edmonton, Canada—this exploratory study represented an opportunity to deepen an understanding of the views of individual academic research scientists representing multiple disciplines from the same institution, with the goal of presenting the findings via a qualitative content analysis to set expectations for other scientists considering the adoption of social media for science communication. The approach to the study was grounded in the results of a pilot survey of the population, conducted in the fall of 2016. Rooted in the individually focused uses and gratifications theory, semi-structured individual interviews allowed me to explore individual motivations for the use of social media.

This chapter will describe the following: research design (exploratory); study participants (purposively selected tenure-track scientists actively using social media for science communication); setting for inquiry (participants' offices on the University of Alberta campus);

research instrument (semi-structured interview guide designed within the framework of the uses and gratifications theory); procedures for execution of the study (executed according to ethics approval); and the process for data analysis (an inductive qualitative content analysis rooted in the naturalistic paradigm), which emphasizes reliability and verification while noting limitations of the research design.

Design

This study was designed to build upon the quantitative data currently available in the literature as well as the data from a pilot survey of the population in order to develop a richer, deeper understanding of the factors that motivate individual academic research scientists to use social media. The study adopted an exploratory design to examine scientists' social media practices using the theoretical lens of uses and gratifications.

Exploratory research was the appropriate design in this case due to its flexible nature and its use of smaller sample sizes that are suited to this project (Jupp, 2006; Whiting & Williams, 2013; University of Southern California, 2018). Mayan (2009) defines the context in which exploratory research is the desired design: "...if a basic descriptive and summary of the phenomenon is desired [Sandelowski, 2000]" (pp. 52-53). While it cannot provide definitive conclusions or generalizations, exploratory research can provide theoretical insights and help suggest directions for future exploration for research (Jupp, 2006; University of Southern California, 2018). Through my exploratory approach—often referred to as "descriptive" (Mayan, 2009; Sandelowski, 2000)—I stayed close to the data (Mayan, 2009) to avoid abstraction and aim for straight description.

As I had enough familiarity with the phenomenon to generate questions though not so much as to be able to predict answers (Mayan, 2009, p. 71), I used the qualitative approach of semi-structured individual interviews to examine the practice in context (De Vaus & de Vaus, 2001) of scientists using social media for science communication. As is often the case with exploratory or descriptive design (Mayan, 2009), sampling was purposeful in order to identify interview participants who would provide the richest information about my topic. I allowed participants' responses to drive analysis inductively (Mayan, 2009) rather than deductively confirming a preconceived hypothesis (as is the focus of observational design [University of Southern California, 2018]) or with the goal of constructing a new theory (such as the grounded theory approach [Jupp, 2006]). Rather, by using the theoretical approach of uses and gratifications to frame the way I conceptualized the study and informed my line of inquiry, I used an exploratory approach to address the gap in the literature by adding qualitative depth to the breadth of the primarily quantitative extant literature, with specific examples provided by study participants.

Participants

This study considered the social media practices of academic research scientists at post-secondary institutions. This population is of interest as they are working to develop scientific solutions to society's most pressing problems—and being publicly funded in order to do so—meaning that it is crucial for society to understand what they are doing and why they are doing it as well as how it affects society at large. Social media is providing the possibility for democratizing science communication, meaning that this population may wield greater power on a global stage than in generations previous. And while it is recognized that, however slowly,

scientists are increasingly adopting social media, what is motivating them to do so in spite of the well documented barriers to adoption, including lack of time, training, incentive, and recognition? Representing multiple disciplines and career stages, each individual may have different motivations for using social media as well as nuanced gratification resulting from the practice. A better understanding of the motivations and satisfactions of those who appear to be successfully using the tools may help set expectations for those considering adoption.

Participants were selected using purposive sampling. Purposive sampling is a non-probability method with a deliberate approach to participant inclusion based on the qualities of characteristics of the participant, who are expected to provide unique and rich information (Battaglia, 2008; Crossman, 2017; Etikan, Musa, & Alkassim, 2016; Palinkas et al., 2015). Purposive sampling is suggested as a best practice for semi-structured interviews (Miles & Gilbert, 2005), which was my approach to data collection as described in the subsequent section.

As Etikan et al. (2016) describe, in purposive sampling, "the researcher decides what needs to be known and sets out to find people who can and are willing to provide the information by virtue of knowledge or experience," (p. 2). An additional benefit of purposive sampling with alignment to my exploratory work is its expediency in reaching the targeted sample (Crossman, 2017).

There are several types of purposive sampling (Crossman, 2017; Etikan et al., 2016; Palinkas et al., 2015): maximum variation/heterogeneous (employed when one is looking to document shared patterns across different conditions); homogeneous (when one is looking to reduce variation in those conditions); typical case (when one is looking to describe typical or "normal" cases); extreme/deviant case (when one wants to learn from outliers or unusual manifestations); critical case (when one is looking to logically generalize findings); total

population (when the researcher wants to understand the entire population representing the characteristics in question); and expert sampling (when one is seeking the contributions of participants with particular expertise).

As this study focused in on research scientists in the University of Alberta's Faculty of Science who are actively using social media for science communication, and given the distinctions of types of purposive sampling as detailed above, my approach aligned most closely with expert sampling, evidenced by the following inclusion/exclusion criteria.

Inclusion criteria. Findings from a pilot survey conducted with this population in the fall of 2016 provided baseline data, which helped inform inclusion criteria for this exploratory study. The pilot survey received a 33 percent response rate from 332 tenure-track faculty members. Respondents indicated that 63 percent are actively using social media for professional purposes for various reasons (including raising awareness of science; staying abreast of scientific findings; networking with professional colleagues; and sharing scientific findings from within or beyond personal laboratory/research group). Responses also indicated which of the seven departments were most professionally active: biological sciences, chemistry, and earth and atmospheric sciences. Since the survey, I maintained ongoing conversations with many of the pilot participants who suggested additional avenues of exploration to enhance my inquiry for this exploratory study.

The criteria for participant inclusion in this exploratory study were that the participant must not only be a tenure-track faculty member in the University of Alberta Faculty of Science but must also be an active user of social media for science communication. In this case, "active" was defined as engaging with at least one social media platform at least weekly. In this case, "social media" was defined by publicly available platforms such as Twitter, Facebook, and/or

Instagram, rather than academia-specific social media such as ResearchGate (similar to the focus detailed in the literature review). Additionally, while they need not be universally supportive of the practice, all needed to have experienced some perceived benefits of the practice contributing to their ongoing use.

While efforts were made to achieve a reasonable mix of disciplines, ages/career stages, and gender/diversity, I focused primarily on recruiting those who provided the richest description of active practices as well as those who were open to sharing their experiences, both positive and negative. I aimed for a mix of early-, mid-, and senior-career scientists from the three departments with the highest use of social media for science communication (biological sciences; chemistry; and earth and atmospheric sciences).

Exclusion criteria. Exclusion criteria included non-tenure track staff members, students—graduate or undergraduate—or tenure-track faculty who do not actively use social media or who use social media only for personal reasons, not as part of their professional practice.

Sampling. The pilot study from the fall of 2016 helped me identify potential participants who fit the inclusion criteria. From that pool, I contacted six scientists to request an interview, all but one of whom agreed to participate. With their verbal consent, I followed up via email to confirm interview time and location. While these initial verbal discussions indicated consent, and while participation in the interviews themselves indicated implied consent, consent was also explicitly confirmed with signed consent forms (see Appendix A).

Setting

The face-to-face semi-structured individual interviews were conducted in participants' offices on the University of Alberta campus. The benefits of this location were convenience, comfort, privacy, and minimal interruption (Herzog, 2005). While other possible settings existed, including campus coffee shops as well as my office, I was mindful of minimizing noise and distraction as well as neutralizing any perceived power dynamic (Herzog, 2005). Additionally, being in their offices allowed participants the opportunity to, in some cases, demonstrate how they use the tools on mobile devices and/or personal computers in as natural a manner as possible.

Instrument

In order to gather the highest quality data to best address my research question, I conducted semi-structured one-on-one interviews with open-ended questions (Mayan, 2009; Merrigan, Johnston, Huston, & Logan, 2012) with a guide to stimulate discussion (see Appendix B for full interview guide). This open-ended approach was designed to provide insight into what the interviewee believed to be most relevant in the discussion (Bryman, 2015) and provided me the opportunity to probe and prompt responses to elaborate with specific examples (Arksey & Knight, 1999).

While there are challenges to this data collection approach—most notably the need for good listening skills on my part with minimum interruption and maximum emotional control to ensure participants were able to respond fully (Adams, 2010; Alsaawi, 2014; Mayan, 2009)—the semi-structured approach allowed me to simultaneously maintain focus while remaining flexible and adaptive to ensure the discussion remained conversational with participants (Merrigan et al.,

2012; Quan-Haase et al., 2015; Turner III, 2010). Kvale and Brinkman (2009) discuss the "art of second questions" as one of the most important opportunities for researchers to engage active listening prior to probing the participant, with mindful sensitivity and attention to situational cues. While I used the guide as a conversation starter, the semi-structured format also allowed me the opportunity to ask "second questions" to explore nuances in individual practice as well as topics not previously considered by the researcher or discussed in the literature.

I followed the recommendations in the literature to keep the interview schedule brief, centred around five to eight broad and simple questions to frame the interviews as more of a conversation rather than a "Q&A" (Arksey & Knight, 1999; Miles & Gilbert, 2005). I created short questions as a tactic to ensure I not only maintained focus on participants rather than my notes but that I also minimized the possibilities of the participants misunderstanding the questions (Alsaawi, 2014; Miles & Gilbert, 2005). I developed prompts without leading questions (Miles & Gilbert, 2005), which were used only as a last resort. Prompts were developed as a reminder to me to cover sub-topics of the broad questions (Arksey & Knight, 1999). I followed Arksey and Knight's (1999) suggestion to start with an ice breaker question before moving into the heart of the focus of the research questions, which were grounded in the uses and gratifications theory and themed around the literature review and pilot survey findings.

I pre-tested (and subsequently refined) proposed interview questions with several colleagues as well as two scientists with similarities to those selected for interviews to ensure clarity for the actual interview process (Turner III, 2010).

I ensured a logical flow between questions, moving through easier questioning and then into more challenging areas (Mayan, 2009). The guide moved from a general discussion of the practice, situating social media within the larger context of science communication (Q1: "How

has social media changed science communication?") to specific practices addressing the individual motivations for use as well as perceived satisfaction in use. The table below shows examples of the questions and demonstrates how they were broadly generalized to address the three main objectives underlying the uses and gratifications theory: how people are using mass communication (HOW); what motivates them to do so (USES); and what consequences (GRATIFICATIONS)—both positive and negative—occur as a result (University of Twente, n.d):

HOW **How mass communication is being used** **(How scientists are using social media for science communication?)**	**USES** **What needs are they looking to satisfy?** **(What motivates scientists to use social media for science communication?)**	**GRATIFICATIONS** **How satisfied are they that needs are being met?** **(What are the consequences [both positive and negative] that occur as a result?)**
(Q2) What are the opportunities/challenges social media presents as a tool for science communication?	(Q3) When and why did you first start using social media for science communication?	(Q5) What challenges/successes have you experienced using social media for science communication?
(Q4) Which platforms do you use for which purposes?	(Q4) Which platforms do you use for which purposes?	(Q5) How have your peer/students reacted to your use of social media for science communication?
		(Q8) What motivates you to continue using social media for science communication?

Table 2. Theoretical grounding of interview questions. Demonstrating questions in relation to uses and gratifications.

Finally, as recommended in the literature (Arksey & Knight, 1999; Miles & Gilbert, 2005), I concluded the interviews with a debrief of participants' responses as well as the question "Is there anything you would like to add?" as a final opportunity to have participants lead the discussion.

Procedures

Following approval through the Research Ethics Office at the University of Alberta, I emailed the six participants identified from the pilot survey in the fall of 2016 to arrange a meeting time at their convenience. Interviews were conducted in the spring of 2018 over a four-week period. I scheduled at least two days between interviews to allow for my manual transcription and reflection to ensure adaptation throughout the process (a noted benefit of semi-structured interviews as opposed to a rigid survey questionnaire [Merrigan et al., 2012]).

The interviews were all conducted face-to-face to ensure the richest communication (including the observation of nonverbal cues [Merrigan et al., 2012] to signal my prompts to probe responses and ensure the best flow of interviews) as well as the demonstration of use of social media. These details were captured via field notes both during and immediately after the interviews, with strong attention to reflexivity of researcher bias (Dunne, Pryor, & Yates, 2005). Mayan (2009) describes reflexivity as "the process of being highly attentive to how and why you make decisions and interpretations along the way, critically examining your personal-research role and how this interfaces with all—even the most minute—aspects of the research" (p. 137). Above all, I aimed to be critical of my personal biases, beliefs, background, and role (Tracy, 2013) and how these might have affected my interpretation of the interviews and process, with particular attention to the notes I made during the interview. I also captured audio recordings for later transcription to ensure posterity and accuracy in data collection, which allowed me to cross reference my notes against the actual conversation to ensure I was not misinterpreting meaning in respondents' answers. (Raw data—including audio recordings, transcriptions, and field notes—were stored per the University of Alberta's research ethics requirements in locked files and encrypted electronic files, remaining confidential to the researcher and supervisor only. Per

the University of Alberta's Research Records Stewardship Guidance Procedure [2013] all documentation will be destroyed and deleted in five years following project completion.)

Before each meeting, I emailed the interview subjects to detail the interview protocol (Turner III, 2010) along with providing the informed consent form (see Appendix C) reviewing the intent of the study as well as the open-ended nature of the interview with themes for exploration, to allow interview subjects time to reflect on potential answers to questions in advance and to consider other areas of discussion. In the case of those with whom I have had previous discussions, I reviewed notes from those preliminary conversations as potential prompts for discussion.

At the outset of each interview, I again described the interview protocol, detailing the purpose of the study and addressing any participant concerns. Reintroducing myself and my research topic and discussing how the participants' responses would be used helped to ease into the interview. I addressed the point detailed in the consent form that they may request that their data remain anonymous in the analysis but that it would add more richness to the findings to include some identifying information (primarily name, position, research area, and social media usernames) as part of their professional practice. (As social media practices are inherently tied to the individuals who were interviewed, it was preferred to present identifying information, though all had the option of requesting anonymity.) All consented to being identified.

Once I ensured participants were clear on interview guidelines and comfortable to start, I began the audio recordings. As is recommended in the literature (Mayan, 2009), I closed the interview while maintaining contact, so that I ensured we would have the opportunity to follow up on both sides, both myself as the researcher as well as the participants.

Beyond one of the original six scientists declining participation once it came to the interview stage, there were fortunately no significant challenges, difficulties, or changes I had to make with my instrument or procedures.

Following each interview, to ensure that I focused on collecting and analyzing data concurrently (Mayan, 2009) to inform the iterative process of qualitative content analysis, I personally manually transcribed in full the proceedings; while time consuming, this manual transcription was well worth the investment as an additional opportunity to review the interview to allow for additional initial synthesis and analysis. My transcripts included not only participant responses but also my questions and probing as researcher. It was particularly important to note my contribution to the conversation as a way to ensure transparency in the process and to reflexively ensure that I had not asked questions in a leading manner, which might have unduly influenced responses. I ensured that I emailed all participants a copy of the interview transcript to ensure they were comfortable with how their responses were presented. I also reiterated at that time that they would have the opportunity to review the full data analysis prior to project completion to ensure their comfort level with how their responses were presented, since all chose to be identified rather than remain anonymous. Per my application for research ethics, this stage of review of their comments presented in the data analysis was participants' final opportunity to withdraw from the research.

Analysis

Mayan (2009) equates the process of qualitative inquiry to that of a puzzle, wherein the researcher pieces together a description of the phenomenon through an iterative circular content analysis, checking and rechecking the fit of the findings. In order to analyze the data from my

semi-structured one-on-one interviews, I used an inductive approach based in the naturalistic paradigm of qualitative content analysis (Hsieh & Shannon, 2005). In contrast to the deductive approach of rationalistic inquiry, in naturalistic inquiry, the researcher avoids influencing findings and/or manipulating outcomes (Lincoln & Guba, 1985); rather, the focus is on a "straight description" (Sandelowski, 2000) with minimal interpretation to describe a phenomena in its natural setting (Merrigan et al., 2012), which informed the larger design of my exploratory research.

I used coding as the primary technique to capture emergent themes and categories (Dunne et al., 2005; Saldaña, 2015). Coding is a cyclical, interpretive act, which allowed me to draw comparisons among data to describe the phenomenon (Mayan, 2009; Saldaña, 2015). Here I detail the sequence and process of that interpretation.

As the sample size was small, I used manual coding rather than a software program in order to stay as close to the data as possible (Mayan, 2009); this not only improved my control and ownership (Saldaña, 2015) but it also allowed me to more easily evoke the experience of data collection (Fielding, Lee, & Lee, 1998) rather than divorcing codes from context in order to avoid over analyzing or over interpreting the words (Sandelowski, 2000). My field notes acted as an early form of coding, reflective of what Saldaña (2015) refers to as an heuristic practice of coding during data collection. Transcription of the interviews allowed for additional initial pre-coding (Mayan, 2009; Saldaña, 2015), highlighting words or short phrases that reflected the essence of the data. As Saldaña advises (2015), I used columns for transcripts: one for the raw data and one for notes as part of the coding process. I additionally followed Mayan's (2009) advice to double-space transcripts, note participant details in the header, and number each line of the transcripts to easily identify quotes or points of interest.

I refined the coding as I progressed through the data gathering and qualitative content analysis to detect patterns. Saldaña (2015) characterizes these patterns as similarities, differences, frequency, sequence, correspondence, and causation. I used a combination of my interpretation of the data supplemented with *in vivo* coding (Saldaña, 2015)—direct quotes from participants.

The resulting description, as presented in the subsequent findings section, was organized in a manner most appropriate to the data collected (Mayan, 2009), reflective of the exploratory approach in which data guides analysis rather than confirming a hypothesis. I explored the codes for connection, linkages, and patterns to subsequently develop themes as the outcome of coding (Saldaña, 2015). Excerpts from the transcripts informed my codes which then informed categories, limited to 10 to 12 as recommended in the literature (Mayan, 2009). From those categories emerged the themes surrounding which I drew conclusions about the research. While the interview guide was constructed as a reflection of preconceived themes from the review of the literature, the focus of the analysis was on an inductive approach, revealing themes that emerged from the data itself as a form of reliability and validity in the qualitative research process.

Reliability and validity. Reliability and validity were both important considerations in my analysis, reflecting what Golafshani (2003) articulates as trustworthiness, rigor, and quality in research. (Reliability is defined as "the extent to which a measuring instrument...gives consistent results," [Jupp, 2006, p. 262)]. Validity is defined as "accuracy of measurement, and/or accuracy of applying conclusions from one study to other settings, persons, or situations," [Merrigan et al., 2012, p. 301].) One method to address trustworthiness, rigor, and quality of research to ensure as replicable and accurate an interpretation as possible is triangulation, or "the

combination of at least two or more theoretical perspectives, methodological approaches, data sources, investigators, or data analysis methods," (Thurmond, 2001, p. 1). However, given the limited scope of the capstone project, the qualitative nature of my study, and the small sample size, triangulation was not possible.

In the absence of triangulation to address the consistency and accuracy of my findings, I overcame the challenges of ensuring reliability and validity throughout the data collection and analysis process, primarily by performing member checks (or reviews of the data by research participants [Merrigan et al., 2012]) as well as addressing my own inherent bias as a researcher. I paid particular attention to the fact that I had to be willing to relinquish poorly supported ideas (Morse, Barrett, Mayan, Olson, & Spiers, 2002). I undertook my research with the knowledge that, as Morse et al. (2002) describe:

> ...[Q]ualitative research is iterative rather than linear, so that a good qualitative researcher moves back and forth between design and implementation to ensure congruence among question formulation, literature, recruitment, data collection strategies, and analysis. Data are systematically checked, focus is maintained, and the fit of data and the conceptual work of analysis and interpretation are monitored and confirmed constantly…. (p. 14)

Further, Morse et al. (2002) describe verification strategies for ensuring reliability and validity of data throughout the research process rather than something considered externally only at the end of the process. Specifically, these strategies include the following: methodological coherence; appropriate sampling of "participants who best represent or have knowledge of the research topic" (p. 18); concurrent data collection and analysis; and theoretical considerations, both foundational and formational, moving between macro and micro perspectives. It is within these parameters that I designed my research and conducted data gathering and analysis.

Limitations. Beyond ensuring reliability and validity, there are additional limitations to my analysis including researcher bias (with no secondary coder, though this was mitigated through member checks) as well as sample bias. Battaglia (2008) notes a critical limitation of purposive sampling: "...another expert would likely come up with different sampled elements from the target population in terms of important characteristics and typical elements to be in the sample." (Interestingly, this stands in opposition to Mayan's [2009] advocacy that researcher bias is an inherent strength of qualitative research). Additionally, in an effort to present a succinct analysis within the parameters of a capstone project, there is the risk that condensing details presents the possibility of misinterpretation and may have removed some of the richness of the conversation.

I designed my research in the best possible manner to address these limitations by performing member checks following both transcription and data analysis (as well as reviewing themes with my communication colleagues in the Faculty of Science) as well as detailing the inclusion/exclusion criteria as clearly and rationally as possible so that if another researcher applied the same criteria, he/she would have generated a similar participant pool.

Summary of Research Design and Methodology

This research design and methodology chapter has detailed the exploratory design of my research, working with academic research scientists who were purposively sampled for individual one-on-one semi-structured interviews rooted in the uses and gratifications theory to address the research questions as follows:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media to communicate science?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

As detailed above, in order to best address research validity and reliability, I maintained an inductive iterative process of concurrent data collection and analysis to generate the findings, presented subsequently. Though there are noted limitations to my qualitative approach and purposively selected small sample size, the resulting data analysis and qualitative description detailed in the next chapter describes how an understanding of these scientists' uses and gratifications with social media for science communication may help set expectations for other scientists considering adoption of the practice.

Findings and Discussion

Disruptions to the current climate—political, societal, and technological—are providing opportunities and challenges for science communication. While scientists are increasingly adopting social media for science communication, the extant literature demonstrates a lack of depth in the understanding of the motivations of individual academic research scientists who are doing so. An exploration of their practice may guide future success for these scientists while also setting expectations for others who have not yet embraced social media. It is with this background that the following research questions were considered:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media to communicate science?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

Review of Research Design and Methodology

To probe these research questions, I employed an exploratory design to examine scientists' social media practices, informed through the theoretical lens of uses and gratifications. I engaged this exploratory approach to provide a straight description of my findings. Participants were purposively selected based on predetermined characteristics in order to best inform my research inquiry. The study population consisted of tenure-track academic research scientists from the University of Alberta Faculty of Science who are actively using social media for science communication. I conducted face-to-face, semi-structured interviews over a four-week period in the spring of 2018, guided by open-ended questions to stimulate discussion. I worked with five scientists, representing diversity in career stage and gender, from the three departments

with the highest use of social media for science communication: biological sciences; chemistry, and earth and atmospheric sciences. To provide the richest description possible, each participant agreed to be identified in the findings. (See Appendix D for an overview of study participants, with attention to Twitter profiles as the participants' primary—and in most cases, only—social media presence.)

To ensure data collection and analysis was concurrent and reflexive, I manually transcribed each interview before interviewing the next participant. To ensure accuracy and reliability of my data, I performed member checks by sharing interview transcripts as well as the findings and discussion with each participant. My data analysis was informed by an iterative and inductive approach to a qualitative content analysis. A process of manually coding the data ultimately allowed me to identify patterns in the data and explore relationships between uses and gratifications in order to present emergent themes in a description of the phenomenon of scientists' use of social media for science communication.

Organization of Findings

The organization and presentation of the subsequent findings and data analysis was driven by participants' responses. As one of the aims of my study was to explore the depths of the motivations of individual academic research scientists, the responses are presented as individual narratives. Each vignette contextualizes the conditions and factors influencing the scientists' social media practices (reflecting RQ1), with a view to expressing individual motivations for use as well as consequential gratifications, the latter of which may be shared with others considering the adoption of social media for science communication (reflecting RQ2). The findings section considers each scientist as separate and distinct—presenting the unique

circumstance for that individual's practice—while also considering a holistic exploration of how the scientists responded to the individual questions, mapped back to the theoretical foundations of uses and gratifications. The discussion section illustrates emergent themes and explores relationships between uses and gratifications to generalize the phenomenon through this theoretical framework.

This chapter is therefore organized as follows: the findings section presents individual narratives of the five study participants and also considers how the scientists responded to the individual questions (as presented in Appendix E); the data analysis section presents a qualitative content analysis, with consideration for steps taken to address research validity and reliability; and finally, the discussion section reflects back on the research questions and how my findings add to the literature in the field of science communication, with specific consideration of social media as a tool for the practice. In the research perspective section, I consider my role as researcher as well as the limitations of the study before concluding with a summary of the findings and discussion.

Findings

Here, I explore five narratives surrounding individual academic research scientists' use of social media. The vignettes are presented in chronological order based on when the interviews took place. In addition to the individual narratives, Appendix E provides a chart that reflects back to the design and methodology chapter, linking individual interview questions to the uses and gratifications theory, useful to explore patterns in responses. Considering those two approaches allows for a more thorough qualitative content analysis, explored fully in the next section of this chapter.

Sticking to the science to deflate climate change deniers:
Andrew Derocher and the accessibility of Twitter

> *...if the best public source of information is misinformation, that doesn't speak highly about the science of what we do with polar bears.*
>
> —Andrew Derocher, on what motivated him to join Twitter (Q3)

Figure 1. Andrew Derocher. Screen cap of Twitter profile.

Professor Andrew Derocher is a renowned biologist who studies polar bears and their sea ice habitat to explore the effects of changes to the climate. Due to his expertise and subject matter—what he calls the "poster species" for climate change—Derocher is frequently interviewed by mainstream media. A proponent of science communication, he adopted Twitter following a conversation with a Canadian Press journalist, who indicated a source from Twitter, a well-known climate change denier. Derocher experimented with Twitter as an alternative platform through which to communicate scientific findings and build credibility for a "science-based case" for support. He acknowledges Twitter in grant applications and reports to government agencies and funders, part of the obligation to communicate findings beyond the scientific community.

> *...we can see what the science is telling us. We're a publicly funded institution. The public has a right to know and should know and hear very clearly what we think the situation is.... It wasn't hidden in some academic journal. It was not basically in some vault that nobody could access. No politician could go forward and say they didn't understand that polar bears were maybe at risk.*

With Twitter, he has "learned by doing," noting that though social media takes time to both learn and execute, he maximizes efficiency by incorporating it as a "transition" activity during his daily practice—for example sharing sea ice levels or photos from the field—to contextualize the importance of the research and build profile for published research, his lab, and the university.

Derocher emphasized the main benefits of social media as immediacy (not needing to wait for mainstream media to cover his research, and in many cases being contacted by media after seeing his tweets), accessibility (both ease of the platform and as a way to present information publicly), control of the message presented, profile, and exposure to other science. He uses imagery—in roughly two-thirds of his tweets—to engage his audience. He restricts his tweets to a very specific focus of science (Arctic/sea ice/polar bear/prey), never veering outside professional boundaries into personal life. He is also restrictive in how he uses Twitter, retweeting selectively based on what he perceives as source credibility and relevance. He also never directly engages with climate deniers, instead presenting a fact-based argument to build support for science.

> *...people only care about the things they know about. And if you want them to fund science, you better tell them what you're doing…. I tend to stick to what the science tells us, and that's largely almost from personal experience or peer-reviewed literature…. I can basically deflate [climate change] deniers using my Tweets by putting in a very clear statement that I would want to make about climate change and habitat loss.... There is no debate on this. There is no science on the other side.*

Community connections, and networking beyond the niche:
Sasha Wilson's use of Twitter for real-time science

> *[Social media] has opened [science communication] up to everyone. We used to have these elite science communicators like Carl Sagan and Bill Nye the Science Guy, and [social media has] really enabled all of us to participate from the lab, from the field, from the couch at home.*
>
> —Sasha Wilson, on how social media has changed science communication (Q1)

Figure 2. Sasha Wilson. Screen cap of Twitter profile.

Associate Professor Sasha Wilson represents a minority in her department, one of just eight females out of 60 scientists total. Wilson's fieldwork as a biogeochemist exploring environmental aspects of economic geology can also be temporarily physically isolating, taking her to far corners of the Earth in her quest to address CO_2 sequestration to mitigate the impact of climate change. She adopted Twitter as an experiment after encouragement by one of her postdoctoral fellows. After initially dismissing it as "silly," Wilson soon discovered the serious benefits of social media.

> *I thought, "oh it's silly, it's not worth it." But I started having a closer look at it and realizing that the short snippets of information were a gateway to more in-depth information and a conversation.*

Addressing her concerns that Twitter is a "mishmash of personal and professional information," Wilson restricts her communication to mostly science. Wilson takes a two-pronged approach to Twitter, asking for advice and pitching papers to other scientists and sharing images

of the natural world to engage a non-scientific audience. Wilson has also used Twitter to successfully recruit students and postdoctoral fellows. She uses Twitter for team building and morale boosting in the lab, to profile her department and institution, and as a way to connect to a community beyond her physical location.

In terms of what motivates her to continue using social media for science communication, the real-time connection to a global community is the clear call:

> *…[Twitter] connects minority groups in academia and in science. For a long time, I was the only female faculty member in my old department, and you know, getting stories from other people when I wasn't hearing other narratives was really nice…. And reaching out to people with similar interests in...a broader community than just the people I'll access through email or in the hallway. It's really nice. And I like that I can be in the field on the other side of the world and...people will respond within minutes and give me good advice. So I can do better real-time science with [Twitter].*

Faster than the speed of science:
How Twitter helps Chris Herd get a handle on hot topics

> *My field is changing extremely rapidly, and that makes it fun, and it also makes it challenging, because it's hard to stay on top of things. And in some ways, reading the table of contents from a journal can give you an idea, but social media can get you there even faster.*
> —Chris Herd on what motivates him to continue using social media for science communication (Q8)

Figure 3. Chris Herd. Screen cap of Twitter profile.

The research in Professor Chris Herd's field flies as fast as a fireball. Literally. (He studies Martian meteorites.) Herd adopted Twitter as it had become a rote part of his annual meeting, the Lunar and Planetary Science Conference, where microbloggers using Twitter are given preferential Wifi access and special identity badges. What started as a method to become part of the conference conversation has become routine for Herd, who looks to the social media platform to stay on top of and share the latest research findings in planetary space science.

> *...obviously it's useful for self-promotion, which is the whole point I guess—but it's also useful if there's an interesting study that comes out that somebody else did that's in my field. I can retweet that with a comment that says, "here's why this is important." So that's the thing. That's how things have changed…. [I]t's not just the story that's coming out going directly to people, sort of making it accessible, but it's also that other people who are experts potentially can comment on it and say why this is important.*

Herd references Twitter almost like a massive "Table of Contents," beyond journals specific to his field, often following tweets back to the original research, exploring discoveries he wouldn't normally encounter for potential future citation.

His presence is primarily professional in nature, with several tweets leading to mainstream media coverage and amplification by influencers such as NASA scientists. Careful to not put out ideas that haven't been "completely baked," he also shares his own published research results, so long as they meet what he defines as a "minimum general interest level." He aims to distill scientific arguments and findings to their essence, a skill honed through many years of science communication, now adapted for social media.

> *...this is public funding. And there needs to be an effort to publicize it…. I've always been a proponent of...trying to distill [science] to something that you can convey to someone as an elevator pitch or in a relatively short soundbite. Because I think the people who are really interested are going to do like I do and at least follow [a tweet] through to the press release to get more information if not the original research…. [W]hen I'm ready to [share research], I'm going to look to [Twitter] first and foremost as a way of getting things out.*

Trying Twitter:
How early experimentation led Mike Serpe to social media success

> *There was a lot of confusion...and a little resistance actually. Almost like you were selling out. Like you weren't a hardcore scientist because you were using social media. But now, it's the norm. You have to have it.... Now, there's basically no response. It's just like normal…. And that's what people want now. They want things fast and in very short small bites.*
>
> —Mike Serpe on his peers' initial reaction to his use of social media (Q6)

Figure 4. Mike Serpe. Screen cap of Twitter profile.

Keen to experiment with social media, chemist and Associate Professor Mike Serpe proudly acknowledged that he was one of the first in his department to adopt social media and that now most of his departmental colleagues use Twitter. He notes a challenge of defining personal and professional boundaries, meaning he primarily sticks to science. Twitter helps Serpe navigate the breakneck pace of publishing.

[T]he most important stuff that you'd want to know of is popping up on your Twitter feed as opposed to you going through 5000 TOC [Table of Contents] alerts from journals. I think social media—specifically I'm thinking of Twitter—has made sharing of information much easier, faster, and much more broadly and widely accessible…. [Y]ou get exposed to a lot of different things, and maybe you don't get all the details about all those little things unless you want them. [W]ithout social media, you're so limited in what you have access to.

Serpe works at the nearly nanoscale, meaning he cannot always provide photographs of his study objects. But, noting that social media favours visuals, he doesn't see this as a limitation,

and rather shifts the focus to humanize scientists, presenting photos of lab members and group activities in addition to research, awards, and accomplishments, something positively received by prospective students. (He also infrequently maintains a photo-driven lab page on Facebook for the purpose of team building and recruitment.)

As to what motivates him to continue using social media for science communication, there's no turning back, not only for the access to new knowledge but also for the professional presence.

> *It's almost like you can't go back now. Because I think there would be a lot of repercussions. And I think you'd miss out on a lot of things. So I guess it's a fear of missing out on things that I've had access to by being part of Twitter specifically…. I really think that you can't not have a social media presence now. If you really want to be a success, I really think you need it.*

Serpe also sees social media as a gateway and key avenue to engaging society in science.

> *...how can the public know what's going on at the university that their taxes go to?... You have to tell them. So how do you tell them? Well, you can do radio, you can do...newspapers. Or probably the easiest way and the fastest way is social media…. I think social media is serving a very important purpose in at least showing the public that we're making an effort to prove to them, to show them what we're doing with the money they're giving us.*

Social media and the return of the science spark:
Jillian Buriak creates conversation and community on Twitter

> *Yeah, there's still [resistance to social media] to some degree, but those people look like dinosaurs now…. And in a way, I simply now feel sorry for them. Because they're missing that spark of new science that's so hard to get now. This [Twitter] gives it to me. And I sort of feel that the people who don't use it, their science is sliding.*
> —Jillian Buriak on the motivation to using social media for science communication (Q8)

Figure 5. Jillian Buriak. Screen cap of Twitter profile.

The Canada Research Chair of Nanomaterials for Energy, Professor Jillian Buriak is focused on pushing the boundaries of knowledge in the evolution of solar cells and batteries, advocating for science policy, and growing the science community in her large lab locally, in Canada, and beyond. The editor-in-chief of one of the most highly cited peer-reviewed journals for the American Chemical Society runs two Twitter accounts: one under her own name and one for the journal. She started the latter to shift the perception of the publication as more "nimble, mobile, responsive."

While Twitter is her primary source of social media communication, collaborations in China means WeChat—beyond the scope of consideration for this study—is a necessity for communicating with colleagues and students.

Buriak adopted Twitter after one of her fellow chemistry colleagues kept citing Twitter as a source of information about new papers and publications.

> *He knew things before me, and that was kind of annoying. But I realized that he was getting constructive information from [Twitter], and so I thought. "I've gotta do this."*

Buriak constantly sends Twitter links to new papers to her students and lab group, with strong advocacy for the benefits of the social media platform.

> *What's...important is the constant exposure to new ideas and new science. So it used to be that we would go to a library in the old days with a list of journals, and we would literally flip through all the Table of Contents…. And so by doing that, you were exposed—whether you liked it or not—to papers that were outside of your specific area…. And so it really did spark ideas and free thinking. And I've found that since we no longer do that, everything is online, we tend to get more focused at the results of searches that are very specific to begin with, and so kind of have lost that spark. But social media has brought that back, because following not only journals but New York Times Science, things like that, again, there it is…. It's that spark. It's back.*

Beyond the benefits of Twitter as a source for that spark—perhaps defined more broadly as inspiration—Buriak points to the feeling of community, the creation of conversation, and the opportunity for collaboration, with social media providing a sense of who scientists are as people. "You really do build that sense of community and knowledge far beyond just your little niche here in a department." She additionally uses Twitter as a way to humanize science and build profile and morale for her group.

> *A lot of it is people. So... if we push a paper, we push "hey, congratulations on your new paper." Things like that. Pictures of the group. That's very visual…. And I think that, for me, that's the important message of science: it is people. It's not just all data.*

Data Analysis

Procedures. Detailed in the design and methodology chapter, my approach to data analysis was a qualitative content analysis. As Mayan (2009) suggests, the process of qualitative inquiry is much like a puzzle, where the researcher takes an iterative approach to fitting the pieces together to provide a straight description of the phenomenon. Through a process of coding the data, I captured emergent themes and categories (Dunne et al., 2005; Saldaña, 2015), drawing comparisons among the data to provide a description of the phenomenon. My first instance of coding was through field notes collected during the interviews. I performed a second round of coding through a manual transcription of the interviews, allowing me to stay close to the data (Mayan, 2009) to improve my control and understanding of participant responses (Saldaña, 2015). I explored multiple subsequent rounds of coding through numerous reviews of the transcripts, both individually and holistically, reflective of the circular and iterative approach to coding (Tracy, 2013).

In order to reflect the individualistic nature of my theoretical framework of uses and gratifications and to avoid over interpreting participant responses (Sandelowski, 2000), coding was primarily *in vivo* in nature (Saldaña, 2015), reflecting direct quotes from participants, and supplemented with words and short phrases that captured the essence of the data (as presented in Appendix E). The combination of approaches—individual and holistic—allowed me to identify patterns, what Saldaña (2015) characterizes as similarities, differences, frequency, sequence, correspondence, and causation. This then informed the emergent themes, addressed more fully in the discussion section.

Validity and reliability. As a sole researcher with a small sample size and only one method for data collection, triangulation—"the combination of at least two or more theoretical

perspectives, methodological approaches, data sources, investigators, or data analysis methods" (Thurmond, 2001, p. 1)—was not possible within the limited scope of this capstone with its focus on qualitative exploration. However, I engaged several other strategies to ensure validity and reliability in my analysis. Golafshani (2003) notes the concepts of validity and reliability, rooted in the positivist paradigm and traditionally associated with quantitative research, which emphasizes repeatability of results—or reliability—derived from a reliable research instrument—or validity—require reconsideration in the naturalistic paradigm of qualitative research, where the focus shifts to understanding of a phenomenon in context-specific settings. In Golafashani's assessment, whereas credibility in quantitative research is derived from the research and repeatable results from a standardized instrument, "the credibility of a qualitative research depends on the ability and effort of the researcher," (2003, p. 600).

While "researcher as instrument" is a key component of qualitative research—and my background knowledge in the research subject matter is precisely what facilitated my knowledgeable interpretation of the data from the in-depth semi-structured interviews (Campbell, Quincy, Osserman, & Pedersen, 2013)—I addressed my inherent bias as a researcher throughout the research process to ensure alignment between research design, participant recruitment, and concurrent data collection and analysis (Mayan, 2009; Morse et al., 2002). To avoid researcher bias, something Sarniak (2015) warns happens when a researcher forms a hypothesis and filters participant responses to confirm that bias, I purposely engaged exploratory research and a straight description, motivated to explore the phenomenon for the benefit of the field rather than to push an agenda or prove a hypothesis. Over and above my reflexive and iterative approach, I conducted member checks by engaging research participants to review interview transcripts as well as data presentation for accuracy (Merrigan et al., 2012) and—in the

absence of a secondary coder—had communication colleagues review my thematic analysis, presented in the following section.

Discussion

In consideration of the findings, several key themes emerged from the data. Uses and gratifications—a theory that emerged in the 1970s as a method of exploring the motivations and social conditions driving people's use of particular mass media and their adaptation of said media to meet their needs as well as their associated satisfaction in doing so (Chaney, 1972; University of Twente, n.d.)—helped guide the exploration of study participants' individual needs and personal goals as well as their associated satisfaction with their use of social media in meeting those needs and goals.

The dominant use themes in this study were the following: helping scientists keep up with the speed of science; staying abreast of changes and opportunities in the field; connections to others beyond departments, disciplines, and geographical boundaries; knowledge translation, or the presentation of value to a tax-funding public; humanizing scientists by demonstrating that science is more than just data; and contextualizing science to build credibility and establish a science-based case for support.

Reflecting back to the literature review pertaining to uses and gratifications, Lindgren (2015) discusses several major categorical gratifications in the context of social media, many of which were echoed in participant responses in this study: peer support; socializing; companionship; interaction with interesting people; the "feeling of belonging to a community" (p. 4); and connection to others separated by geographical distance but united by similar interests. Over and above these gratifications, study participants' responses alluded to social

media use as providing inspiration through exposure to different ideas, experiencing excitement upon learning of new opportunities, feeling a satisfaction and sense of belonging through the cultivation of and connection to a community beyond physical barriers, and the sense of fulfilling an obligation and meeting a responsibility to build support for science and transparently share findings, discoveries, and details of publicly funded research.

The following chart identifies the main uses and gratifications identified this study:

Uses	Gratifications
Keeping pace with science, new papers/discoveries, changes, and opportunities	Feeling of inspiration, fun, excitement through exposure to new science
Connecting to others beyond department/discipline/geographic boundaries	Cultivating connection, sense of belonging, and peer support as part of a global community
Knowledge translation/demonstrating value of science to tax-paying public, humanizing scientists and contextualizing science to build support	Fulfilling obligation/responsibility to build support for science and transparently share findings and discoveries associated with publicly funded research

Table 3. Uses and gratifications themes in this study. Themes emerged from qualitative content analysis of participant responses.

By all accounts from these study participants, the gratifications associated with the use of social media for science communication align with and fulfill the needs these scientists are looking to address. Social media for these scientists most clearly serves as a gateway to people and knowledge, accessible in terms not only of the platform and audience but also for democratizing information beyond the academy and science community and into broader society. Many of the scientists in this study indicated they cannot picture a world wherein they don't use social media for science communication, seen now as a necessity for scientific success. With that consideration, the following is a discussion of the findings related to my two research questions.

Research question 1. The following themes emerged in relation to **RQ1:** *What are the factors and conditions motivating academic research scientists to use social media to communicate science?*

As outlined in the literature review and echoed in the findings, the current climate in which science is being practiced—in the midst of climate change and the push to share publicly supported science as well as the way that people are consuming information, not only where (on social media) but also how (quick soundbites)—is changing the need for scientists to communicate. Changes to the communications and publishing landscape are shifting the ways as well as the pace in which scientists are able to communicate.

Scientific discoveries are now moving at such a rapid rate that it is increasingly challenging for scientists to keep pace with new findings, as noted by Herd and Serpe. In addition, scientific searches have changed dramatically. No longer are there happenstance discoveries during late-night library sessions taking scientists outside their specific domain. As discussed by Buriak, searches have become directed and purpose-driven, meaning less exposure to new ideas. All scientists in this study mentioned that social media—specifically Twitter—provides ideas and inspiration beyond their narrow niche. In this sense, social media is seen by the scientists in this study as a way to stay current and increase exposure to other ideas and other scientists, with Twitter acting like a massive scientific table of contents.

Beyond information seeking, information sharing was a dominant theme throughout the interviews. While altmetrics or increased citations did not play a significant factor for any of the scientists in this study, there was a sense from several, including Buriak, Serpe, and Wilson, that exposure for research from one's lab is influencing the use of social media. For Serpe, "the ultimate goal is just making sure people see the article." Wilson has had positive experiences

with her research being shared by others on Twitter and purposely shares the work of others to boost morale and recognize the efforts of students and colleagues, an aim echoed by both Buriak and Serpe. Broadening out from the individual lab to the larger scientific community, Buriak, Serpe, and Wilson noted Twitter as an avenue to facilitate community that transcends boundaries, both geography or subdiscipline.

Moving beyond scholarly communication, morale boosting, and community building and more to the core of science communication, scientists interviewed for this study see social media as a way to mobilize knowledge and contextualize discoveries for a non-scientific audience. This information sharing is being driven by a need to demonstrate the value of publicly funded science to society, ultimately seen as a way to increase support for science. Due to the nature of the platform, scientists interviewed are forced to distill their scientific arguments down to their very essence, something welcomed notably by Derocher, Herd, and Serpe as an opportunity to succinctly lay the foundation for the argument for why science matters. For Derocher, "to some extent, you're simplifying the argument to the very essence. And at some level for general consumption, that's probably what people want to know."

Scientists interviewed for this study have taken to Twitter as a faster way to share with a non-scientific audience, with several, including Derocher, Herd, and Serpe, commenting on not needing to wait for mainstream media and—as a bonus—finding mainstream media are often approaching them as a result of seeing the scientist on Twitter.

In summary of findings related to RQ1, scientists interviewed in this study are using social media to share research, build credibility and promote subject-matter expertise, learn what is going on in the scientific world, keep pace with newly published science, connect to a community beyond their niche, and address the need to share publicly funded scientific findings,

presenting science in a digestible format as a way to build support for science. All scientists interviewed commented in various ways that social media—specifically Twitter—has become an expected avenue through which to enhance their practice and capacity and to build profile for science, scientists, students, research, and for their university and city.

Research question 2. The following addresses the themes that emerged in relation to **RQ2:** *How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?*

Scientists considering the use of social media for science communication should expect to incorporate social media as part of their daily professional practice, something noted by all study participants. It should be expected that social media will take time but that the tools—most notably Twitter as the primary platform used by all five participants—are easy to use and even "self-explanatory" (as noted by Serpe) from a technological perspective. The challenge is not necessarily in the use of the tool, but as Serpe noted, in determining appropriate content: "I do think a challenge is people knowing what's appropriate to put on Twitter, what to retweet, what to like, where the boundary is between personal and professional." It is for this reason that scientists considering adoption may best be advised to "stick to the science," a point that was addressed by all but one study participant, with Buriak advocating for an 80/20 mix of professional and personal as a way to humanize scientists.

However, remaining professional and "sticking to the science" does not mean academic-style posts. As noted by Derocher, "the science [tweets], I'm not sure they're always the best sellers." Herd emphasized, "you don't just tweet out the title of your paper with all its really long words. You're not going to get any traction that way." Buriak echoed this, noting, "if you're just

boring science, no one is going to bother… Really hardcore science-based stuff, that doesn't get retweeted. It has to be kind of in an interesting way." In terms of knowing what will be considered interesting, most scientists in the study noted a trial-and-error approach, with both Buriak and Herd alluding to a "gut instinct."

Scientists interviewed for this study noted photos as a way to create engaging posts, with the consensus that social media lends itself to disciplines with captivating imagery; yet those working outside these boundaries argue that should not be seen as a barrier to social media. For Derocher, who noted that his photo posts are more engaging, "an image...conveys a lot more information than I can within the context of just putting up text." For the scientists interviewed in this study whose topics are not as visually focused—Buriak and Serpe—posting photos of their group members has become a positive way to not only boost morale in their labs but also to aid in humanizing science while profiling people, the university, and the city. (In addition to profiling scientists within one's own lab, Buriak noted enjoying learning about the scientists she interacts with through Twitter: "you know them through...the research that they post, but I think what's also interesting is that you get a sense of who they are as people.")

With regard to peer perception, scientists considering the adoption of social media should expect primarily positive feedback, if any, based on responses from these study participants. Standing in contrast to the Sagan effect detailed in the literature review, several scientists—notably Buriak and Serpe—suggested an inverse effect: that a non-presence on social media presents the perception that your science and your lab are not current.

If one's subject of research touches on controversial topics such as climate change and alternative energy, unsurprisingly, supported by responses from Buriak, Derocher, and Wilson, scientists should expect criticism from dissenters, noted as emotionally draining. While Buriak

and Derocher have both experienced what they call "pointless battles" (Derocher fields regular attacks), Wilson herself has not personally experienced criticism but notes that she is "being watched" by potential detractors.

With the exception of Derocher, the scientists almost universally did not believe they were directly engaging the public, but rather see social media serving as a pathway to the public via other intermediary audiences—such as mainstream media and funding agencies. Both Derocher and Serpe note social media in their NSERC discovery grant applications, and Herd plans to do so in the future. In terms of further amplifying the success of their social media efforts, Buriak, Herd, and Wilson noted searching for existing hashtags. Derocher, Herd, and Serpe have experienced success with having their efforts shared by influencers from within and beyond the science community.

Responses from the scientists in this study suggest that social media is an essential experiment and accessible avenue for scientists both seeking and sharing information, providing connection to a global community, building profile for science and scientists, and offering inspiration through constant exposure to new ideas and new science.

Research Perspective

My professional role as the director of communications in the Faculty of Science, where all study participants are employed as tenure-track scientists, gave me a unique insider insight (Mayan, 2009, p. 79) in the sense of direct access and a previous professional relationship, a general awareness and understanding not only of their science and the context in which they practice their science, but also their use of and support for social media. However, though I work in science communication and have pre-existing professional relationships with study

participants, I am neither a scientist nor tenure-track academic researcher. From this sense, I may also be considered an outsider, exploring questions that those outside the scope of the profession might also probe. While my unique perspective may have influenced my purposive sampling of study participants, careful attention to reflexivity in my role as researcher led to what I argue is a strong and rigorous study with valid research results.

Limitations

In spite of my efforts to ensure reliability and validity of findings, the major limitations of this study were its exploratory nature and small sample size, which—while essential for the limited scope of a capstone project—did not allow for statistical generalizations or critical theoretical insights. Additionally, my purposive sampling method means that other researchers may have used alternative criteria to identify interview subjects. While an unstructured interview approach may have led to more nuanced discussions, my semi-structured strategy was designed to guide a conversation rather than provide rigorously limiting questions. The conversational approach allowed participants to highlight what they believed to be most relevant to the discussion (Bryman, 2015) while ensuring focus remained on the research questions.

An additional limitation, this study focused on uses and gratifications as it pertains to scientists' use of social media for science communication without consideration of other important factors, including dialogue and audience engagement, identified as a gap in the scant qualitative data presented in the current literature (Grand et al., 2016; Smith, 2016; Su et al., 2017). It is challenging to consider communication without considering audience and outcomes. Therefore, future studies could include a wider approach to consider both audience perspective as well as a content analysis of associated communication to explore depth of engagement.

Summary of Findings and Discussion

As science and scientific ideas continue to come under politicized scrutiny, and as funding agencies continue to push open access to research, social media is providing scientists an opportunity to directly influence the collective conversation. A qualitative exploration of the factors and conditions motivating scientists' use of social media reveals uses and gratifications that transcend journals, conferences, departments, subdisciplines, and geographic locations. That which cannot be measured—by number of scientists, tweets, or followers—is not only immeasurable but also invaluable: in other words, we need to consider the quality of communication in addition to quantity.

Perhaps what is most interesting that is not captured in the current literature are the things that cannot be measured as illustrated in this study, providing a strong argument for the consideration of qualitative research in addition to the quantitative methods dominant in the extant literature. It is not just the number of cross-disciplinary connections and collaborations, but rather the sense of community created. Not the quantity or number of potential future citations, but rather the quality of communication and the source of inspiration through exposure to new science. Not the number of retweets and direct engagement with the public, but rather the opportunity to influence the current conversational climate as it pertains to science. Not the concern about what gets lost in translation when science is distilled into sound bites, but rather what is gained when science communication via social media distills an argument to its essence, both piquing curiosity and providing a gateway to deeper understanding. In other words, it is not just the quantity but also the quality of use and subsequent gratification of scientists' use of social media for science communication that counts.

With consideration of my findings and discussion, it is now possible to contextualize this research within the field of science communication and social media and to propose considerations for future research growing out of this initial exploratory work, both of which will be discussed in the subsequent conclusion.

Conclusion

Socio-political changes and technical disruptions are affecting the need, challenges, and opportunities for science communication as well as the channels through which to do so. In order to deepen our understanding of why scientists are using social media for science communication, this research study presented a qualitative exploration of the following research questions:

RQ1: What are the factors and conditions motivating academic research scientists to use social media for science communication?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

This concluding chapter summarizes the key findings from this study, highlights those most significant, and explains the significance of the findings in relation to the research questions. It then places those findings in context, suggesting contributions to the extant literature related to science communication and social media. The conclusion also considers how the findings may influence professional practice. I briefly detail the limitations of the study before outlining opportunities and specific recommendations for future research based on these limitations and overarching findings. I then conclude this section and this capstone project with a summary of the key contributions of the study to the field and practice of science communication.

Summary of Findings

As outlined in the literature review, sharing science beyond academia is the core impetus for science communication. Seeking science, though not generally associated with science

communication, is a core tenet for academic research scientists, who must build upon and challenge existing knowledge to further the understanding and development of the world around us. Social media presents an avenue where scientists can both seek and share information, a key consideration today.

The scientists interviewed for this study were motivated to use social media to remain current with changes and opportunities in science, to connect with a global community of scientists, to share the findings of their publicly funded research beyond the scientific community, to demonstrate that science is more than just data, and to contextualize science to build support in society. The subsequent gratifications that resulted from these various uses by study participants include experiencing inspiration through exposure to new ideas, cultivating a sense of belonging to a global science community, and fulfilling an obligation and responsibility to transparently share science beyond academia. The alignment of resulting gratifications with these scientists' use of social media for science communication suggests they are motivated to continue using the platforms.

This study presents a qualitative and uniquely Canadian context to contribute to the literature in the field of science communication and social media. Canadian scientists have recently been seen to have been "unmuzzled," (Abedi, 2015; Proudfoot, 2017; Waters, 2015) while their colleagues to the south are coming under increased control in terms of what they can and cannot communicate (Chen, 2017). This study therefore speaks to the democratization of not only science but also science communication: anyone, anytime, anywhere can contribute to the conversation. (Notably, however, while the scientists in this study did not necessarily interpret themselves as directly engaging the public, they have universally chosen Twitter, the platform fifth most popular among the public [Greenwood, Perrin & Duggan, 2016], presenting a possible

disconnect for direct engagement opportunities, something reflected as a concern in some of the extant literature [Bombaci et al., 2016; Collins et al., 2016].)

Given the dominance of the discussion of altmetrics in the current literature (Eysenbach, 2011; Liang et al., 2014; Priem & Costello, 2010; Shuai et al., 2012; Van Noorden, 2014) surrounding scientists' use of social media, I was surprised that citation rates and scientific impact was of little focus for these study participants. These scientists were not motivated by numbers achieved through altmetrics. While all acknowledged boosts in impact were possible, this was not a consideration: the focus instead was on exposure to new science and the perceived need to communicate findings with the scientific community and beyond academia. Study participants were seemingly intrinsically motivated by the need to both seek information to further advance science and to share information to further support for science.

Contrary to the existing literature, the study participants were not negatively affected by the Sagan effect—a historic professional stigma, which suggests that those who popularize science are viewed by peers to be less scientifically important. While some indicated pushback from peers in their early use of social media, none were presently concerned, with a couple suggesting the opposite perception, questioning why a scientist would not have a social media presence, with the potential that a non-presence on social media may indicate stagnation. This perception shift is an important factor to consider in future research as it stands in contrast to recent arguments that the Sagan effect persists (Ecklund, James, & Lincoln, 2012; Liang et al., 2014; Martinez-Conde, 2016).

In spite of the barriers noted in the literature (Carr et al., 2017; Grand et al., 2016; Nature, 2017) referencing lack of time, training, and incentive (recognition as part of academic evaluation) as inhibiting scientists' use of social media, I was encouraged that the scientists in

this study were not deterred by these challenges or the lack of extrinsic reward and were rather intrinsically motivated to seek and share information. None of the scientists had strong opinions regarding administrative support or social media being considered in annual evaluations, with several suggesting that this would not be a useful evaluation metric. Rather, they emphasized that the most effective administrative support should include the provision of best practices and suggested usage guidelines and policies as well as the amplification of the efforts of individual scientists (retweets, etcetera) by official institutional channels.

Interestingly, what was presented as a challenge in the literature—the danger of science getting lost in translation when simplified into soundbites (Brossard & Scheufele, 2013, Darling, Shiffman, Côté, & Drew, 2013; Grand et al., 2016)—was seen not only as a necessity but also an opportunity for these scientists to cut to the core of the essence of the argument of why science matters to society.

Findings in Context

The findings speak to the convergence of three areas of research: the need for increased support and research in the area of social media for science communication (Brossard, 2017; Bucchi, 2017; Fletcher, 2016; Mojarad, 2017); the need for the exploration of dialogue and engagement through qualitative research surrounding the use of social media by scientists and academics more broadly (Grand et al., 2016; Jia et al., 2016; Smith, 2016; Su et al., 2017); and the opportunity for the use of the theory of uses and gratifications to further research into social media (Quan-Haase et al., 2015; Whiting & Williams, 2013).

Much of the extant literature speaks to “scientists” as an analogous mass, without consideration of individual needs. As social media is by its very nature a medium focused on the

individual, it is critical to give individual voice to the needs of individual scientists, which this study speaks to, with its grounding in the individualistic uses and gratifications theory. While broad categorizations may be drawn with regards to science communication as a whole, the needs of every individual will be slightly unique, as illustrated through this study. While there are alternative approaches in this emerging field, focused on quantitative research in a broad context, which may have provided different results as suggested by the literature, I took the approach of the qualitative exploration of a very targeted segment of scientists to provide voice to these individual scientists; this approach facilitates an improvement of the conversation surrounding the use of social media for science communication, helpful in setting expectations for those who have not yet adopted the practice, adapting the best practices of those who have, fostering potential communities of practice, and working with funding agencies, policy makers, and supporters of science.

With regards to professional practice, these findings may serve to aid training or suggested guidelines for the use of social media. As the study participants are based at the University of Alberta—one of Canada's top five universities—the findings may have potential implications beyond science to academia as a whole, as all Canadian federal tri-council research funding agencies (not just Canada's Natural Sciences and Engineering Research Council) are focused on knowledge mobilization for publicly supported research.

Future Direction

Several limitations of this study suggest directions for future research. The small sample size focused on individual academic research scientists from the University of Alberta in Canada, all of whom are tenured. Future studies could broaden out to include scientists from other

universities as well as pre-tenure scientists, who may express different motivations for using social media. Additionally, the study was focused on the perspective of scientists without consideration of audience engagement via a corresponding content analysis of social media communication, suggested for future consideration. This is particularly relevant in light of the just-released study by Côté and Darling (2018) who explored scientists' Twitter followers to determine whether they were engaged with "inreach" (communicating with other scientists) and/or "outreach" (communicating with a non-scientific community). The researchers found more audience diversity to include public, the media, and research and educational organizations once a scientist reached more than 1000 followers, increasing communication beyond inreach toward outreach. (With fewer than 1000 followers, scientists were engaging primarily with other scientists [~55 percent]).

While the focus of this study was intended to look at social media broadly, the study participants' use of social media meant a narrowing in on Twitter; it is advisable in future to maintain a broad focus rather than platform-specific considerations in order to address wider implications for science communication in the future, no matter the channel, given the rapid changes in the social media landscape. For example, Jillian Buriak uses WeChat to communicate with colleagues in China; given China's increasing dominance in science (Guarino, Rauhala, & Wan, 2018), this will be an important consideration for future research.

Disconcertingly, several months following our interview, Buriak followed up to share a recent article discussing the use of social media to harass female academics (Veletsiano & Hodson, 2018), an experience she said will likely lead to discontinuing her use of Twitter in the near future. The other female study participant—Sasha Wilson—indicated social media is useful for connecting with other minorities in science, with Wilson referencing other women

specifically; while acknowledged in the findings and discussion, this avenue requires deeper exploration and consideration in future research, both the connection of the community of female minorities in STEM as well as the potential for the use of social media for harassment.

Additional consideration should be given to the blending/blurring of scholarly communication and science communication, as scientists are using social media for both endeavours, each with unique considerations of purpose and audience. It is advisable that a future focus on scholarly communication broaden beyond the focus on altmetrics, as the scientists in this study were focused on intrinsic benefits such as inspiration and an obligation to share rather than extrinsic benefits of increased citations, the latter of which may influence future communication with universities, policy makers, and funding agencies.

With regard to these groups, future research should consider an audit of communication (including support tools) surrounding the use of social media for science communication by universities, policy makers, and funding agencies, with particular focus for the latter on grant applications and open-access obligations, noted by several study participants. This may aid in the development of policies and guidelines for use, encompassing best practices and fostering the growth of communities of practice.

Perhaps one of the most interesting and important areas for future research exploration is a potential shift in the Sagan effect due to the increased adoption and acceptance of social media as a legitimate tool for science communication, both within the scholarly community and beyond in the public at large. Shifts in perception may be influenced by the increased need for science communication—given changes in the global sociopolitical landscape and disruptions to communication technology—and the simultaneous adoption of social media as a tool through which to do so.

Summary of Conclusion

Disruptions to the global sociopolitical and technological landscape are expanding the need, challenge, opportunity, and capacity for science communication. Though adoption is slow, scientists are steadily increasing their use of social media for science communication. While this emerging field of research presents a broad depiction of the phenomenon from the viewpoint of how scientists are using social media, there is little depth of qualitative understanding exploring why individual research scientists are using social media. With this background, the following research questions were explored:

RQ1: What are the factors and conditions motivating individual academic research scientists to use social media for science communication?

RQ2: How can examining this phenomenon through the lens of uses and gratifications help set expectations for other scientists who may be considering using social media for science communication?

This exploratory study provided the personal voices of five academic research scientists at a Canadian university who were intrinsically motivated to both seek and share information via social media as a way to enhance their professional practice and build support for science in society. The findings suggest directions for future research that build upon this qualitative inquiry and broaden out beyond one individual university to consider dialogue and audience engagement and implications for both professional practice and policy development as well as a potential lightening of a historic tension in science communication given shifts in the climate in which science is now being communicated.

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Appendix A: INFORMATION LETTER and CONSENT FORM

Study Title: Science gets social: why scientists use social media to communicate

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Background

- **Invitation to participate in research project:**
  - There is increasing attention being given to social media as a platform for science communication. While a review of the literature provides breadth of understanding of the practice, there is limited depth in understanding of the motivations of individual scientists.
  - You are being asked to participate in this study to both enhance the extant literature on scientists' use of social media for communication as well as to strengthen the communications efforts by the University of Alberta Faculty of Science.
  - As the Director of Communications for the University of Alberta Faculty of Science, I am interested in effective storytelling about the latest research and teaching innovations by our ~300 faculty members, ~6000 undergraduate students, and roughly ~1200 graduate students. We look at a mix of platforms which includes mainstream media as well as social media, and it is to the latter that I am focusing for this particular project.
  - Contact information was obtained via the University of Alberta website.
  - The study's findings will be used to meet the final requirements of a graduate capstone.

Purpose

- The study's findings will be used to meet the final project requirements for a Master of Arts in Communications and Technology.
- The results will also be incorporated into our communications strategy for the Faculty of Science with the proposed benefit of increasing exposure for our scientists and the work they are producing with the ultimate aim of increasing public engagement with science via social media.
- The results will be framed to help set expectations for scientists considering adoption of social media for science communication.

Study Procedures

- Proposed is semi-structured individual face-to-face interviews. Interviews will be arranged directly with participants based on availability.
- Participant responsibilities will include roughly 60 to 90 minutes for the face-to-face interviews.
- The study will be completed by August 2018.
- Interviewees will be selected based on interest and use of social media.
- Interviewees will be voice-recorded for transcription purposes only.

Benefits

No monetary benefits. There may be no direct benefits. Intrinsic benefits may include contributing to best practices of how colleagues can use social media, to improve personal and professional use of social media, to further advocate for the use of social media by colleagues, to improve Faculty of Science use of social media thereby enhancing institutional reputation.

Risk

The only perceived risk is the use of respondent's' time. It is estimated to take roughly 60 to 90 minutes for individual interviews, with possible follow-up for clarification.

Voluntary Participation

- You are under no obligation to participate in this study. The participation is completely voluntary, and you are not obliged to answer any specific questions even if participating in the study.
- Even if you agree to be in the study you can change your mind and withdraw participation prior to or during the interview.
- You will be provided the opportunity to review transcripts as well as the final report prior to submission to ensure your comfort with all data included. After this review, data may no longer be withdrawn from the study. If there is interest, you may request a copy of the final paper.

Confidentiality & Anonymity

- The research will be used to enhance the Faculty of Science communication strategy as well as the final capping project for a Master's degree.
- You may choose to be personally identified based on your professional practices and uses of social media. Though you may also request anonymity in the data analysis and findings discussion, disclosure of personally identifiable information may enhance research findings.
- Raw data will be kept confidential but will be accessible to the researcher and communications team in the University of Alberta Faculty of Science as well as capstone project supervisor.
- There is also a proposed data management regime to secure all data captured in the study. Data will be digitally stored in a secure location (password protected) for a minimum of five years following completion of research project, subsequently to destroyed in a way that ensures privacy and confidentiality.

Further Information

- If you have further information, please contact Jennifer Pascoe, Director of Communications, University of Alberta Faculty of Science, Jennifer.pascoe@ualberta.ca 780.492.8813
- The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta. For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Consent Statement

I have read this form and the research study has been explained to me. I have been given the opportunity to ask questions and my questions have been answered. If I have additional questions, I have been told whom to contact. I agree to participate in the research study described above and will receive a copy of this consent form. I will receive a copy of this consent form after I sign it.

Participant's Name (printed) and Signature	**Date**
Name (printed) and Signature of Person Obtaining Consent	**Date**

Appendix B: INTERVIEW GUIDE

Preface: (to set interviewee at ease)

- Thank you so much for taking the time to talk with me today about your experiences. I'm really impressed with how you use social media so I'm looking forward to hearing a little more from you about how you do what you do seemingly so successfully. While the interview transcript will remain confidential though some of your answers may appear in the final analysis. I will give you the opportunity to review both to ensure you are comfortable with how the findings are framed. The idea is to deepen understanding of your individual practices so that we can share advice/best practices for other scientists considering adopting social media.

History/Context (as a warm up to the conversation / set the tone):

- How has social media changed science communication?
    - (Probes: speed, reach, removing barriers, increasing access, community conversation)
- What are the opportunities/challenges social media provides as a tool for science communication?
    - (Probes: distilling science into soundbites, audience confusion)

Personal practice (to drill into the how and why as discussed in uses and gratifications):

- When and why did you first start using social media for science communication?
    - (Probes: conferences, peer pressure/communication, to share papers, to clarify misconceptions)
- Which platforms do you use for which purposes (how)?
    - (Probes: When/how often, Twitter for conferences/sharing papers/findings, Facebook for groups, Instagram for field/lab photos, questions/conversation, hashtags/links/emoticons)

Feedback/Consequences (to drill into the positives and negatives that occur as a result of use):

- What are some examples of challenges or successes you've experienced using social media for science communication?
    - (Probes: interest from industry, response from media, engaging conversation with "public"
- How have your peers/students reacted to your use of social media for science communication?
    - (Probes: asked for help to start using tool/encouragement/support, criticism/admonishment/discouragement)
- How do you think you can best be supported administratively to continue using social media for science communication?
    - (Probes: academic recognition, training, policies)
- What motivates you to continue using social media for science communication?
    - (Probes: positive response, global climate, addressing funding agency needs)

Closing:

- Was there anything we didn't cover today that you would like to add?

Appendix C: EMAIL with INTERVIEW PROTOCOL

Dear [research participant],

Thank you for your support of my research exploring why scientists are using social media to communicate. As discussed, I am now following up to arrange an interview with loosely structured, open-ended questions so that I can better understand your use of the tools.

I would like to schedule the interview at your convenience in March or early April prior to the end of the winter term. It will take roughly 60 to 90 minutes. To ensure minimal disruption and maximum efficiency, I suggest we meet in your office. This will also provide us the opportunity to walk through your use of social media tools on your desktop computer and/or mobile device.

In advance, please review the attached informed consent form. While the audio recordings, transcripts, and field notes will remain private and secure, there may be some identifying data in the ultimate analysis based on the pre-existing knowledge of your unique research area and social media presence.

Thank you again in advance for your insight. I am sincerely looking forward to our discussion. In the meantime, please be in touch with any questions.

Wishing you a wonderful day,
Jennifer

Appendix D: Study Participants

Name	Position	Department	Twitter Handle	Twitter Bio	Interview
Andrew Derocher	Professor	Biological Sciences	@AEDerocher	Biological sciences prof @UAlberta. Polar bears have been my main study species for 35 years.	March 26, 2018
Sasha Wilson	Associate Professor	Earth and Atmospheric Sciences	@_SashaWilson_	Biogeochemist working on sustainable mineral resources. Notorious for eating minerals, making rocks out of air. Assoc Prof @The_EEGL @UofA_EAS. Opinions my own.	April 3, 2018
Chris Herd	Professor	Earth and Atmospheric Sciences	@SpaceRockDoc	Meteorite expert and curator, prof at the University of Alberta, Principal Director of ISSET, rec hoops player, kids hoops coach	April 5, 2018
Mike Serpe	Associate Professor	Chemistry	@SerpeGroup	We study the fundamental behavior of polymeric materials, polymer colloids, and photonic materials for a variety of applications.	April 18, 2018
Jillian Buriak	Professor	Chemistry	@JBuriak	Prof. of Chemistry, CRC of Nanomaterials for Energy, UAlberta; Editor-in-Chief of Chemistry of Materials (ACS Publications), running addict. Oh, and mom of two.	April 23, 2018

Appendix E: Overview of Participant Responses to Individual Questions

Question	A Derocher	Sasha Wilson	Chris Herd	Mike Serpe	Jillian Buriak	Overarching
General overview of the field of science communication and social media						
Q1: How has social media changed science communication?	Immediacy Control Accessibility Transparency (demystifies science, communicate results, publicly available, facilitates relationship between scientists and the public)	Opens it up to everyone - democratizing access to all scientists from anywhere	Expectation of communication Public is no longer main consumer Providing gateway to take people back to original research Faster than Table of Contents, a way to flag things to follow up	Easier and broader sharing of information Accessibility Learning of new studies and funding opportunities	Building community beyond niche Humanizing scientists	Speed Access/ accessibility Accountability Gateway Increased info Community Andrew targeting public Others slightly more science-specific
HOW: How mass communication is being used (How scientists are using social media for science communication?)						
Q2a: What are the opportunities social media presents as a tool for science communication?	Pushing back against climate change deniers Images as opportunities to convey more information than text Transition activity Can be quick Feedback on public understanding Profile research, lab, university, students, papers Making research findings publicly	Broader conversation Pitching papers to other scientists Sharing images of natural world to make science more accessible to non-scientists Short snippets of information as gateway to in-depth information and a conversation Can ask questions during fieldwork to help with	Distilling science into elevator pitch or soundbite Access to areas of science beyond immediate discipline Follow the tweet back to the original paper	Technology is easy to use Learning of others doing excellent science and building connections Network expansion Opening up opportunities Faster way to stay on top of science than reading TOCs As a way to get information from other areas of chemistry Recognizing work of students: news,	Fun Exposure to new ideas outside immediate discipline Brings attention to other issues (eg. diversity in STEM)	Immediacy Multiple audiences Useful to distill science down to make it accessible Easy to use Broader perspective Gateway Making science accessible Profile

	available Simplifying argument to essence Contextualizing science Gets powerful new insights from other areas of science he wouldn't normally encounter Easy to use Reports to government as another avenue for information dissemination	real-time science		accomplishments, awards, papers Exposure for research Recruitment Journalists and bloggers who follow him potentially act as conduit to general public		
Q2b: What are the challenges social media presents as a tool for science communication?	Critical negative feedback from climate change deniers Takes time Ephemeral/brevity Anonymity of audience	Can open yourself up to attack if research is politically contentious (climate science)	Getting people's attention can be challenging	Knowing what is appropriate to post / boundary between personal and professional	Takes time Arguments can be emotionally draining Can be susceptible to trolls given that work addresses alternative energy	Time consuming Personal/professional boundary Additional challenges if your science touches on larger societal concerns (like climate change and alternative energy)
Uses: What needs are they looking to satisfy? (What motivates scientists to use social media for science communication?)						
Q3: When and why did you first start using social media for science communication?	Learned via CP reporter that journalist was using climate change denier on Twitter as a source of information and wanted to provide accurate information	Upon recommendation by postdoctoral fellow Gateway to more information Sharing announcements from lab, new research, milestones	Used extensively for annual Lunar and Planetary Science Conference To share what others are doing and comment on the importance as	To show activities and photos of research group as a way to aid in recruitment of new group members	Colleague recommended as an avenue to learn of new research	Profile Influenced by science colleagues and additionally influencing colleagues

	Credibility / Building a science-based case Media reach out after seeing tweets Raises profile of Faculty		a way to establish credibility			
Q4: Which platforms do you use for which purposes?	Twitter for aforementioned reasons	Twitter for aforementioned reasons	Twitter for aforementioned reasons	Twitter for aforementioned reasons Additionally, Facebook lab page for job announcements and photos of group	Twitter for aforementioned reasons Additionally, WeChat for communicating with previous and current Chinese group members	Twitter is the dominant platform, echoing findings in the extant literature
GRATIFICATIONS: How satisfied are they that needs are being met? (What are the consequences [both positive and negative] that occur as a result?)						
Q5a: What successes have you experienced using social media for science communication?	Connection to media who either retweet or follow up Contextualizing science and building credibility with images, data, evidence with simultaneous counter-strategy of "deflating deniers" People indicating support for his science Point of contact with colleagues and beyond Another form of media information	Real-time advice during fieldwork Recruitment of students and postdoctoral fellows	Being retweeted by influential organizations, scientists, media, and Faculty of Science	Funding and speaker opportunities and awards Positive feedback from students and prospective students about photos of life and also research in the lab	Perception of journal as nimble, mobile, responsive, accessible People from beyond science community (#yegbike, politicians, renewables) comment they see her on Twitter. Creation of community of scientists frustrated with government policies as a way to create support for science	Awareness - either becoming aware or others being made aware Community Contextualizing Immediacy Real-time feedback Efforts amplified by others (media, other scientists, funding agencies, Faculty)

Q5b: What challenges have you experienced using social media for science communication?	People voicing dissent Pointless battles with deniers May be talking to people who already support/have understanding Hit and miss Ephemeral platform	Knowing permissions around privacy issues (eg, sharing photos)	Reticence to share ideas before published	Knowing what is appropriate to tweet, shying away from anything controversial	Attacks by trolls, meaning reticence to engage and therefore "retreat to echo chamber" and avoid useful exposure to contradictory opinions as opportunity to hone personal argument	Trolls/battles/ dissenters Knowing when/what is appropriate to share
Q6: How have your peer/students reacted to your use of social media for science communication?	Most peers have been have been positive, though all agree, including Andrew, that Twitter is hit and miss in terms of impact For students, Andrew does not advocate for anything other than peer-reviewed research. If students are active, he advocates professionalism and not letting it take too much time	Some peers, mostly older, have been dismissive. Others have embraced. Students have been very positive, particularly undergrads, who follow and ask questions	Has not had much engagement with campus peers or students and leaves it up students whether they engage	Peers were initially resistant, but now it's the "norm." Students like it as it gives an quick idea of what's going on in the lab both research- and life-wise	Many have joined	Some positive, some neutral, some adopting use because of influence
Q8: What motivates you to continue using social media for	Another form of dissemination Twitter is an accessible way to engage in	Positive experiences Reaching out to a broader community than those physically	Faster (and more fun) way to stay on top of the changes in the field Sharing	It's now the norm Fear of missing out on information If not present,	Social aspect So that you don't miss out on something Important way to	Reaching beyond physical network Necessity Profile for research, lab,

science communication?	outreach and communication	located in same space, connecting with minorities in academia/science Better real-time science (crowdsourcing questions) Team building for lab	published work Works well if done effectively	perception that group isn't active/current/relevant To tell the public what their tax dollars are funding Scientists now need social media to be successful	advertise Edmonton and for the university Can't live without it as a scientist	department, university, city. Community connection Accountability to the public and funding agencies
Administrative support						
Q7: How can you best be supported administratively in your use of social media for science communication?	No financial incentive and not a meaningful academic metric. Could possibly considered as part of "service" Training would possibly be useful but also challenging as professors experience "training fatigue"	Having policy guidelines, particularly as it pertains to personal/professional boundaries Incorporating as part of "service" in the sense of departmental/institutional promotion Training and a community of practice for sharing best practices	Helpful when Faculty amplifies efforts Suggestions/reminders about hashtag initiatives (eg, #museumselfieday, #thinsectionthursday) Social media training, even for those who already using the tools, as a way to build a community of practice	Having the Faculty promote tweets by individual scientists (retweeting and promoting tweets)	Unsure	Guidelines Training/ Tipsheets Amplification of efforts through administrative support Community of Practice Potential consideration as service