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# Examining Canada's Scientific Literacy Through COVID-19 Tweets

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**Abstract**

Scientific misinformation spread on social media is a concern for science communicators, health communicators, and science educators alike. During the COVID-19 pandemic, the World Health Organization (WHO) released a statement that modern technology has created an *infodemic*, undermining the COVID-19 response effort. Misinformation spread online threatens public health and can endanger lives. So how do we combat it? The leading solution is education, in particular, equipping individuals with scientific literacy. Scientific literacy, or the ability to critically evaluate, understand, and make decisions regarding scientific information, is the goal of science curriculums globally. There has been much research over the past couple of decades regarding the usage of scientific literacy in formal learning environments. In contrast, the relationship between scientific literacy and online informal learning environments such as social media is not well understood. Our case study sought to help fill this gap in the research by exploring how Canadians employ scientific literacy on Twitter—a popular social media site—when discussing the COVID-19 pandemic. We conducted an exploratory qualitative case study exploring 2 600 tweets originating from accounts with user locations in Canada and shared on Twitter during the first ten months of the pandemic (March 2020 to December 2020) to see whether and how they displayed scientific literacy. In addition, we examined the trends and factors that affect the usage of scientific literacy online. Using qualitative content analysis techniques and supplemental statistical analysis, we found that 10% of tweets sampled displayed scientific literacy, while 2% did not exhibit scientific literacy. There were no interprovincial differences in how Canadians displayed scientific literacy, with all provinces sampled exhibiting scientific literacy in approximately 10% of tweets. Furthermore, scientific literacy was not affected by how often the user tweeted, how many followers they had, or the month the tweet was shared. We discovered a strong relationship between the tweet's topic and if it displayed scientific literacy or a lack of scientific literacy. Our study provides more insight into how scientific literacy is displayed online. Future researchers can use this as a starting point to conduct studies exploring how scientific literacy is employed in online spaces in different locations and contexts globally.

**Keywords:**

scientific literacy, informal science, social media, COVID-19, science communication, Twitter, Canada, scientific issues

**Summary for Lay Audience**

In recent years, the amount of scientific misinformation on social media has been concerning to researchers, educators, and citizens. The COVID-19 pandemic has only exacerbated the amount of misinformation in online spaces. The question in many individuals' minds is, how do we combat it? The leading solution is to equip individuals with scientific literacy. Scientific literacy refers to the critical thinking skills necessary to navigate, evaluate, understand, and make decisions regarding scientific information. Researchers have studied scientific literacy in classrooms and other traditional education settings for many decades. Unfortunately, less is known about how scientific literacy is used in online environments such as social media. Our study sought to learn more about scientific literacy usage online. We explored how individuals in Canada navigate, discuss, and share information related to the COVID-19 pandemic on Twitter and the use of scientific literacy within these tweets. We also examined what potential factors affect the usage of scientific literacy, such as location, the date the tweet was shared, and the topic. Our study provides further insight into scientific literacy usage online and can inform future studies examining how to combat scientific misinformation on social media.

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## Dedication

This thesis is dedicated to my grandfather, Dr. Paul Dixon.

Our conversations about public science education, physics, and learning at the beginning of my Masters was the spark for my research. Thank you for encouraging me to study physics and science education. I would not be where I am today without you and the rest of my family's support.

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**Chapter 1 – Overview**

Scientific literacy is an important and overarching goal of many stakeholders, including science educators, science education researchers, and policymakers interested in advancing individuals' acquisition of science and science-related knowledge, skills, and dispositions (Lin, 2014; Sadler et al., 2006). It is recognized as essential for individuals to make informed decisions about scientific issues that affect their lives (Garthwaite et al., 2014; Holbrook & Rannikmae, 2009; Roberts & Bybee, 2011). Scientific literacy expands on science literacy. Scientific literacy includes understanding how science is connected to the world around you, the habits of mind, and the confidence to make scientifically informed decisions. Further, scientific literacy includes understanding the nuances of how science and scientific matters are communicated to the public. These skills expand on science literacy which focuses on the understanding of scientific facts, processes, and methods. Science and scientific research are woven into our modern way of life. The National Research Council's National Science Education Standards (NSES) (1996) definition of scientific literacy even goes as far as to state that it is required for "participation in civic and cultural affairs, and economic productivity" (p. 22). Decisions made on scientific issues such as climate change, the opioid epidemic, and vaccinations have the potential to impact society. As such, it is crucial that citizens are equipped with scientific literacy skills to make these complex decisions.

While scientific literacy is and has been an important goal globally for several decades, we must consider how the term's usage has changed with the emergence of new scientific issues and public science resources. Furthermore, it is equally important to investigate how and in what contexts it is used outside of school and other formal education settings.

**Social Media, Science, Scientific Communication**

In the past couple of decades, researchers have seen a rise in the use of the internet to learn about scientific information (Brossard & Scheufele, 2013). Scientific knowledge previously considered "specialized" and difficult to access is now available to anyone via the internet (Peters, 2013). Social media platforms have become popular online resources for people to connect and share ideas and knowledge among themselves with ease compared to traditional media platforms. It allows for multidirectional communication, where individuals can interact with researchers, scientists, and health experts to get clarification and learn more about the information they are seeking. Vital scientific knowledge can be more easily and quickly disseminated through social media than through traditional media (e.g., print and broadcast). Therefore, the internet allows individuals to stay informed about the latest scientific findings and issues, despite the several associated drawbacks.

With the advent of the internet, communicating and consuming information has drastically changed. The unique participatory culture of social media does not exist in traditional news media (Langhans & Lier, 2014). People no longer need to be journalists or experts to share their opinions and ideas about a topic. Moreover, these shared ideas do not have to be factual. This lack of quality assurance has led to the widespread distribution of misinformation or *fake news* online (Sinatra & Lombardi, 2020). The real danger of fake news is that individuals can easily accept these false ideas as facts if they do not have the awareness or motivation to verify the validity of the information being consumed. While some misinformation, like an incorrect Einstein quote, can be harmless, belief in other misinformation, like vaccines can cause autism, can have dire consequences. In terms of scientific information, misinformation about scientific issues that affect society, such as vaccinations and climate change, is concerning. Individual actions and decisions made about these issues can impact the larger community. Scientific issues such as these have social, ethical, and moral implications, causing them to be unnecessarily polarizing. Information presented on social media takes advantage of some individuals' inclinations to be sensationalistic, suspicious of science and government, and uncritical consumers of information. Too often, information is situated in moral and political terms. This phenomenon occurs because consumers tend to pay more attention to the information presented in this format (Feinstein, 2015; Wu et al., 2018). The COVID-19 pandemic demonstrates this phenomenon.

Online media and science communication are complex social phenomena. Researchers have not fully understood the accessible nature of the internet and how it allows for the sharing and propagation of both information and misinformation. Furthermore, there are few to no gatekeepers on social media platforms, thus allowing for any information to be shared, whether factual or not (Zha et al., 2018). The vetting of information is left to the consumer, who may or may not be equipped with the scientific literacy skills required for the job. The comments and conversations occurring in online spaces can also influence the interpretation of the information being read (Brossard & Scheufele, 2013). Scientists and laypersons alike have been increasingly using social media platforms to inform and be informed about important societal issues (Brossard, 2013; Davies & Hara, 2017; Jang et al., 2019; Reid & Norris, 2016). This fact alone makes it essential to understand the nuances of social media platforms and how people are using critical thinking skills, such as scientific literacy when navigating scientific information on social media.

**Countering Misinformation through Scientific Literacy**

In September 2020, the World Health Organization released a statement that cited technology as the cause of the infodemic undermining the COVID-19 response effort (World Health Organization, 2020). Unfortunately, it cannot be left to social media and other internet platforms to shield users from misinformation. Artificial intelligence that examines the veracity and appropriateness of information posted on various platforms is imperfect, sometimes allowing misinformation to remain while taking down legitimate information (Matsakis & Martineau, 2020). Furthermore, manual moderation is costly, time-consuming, and labour intensive. Therefore, social media moderation is a band-aid solution, as it does not address the root of the problem. Well-informed, scientifically literate individuals are the first line of defence to stop misinformation and its harmful effects.

Educational and science communication researchers have recognized that society should be equipped with the skills and education required to address the prolific spread of misinformation. Educational researchers examine different tools and skills that individuals can employ when navigating online information. Traditionally, students have been taught to evaluate the information source (e.g., the website or the account posting said information) to determine if the information is reliable. Sinatra and Lombardi (2020) suggest that the current methods for evaluating sources and information validity are too detached from emotions – especially when information is being framed to align with people's beliefs and feelings. Sinatra and Lombardi (2020) offer an alternative method, *plausibility judgements*, which involves gauging the legitimacy of the information being read using the source's reliability, personal background knowledge, and examining alternative explanations. They call for science teaching to move away from facts and towards the scientific process. Another method educators teach to combat misinformation is incorporating *media literacy* into the science classroom. Media literacy acknowledges the benefits that the internet and other media sources can provide and support individuals with the ability to think critically about what they read, protecting them from misinformation (Reid & Norris, 2016). Many of these skills described by educational researchers appear to overlap with various aspects of scientific literacy. Thus, further amplifying the importance of scientific literacy in arming citizens against misinformation.

Science communication researchers have identified the two primary methods to combat misinformation online: artificial intelligence (AI) in the moderation of online platforms and education. As mentioned previously, researchers acknowledge the imperfection of AI and believe that AI alone cannot cure the infodemic.  The ideal method to end the infodemic is to prepare individuals with the ability to recognize misinformation and prevent it from being shared. Researchers wish to equip individuals with knowledge from science and other fields to navigate the sea of information and become informed members of society (Lee & Campbell, 2020). Educators need to prepare students with the skills required to navigate the growing online world (Lazer et al., 2018). Science communication researchers look at social media users' habits, how they interact with information online, and prevalent misinformation characteristics (Brossard & Scheufele, 2013; Scheufele & Krause, 2019; Yang et al., 2017). By further understanding how individuals interact with information online, they can create targeted campaigns to share scientific knowledge better and help educate individuals on avoiding misinformation online.

In an ever-increasing technologically and scientifically sophisticated world, more than ever, scientific literacy is needed to enable individuals to make informed decisions about scientific issues that affect their lives. Scientific literacy and its importance have been an ongoing discussion among science educators, communicators, and educational researchers alike. We have international assessments, such as the Programme for International Student Assessment (PISA), that provide us with important statistics on school-aged children's level of scientific literacy but none that evaluate adults'. Additionally, many research studies focus on how scientific literacy is developed and used in formal schooling. Unfortunately, less is known about how individuals outside of the formal schooling environment use scientific literacy in their everyday lives, including on social media platforms. Individuals do not stop learning when they leave school. It is a continuous lifelong process. Scientific literacy needs to be continually practiced by individuals when they learn scientific information, no matter the environment or setting. Therefore, how individuals use scientific literacy in their lives needs to be further explored.

With increased access to information, irrelevant of one's educational background, individuals have the autonomy to learn whatever they want, whenever they want. Collecting and synthesizing information from multiple sources and perspectives and learning information through social media and other online platforms can be psychologically demanding (Sinatra & Lombardi, 2020). Incorrect interpretations of important information regarding scientific issues can be detrimental to individuals and society (World Health Organization, 2020a). Research to understand science and health communication in online environments is ongoing, yet it is a relatively new field. Meanwhile, scientists use social media platforms to share their research and knowledge with the larger public (Davies & Hara, 2017).

Social media and online platforms are being incorporated into existing health and disaster communication plans without fully understanding how people relate, consume, and interact with information on these platforms (Zade et al., 2018). All the while, educators work to prepare students to become lifelong learners and independently navigate the world.  At the same time, science communicators call for a better-educated society when interacting with scientific information online. Researchers in a multitude of disciplines are all trying to reach the same goal of having a competent and critical internet user population. Nonetheless, there remains a lack of sufficient empirical research in these areas. Scheufele and Krause (2019) called for a multidisciplinary effort to address this gap in the research.

**Purpose Statement**

The following research study addresses the lack of research on the use of scientific literacy by individuals in online environments, specifically social media. Using Twitter data collected during the initial months of the COVID-19 pandemic, our study examines how individuals navigate a complex scientific issue on Twitter. Our study combined research literature and methods from education, science communication, disaster/crisis communication, and data science fields. Our research aimed to understand how scientific literacy is being expressed in online environments and how these online environments affect this expression. Through an exploratory case study, we explore the following two research questions: (1) What is the nature of scientific literacy usage in Canada on Twitter when navigating, discussing, and disseminating information about the COVID-19 pandemic? (2) What are the trends and factors affecting the usage of scientific literacy in Canada on Twitter?

**Significance of the Study**

We examined a single social media platform, Twitter, during the first ten months (March 2020 to December 2020) of the ongoing COVID-19 pandemic. This study is timely due to the COVID-19 pandemic, further increasing the use of social media by the public to stay connected and share (mis)information during these socially distant times. The COVID-19 pandemic has also increased the need for citizens to understand scientific knowledge and follow public health officials' recommendations. As new scientific information is constantly being presented to the public, individuals must assess and adjust their actions based on the latest scientific research to mitigate the danger posed by the virus and its variants. Many citizens are receiving this information through online sources. The current pandemic has even been called the “First Social Media Pandemic” due to the concurrent, prevalent use of social media (Rosenberg et al., 2020). Misinformation has also been more widespread than ever, becoming increasingly more complex and challenging to recognize.

We began developing this research project before the beginning of the pandemic. COVID-19 provided us with the perfect case to examine the use of scientific literacy online regarding scientific issues. We adopted our research study to take advantage of this. Furthermore, we chose to investigate Canadian tweets since the Canadian context offers us a specific and unique perspective undergirded by Canada's socio-demographic, educational, and political fabric. Examining Canadian tweets also allows us to narrow the scope of the research to a specific, well-defined geographic/political landscape so that results from the study can be related to and associated with factors unique to the Canadian context. For example, the Canadian government, media, and citizens have had different approaches to combat the pandemic than the United States and elsewhere. Thus, it is essential to examine the various contexts individually when examining context-specific issues, such as the pandemic. Assertions made in our study can be connected to the Canadian policies related to education, media literacy, and science communication. Finally, we chose to examine Twitter to limit the scope of our research project because Twitter provides us with open access to its data. These elements built our case study and helped determine our research methods to address our research questions.

**Positionality**

In the first year of my Physics undergraduate degree, one of my professors explained the nature of scientific theories. For example, they said that a theory, such as Einstein's theory of general relativity, can never be proven, only disproven. The theories that we use are the most accurate explanations and substantiated by the evidence we have but are not infallible. Everything in science has the potential to be disproven, including well-established theories and facts. In 2016, the Laser Interferometer Gravitational-Wave Observatory (LIGO) experiments detected gravitational waves, adding further evidence to general relativity theory (Ananthaswamy, 2019). However, research at the quantum level has exposed gaps in Einstein's theory (Hamer, 2019) and has prompted the elusive quantum gravity search. Demonstrating that the theory of general relativity cannot fully explain gravity everywhere in the universe, but it remains the most accurate and current explanation of gravity. Understanding the nature of scientific theories has shaped how I view science and the world. As a society and individuals, we form ideas and create different ways of thinking that are the best explanations of the phenomenon we experience, based on all the evidence we encounter. As we are introduced to new evidence that may create fissures in our explanations, we can revise our ideas and create new ones. Understandings and explanations may also differ depending on the types of evidence and experience of the society or individual.

Learners come into every new situation with pre-conceived ideas, no matter how unfamiliar they are with the phenomena. They base these preconceived notions on their previous learning and experiences (Danver, 2016). Learners' prior knowledge, experience, and personal contexts play an essential role in their learning. They build upon this prior knowledge to construct new ideas and understanding (Danver, 2016; L. Lin, 2015). Brookfield (2017) posits that adults' self-directed learning is powerfully affected by their background and can be constrained by it, thus, emphasizing the importance of considering a learner's historical, social, and cultural contexts. Vygotsky's theory of social constructivism explains this process of learning. Social constructivism suggests that learners use prior knowledge to construct new knowledge through social interactions with others in their localized cultural, societal, and historical contexts (Danver, 2016; Ebbers, 2017; Pricopie, 2020). In doing so, learners interact and work together to create meaning within their own social and cultural groups (Brookfield, 2017).

Educational researchers who examined the use of scientific issues in the classroom have identified that the practice is rooted in progressive pedagogy, or more specifically, social constructivist, sociocultural, and situative learning theories (Lee et al., 2019; Lindahl et al., 2019; Robottom, 2012; Sadler, 2009; Sadler & Zeidler, 2005). These theories are all based on the idea that learning about scientific issues experienced in everyday life is social and collaborative. Our research study expands on the research of scientific issues and literacy in classrooms by examining adults' use of these concepts in informal learning environments. People use language to connect, interpret, and exchange information on social media platforms. Under the theory of social constructivism, one of the most critical and central tools used to construct knowledge is language. Humans use communication and language to connect, create, and communicate meanings of things in the metaphysical and physical worlds (Leeds-Hurwitz, 2009; Pricopie, 2020). In the modern age, this process continues to be used in online spaces.

We use social constructivism and its tenants of how learning is shaped through social interactions throughout one's lifetime as the theoretical framework for this study. This study examines social media, which is inherently designed to share information in a social setting and form meaning through peer-to-peer interaction. Furthermore, it explores how people use scientific literacy and their previous scientific knowledge to make sense of new information, thus, making social constructivism a fitting choice for this study's theoretical framework.

**Study Overview**

Our case study began with an exhaustive literature search of scientific literacy definitions and competencies. It examined the similarities and differences between scientific and science literacy and their various definitions. Following this, we developed a working definition of scientific literacy for this study. The remaining sections of the literature review analyze and synthesize current science and health communication research, focusing on online environments. Our methodology used in this study is laid out in the third chapter of this paper. The third chapter includes our chosen delimitations, such as tweets only from Canada, the period of March 2020 – December 2020, specific hashtags collected, and the language of tweets. Following the methodology, we present and discuss our findings. Finally, concluding with a discussion of our study's limitations, future directions, and significance.

# Chapter 2 – Literature Review

This literature review aims to cover two significant areas of literature pertaining to this research regarding Canada's usage of scientific literacy on Twitter. The first section briefly reviews prevailing literature on scientific literacy, focusing on the term's varied definitions and use. Helped by the literature, we then present our operational definition to guide our work. Building on an overview of commonly referenced reports and sources from Canadian and international curriculum documents and peer-reviewed journal articles, we will highlight common themes from different visions of scientific literacy and then develop the definition employed in this research. The second section reviews the current research literature relating to science communication and online media. This section begins with a broad overview of the literature before narrowing the focus to the COVID-19 pandemic and the social media platform Twitter.

## Scientific Literacy

It is essential to define what we refer to as scientific literacy before looking for its usage in online environments. While widely used globally in education literature and curriculum documents, there remains a lack of commonly accepted definition of scientific literacy (Fives et al., 2014; Gormally et al., 2012; Holbrook & Rannikmae, 2009; Naganuma, 2017). Roberts (2013) describes scientific literacy as an "umbrella concept," which is used throughout science curricula to reference a variety of knowledge types, skillsets, and competencies. The broadness of the term has subsequently made it problematic to formulate a simple definition (Holbrook & Rannikmae, 2009) and develop tools for assessing scientific literacy (Fives et al., 2014). As scientific literacy is used within the context of society and individuals within it, it is expected that varying definitions and usages of the term exist. Therefore, it is not as essential to have a universal definition of scientific literacy as it is for scholars and researchers to define scientific literacy within the socio-cultural milieu of their research.

While scientific literacy usage is broad in both the research literature and curriculum documents, many definitions describe the same competencies required of a scientifically literate person. For example, the research literature states that a scientifically literate individual must understand scientific concepts (e.g., the water cycle, digestive system, and how plants make food). However, the same literature does not always delineate these scientific concepts. Due to the ambiguities and nuances in the various definitions, we cannot assume that there would be consistency in the way readers interpret the meaning of scientific literacy. Similarly, if the goal of the curriculum is to teach scientific literacy, curriculum documents must describe the specific knowledge, skills and depositions that make up scientific literacy.

The aforementioned ambiguity motivates spending a good portion of this chapter defining scientific literacy. We will be determining the difference between science and scientific literacy in this study, reviewing commonly referenced sources scholars and curriculums use when describing scientific literacy, and examining common themes found in descriptions of scientific literacy. Afterwards, we will introduce a working definition of scientific literacy for this study. Documents and articles reviewed in these sections span the last 21 years (2000 – present). We only examined literature written before 2000 if multiple reports referenced it. Source types include research papers focused on developing a definition/understanding of scientific literacy or a scale to measure scientific literacy, Canadian curriculum documents, and documents from various science education stakeholder organizations (e.g., AAAS, OCED, STAO).

***Scientific Literacy vs. Science Literacy***

A complexity we encountered when defining and understanding the definition of scientific literacy is the usage of the term similar yet different term *science literacy* within the field of science education. Some authors and curriculum documents use scientific and science literacy interchangeably, while others refer to them as two different competencies. The usage of both terms depends on the author/publisher’s dialect and the time and place its usage was documented. For instance, the American Association for Advancement of Science (AAAS) exclusively uses science literacy in its Project 2061 documents (AAAS, 2020; Roberts & Bybee, 2014), potentially causing an increased usage of the term in the United States. Conversely, other international documents, such as those in Canada (Council of Ministers of Education, 1997a) and Europe (Millar, 2006; OECD, 2019), have a clear preference for scientific literacy. A rationale for this preference in Canadian provincial curriculum documents may be its usage in the Pan-Canadian curriculum document (Council of Ministers of Education, 1997a). The Pan-Canadian curriculum documents serve as a national framework that provincial departments and ministries of education utilize to guide the development of their curriculum documents (Science Co-ordinators’ and Consultants’ Association of Ontario (SCCAO) & Science Teachers’ Association of Ontario (STAO/APSO), 2006).

Further, the period when a piece of literature is written also influences the usage of the terms. For example, Roberts’ (2013) article "Scientific/Science Literacy," initially published in 2007, used the two words interchangeably, referring to them both using the acronym “SL.” In a more recent article titled "Scientific Literacy, Science Literacy, and Science Education," Roberts and Bybee (2014) clearly state that "Science literacy is not the same as scientific literacy" (pg. 545). This evolution in the terms’ usage suggests a change in perspective by Roberts and many others. Finally, educational studies, journal articles, and curriculum documents predominantly use scientific literacy. In contrast, the readings examined from the journal *Nature* (Corner, 2012; Feinstein et al., 2013; Kahan et al., 2012; Macilwain, 1995; McCaffrey & Rosenau, 2012) typically lean towards using the term science literacy. Even among the *Nature* articles, there remains ambiguity around what science literacy refers to, as demonstrated by the debate around Kahan et al.'s (2012) study. Kahan and colleagues’ (2012) study found that people with higher degrees of science literacy were more skeptical about climate change risk. However, the definition of scientific literacy used in their study has been debated by other researchers.

Consistent with the Roberts and Bybee (2014) paper, several researchers argue that scientific literacy and science literacy are different. For example, Holbrook and Rannikmae (2009) and Maienschein (1998) suggest that science literacy refers to what we traditionally think of as *school science* or knowing specific science facts and skills. In contrast, scientific literacy, or civic scientific literacy, refers to the knowledge and critical thinking skills required to understand science in everyday life to make informed decisions (Naganuma, 2017). These two separate definitions align with Roberts's (2013) two visions of scientific literacy, which we will review in-depth later in this chapter. Since this study takes place in a Canadian context, we followed the Pan-Canadian curriculum's usage of scientific literacy. We refer to scientific literacy and science literacy as two separate terms.

### ***Commonly Referenced Sources***

A research literature review revealed that researchers commonly cite 'standard' definitions for scientific literacy from a few well-known documents. Noteworthily, these commonly referenced documents all endorse the notion that scientific literacy refers to understanding and learning about science in everyday life. This idea contrasts with what is typically described as school science which is regularly characterized as the rote memorization and retrieval of facts about science. A complete list of commonly cited sources and their description of scientific literacy can be found in Table 1**.**

Roberts's (2013) paper "Scientific/Science Literacy" is one of these commonly cited definitions. Roberts describes "two visions" of scientific literacy. Roberts' Vision I of scientific literacy is what some scholars refer to as science literacy or school science (Roberts & Bybee, 2014). This vision relates to the foundations of science and the understanding of science content itself (Naganuma, 2017; Roberts, 2013; Roberts & Bybee, 2014; Romine et al., 2017). Vision 2 refers to what scholars often identify as scientific literacy or how science interacts with society and human endeavours (Roberts & Bybee, 2014). Roberts' visions of scientific literacy were included and considered in this paper's scientific literacy operational definitions of scientific literacy.

**Table 1**

*Commonly Cited Definitions of Scientific Literacy*

| Source | Description of Scientific Literacy |
| --- | --- |
| Roberts & Bybee (2011) pg.546 | Two broad visions of scientific literacy.<br><br>"Vision I looks inward at science, to build curriculum from its rich and well-established array of techniques and methods, habits of mind, and well-tested explanations for the events and objects of the natural world."<br><br>"Vision II … begins by looking outside science to build curriculum that illuminates how science permeates and interacts with many areas of human endeavor and life situations." |
| PISA (2015/2018)<br><br>(OECD, 2019, pp. 100–101) | "Scientific literacy is the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen.<br><br>A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology which requires the competencies of:<br><br>• **Explaining phenomena scientifically:** Recognising, offering, and evaluating explanations for a range of natural and technological phenomena.<br><br>• **Evaluating and designing scientific enquiry:** Describing and appraising scientific investigations and proposing ways of addressing questions scientifically.<br><br>• **Interpreting data and evidence scientifically:** Analysing and evaluating data, claims and arguments in a variety of representations and drawing appropriate scientific conclusions." |
| National Science Education Standards<br><br>(National Research Council, 1996, p. 22) | "Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. […] Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately." |
| Pan-Canadian Curriculum<br><br>(Council of Ministers of Education, 1997b, sec. 2) | "Scientific literacy is an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them." |

One of many researchers' primary sources for scientific literacy definitions is PISA documentation created by the Organization for Economic Co-operation and Development (OECD). Every three years, the PISA assessment occurs in OCED member countries and assesses students' reading, mathematics, and science knowledge (OCED, 2021). In the OECD's PISA 2018 Science Framework, there is an emphasis on scientific literacy as a "key competency" that "is broad and applied" and is not just a knowledge of science concepts and theories but an understanding of how science is applied in real-world contexts (OECD, 2019, p. 98).

Since 2000, when PISA began, scientific literacy has been the science assessments focus. The current definition of scientific literacy used by PISA was first published in PISA 2015 Framework. The previous version of the definition of scientific literacy first appeared in the PISA 2006 framework. Scholars have noted that the current definition shifted away from the 2006 version's focus on the foundation of science and its concepts. The 2015 description is a broader definition focusing on procedural and epistemic knowledge (Roberts & Bybee, 2014). Specifically, it describes how students apply science in the real world versus just knowing scientific concepts. In the most recent 2018 assessment, the OCED switched from using the term science literacy to scientific literacy. The PISA 2018 Science Framework states that this change "underscores the importance that the PISA science assessment places on the application of scientific knowledge in the context of real-world situations" (OECD, 2019, p. 101). Since PISA is an internationally used assessment, researchers often base their definition on or consider OCED's description of scientific literacy (Garthwaite et al., 2014; Naganuma, 2017; Roberts & Bybee, 2014; Rusilowati et al., 2016; Widayoko et al., 2019). We also considered the OCED's definition of scientific literacy when creating our operational definition of scientific literacy.

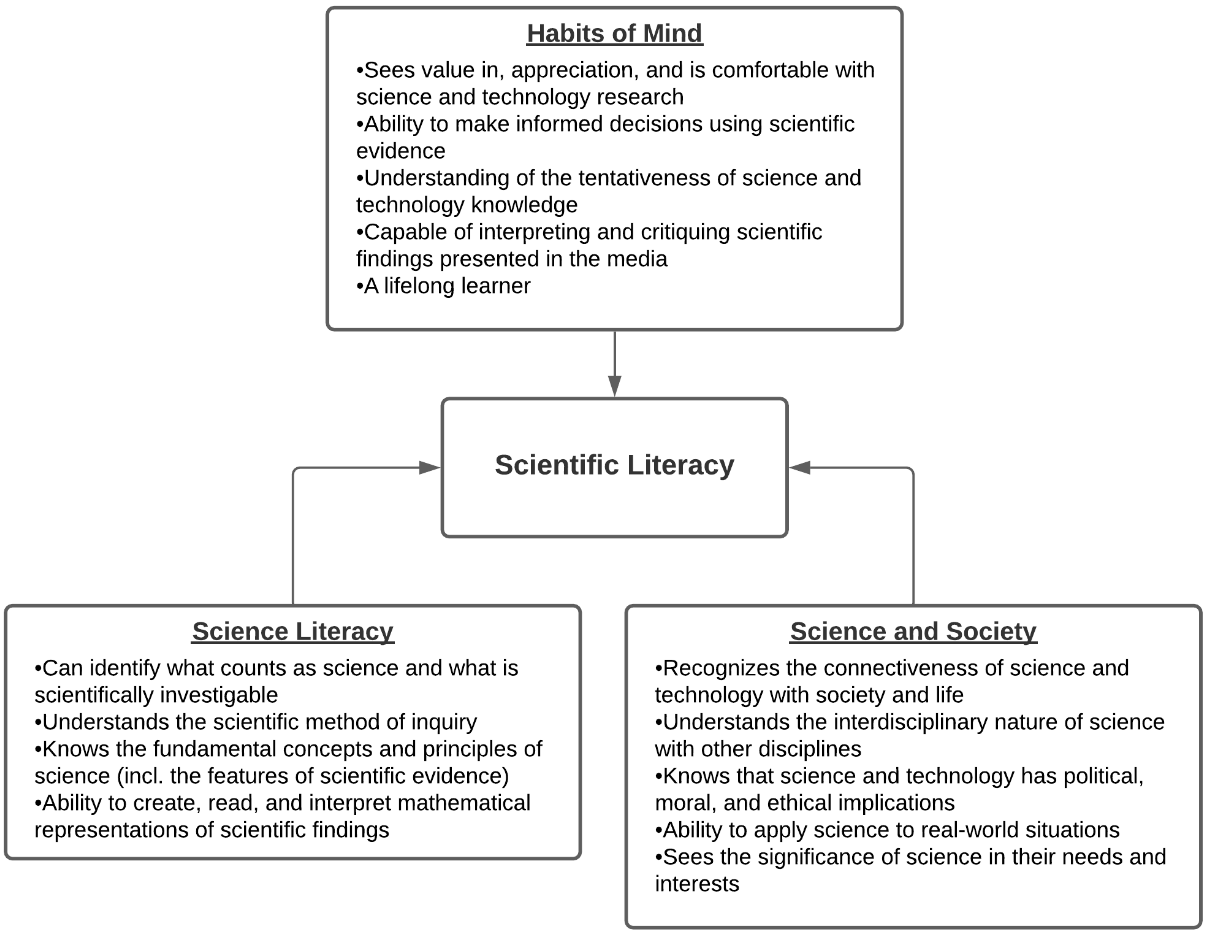
A third commonly referenced document by both researchers and curriculums is the United State's National Science Education Standards (NSES), published by the National Research Council (NRC) (National Research Council, 1996). K-12 science curriculums in the United States use this document as a guide. The NSES is referenced by the Pan-Canadian curriculum documents (Council of Ministers of Education, 1997a), the United States' Framework for K-12 Science Education (National Academy of Sciences, 2012), the Next Generation Science Standards (Next Generation Science Standards, 2013), and by Roberts (2013) and Roberts and Bybee (2014). Their scientific literacy definition focuses less on knowing scientific concepts and more on applying scientific skills and practices in everyday life (National Research Council, 1996).

### ***Scientific Literacy Themes***

Following a thorough literature review outlined in the following sections, we have defined scientific literacy through three overarching themes. We have chosen three themes to group scientific literacy competencies: *Habits of Mind, Science and Society, and Science Literacy*. The three themes of scientific literacy are interconnected with one another – they work together, with each of the competencies described in one theme supporting competencies in the other two. Scientific literacy is the combination and intersection of the competencies categorized by habits of mind, science and society, and scientific literacy.

**Figure 1**

*Traits of a Scientifically Literate Person (3 Themes)*




**Habits of Mind**

A key component to being scientifically literate is having the habits of mind. Before someone can apply the science skills they have learned to solve problems in everyday life, they first need to understand the value of those skills when solving such science-related problems (Fives et al., 2014). As previously discussed, scientific literacy goes beyond just knowing science. Thus, being scientifically literate does not merely revolve around completing and excelling in classroom activities, assignments, and formal examinations. Instead, scientific literacy involves having the skills, attitudes, and dispositions to think scientifically in formal and informal settings and to apply these temperaments in the real world

(Adeleke & Joshua, 2015; Mun et al., 2015; National Research Council, 1996). More specifically, scientifically literate individuals can make informed decisions about issues that affect them and their everyday lives.

A person must have the ability to make evidence-based conclusions to make decisions about issues that directly affect them (Garthwaite et al., 2014; Holbrook & Rannikmae, 2009; Roberts & Bybee, 2014). Multiple curriculum documents highlight this skill. One example is NSES's (1996) definition which highlights the requirement of scientific literacy for personal decision-making. The NSES (1996) states that "scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed' (pg. 22). The Pan-Canadian curriculum's (1997b) definition echoes this sentiment: "scientific literacy is an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities" (Council of Ministers of Education, 1997a, Chapter 2. A vision for scientific literacy in Canada). As well in Millar's (2006) examination of the Twenty-First Century Science project in the UK, that "scientific literacy includes the knowledge and understanding needed to use [scientific knowledge] safely and effectively, or to make better-informed decisions about whether or not to use [scientific knowledge]" (pg. 1508). All these emphasize the importance of scientific literacy to everyday decision-making.

An individual must have relevant disciplinary knowledge and enough trust and appreciation of science to use scientific information in personal decision-making (Holbrook & Rannikmae, 2009; Roberts & Bybee, 2014).  Further, one must understand that science is dynamic (Holbrook & Rannikmae, 2009); thus, scientifically literate individuals know that they should use new evidence to modify their understanding and knowledge of the physical world. The COVID-19 pandemic, for instance, highlights the importance of this process. More recent and accurate scientific evidence guides governmental recommendations as we learn more about the COVID-19 virus and its variants.

To be comfortable with science, understand its tentativeness, and employ it in decision-making, individuals must make sense of the scientific information they read. According to the National Science Teaching Association, “science is a human endeavour” (2020, sec. Declarations). Therefore, subjective interpretation is unavoidable. Consequently, a scientifically literate person must have a “critical attitude” (Naganuma, 2017, p. 304), which is the ability to interpret, critique, and be skeptical of scientific findings that are included or omitted in reports (Gillies, 2020; Mun et al., 2015; Roberts, 2013; Science Co-ordinators’ and Consultants’ Association of Ontario (SCCAO) & Science Teachers’ Association of Ontario (STAO/APSO), 2006). This is because most individuals do not receive scientific information in its purest form. Instead, mass media interprets information and subsequently disseminates it to the public.

Further, the average person does not subscribe to scientific journals and cannot accurately remain informed with the latest findings (Reid & Norris, 2016). The Science and Media in the Digital Age section of this chapter will further discuss this phenomenon. However, we bring this point up here because understanding science in the news is another essential skill for a scientifically literate person. This skill is also often referred to as *Science Media Literacy,* defined as the ability to understand science in the media (Fives et al., 2014). This skill is vital because science in the media has a different presentation style and intention than science classes, textbooks, or journal articles that present science (Rundgren et al., 2012).

To evaluate media claims, one must use critical thinking skills and the knowledge that science is highly connected with human endeavours. The notion that individuals should be critical of the information presented to them is not meant to encourage individuals to reject that information or develop conspiracy theories. Instead, individuals are encouraged to examine what information is being presented, consider whether some information was omitted, identify possible sources of bias, determine the reputation and credibility of the source of the information and the level of scientific rigour to which the information has been subjected.

Finally, if not most importantly, having the habits of mind required to be scientifically literate stipulates that individuals be lifelong learners. People will continue to engage in scientific information after graduation from formal educational institutions and throughout their lives in informal settings. Hence, they should retain the metacognition, skills, attitudes, and knowledge they require to make informed personal decisions.

**Science and Society**

Science and technology are intrinsically connected and vital to society to the extent that they allow us to understand the physical world. A scientifically literate person recognizes this interconnectedness. Science is not encountered in isolation but within personal, societal, and global perspectives (Roberts & Bybee, 2014). An increasingly prevalent theme in curriculum documents and research literature addressing scientific literacy is the idea that science should be considered in the context of everyday life. Indeed, science education has shifted from learning science solely in isolation to relating it to the real world. This shift is seen in issues-based curricular approaches (Holbrook & Rannikmae, 2009), situated learning (Sadler, 2009), and other emerging teaching pedagogies.

The PISA and AAAS definitions of scientific literacy stress the importance of understanding that scientific knowledge occurs in personal and social contexts (AAAS, 2009; Naganuma, 2017; OECD, 2019). Other educational programs reflect this importance, such as Twenty-First Century Science (Roberts & Bybee, 2014) and the Pan-Canadian curriculum (Council of Ministers of Education, 1997a). Furthermore, as science is a human endeavour, it is also embedded in other human initiatives (Holbrook & Rannikmae, 2009). Science is an interdisciplinary field with connections to the arts, humanities, history, and other areas. Science pulls knowledge from various social studies and vice versa (McComas et al., 2002). Hence, just as scientifically literate people recognize science's interconnectivity with the world, they also understand its interdisciplinary nature.

A recurring theme throughout this and other research literature is that scientific literacy provides a person with the necessary skillset for making intelligent, informed personal and societal (public) decisions that have implications for their and others' lives (Hazelkorn et al., 2015; Millar, 2006; Ministry of Education, 2007; National Academy of Sciences, 2012; National Research Council, 1996). Holbrook & Rannikmae's (2009) paper, "The Meaning of Scientific Literacy," examined multiple educational documents that attempted to define scientific literacy. All the documents they reviewed contained a reference to the concept of scientific literacy for citizenship. This idea aligns with the aims of school science to prepare students for what they will encounter later in their lives (Adeleke & Joshua, 2015). Further, Roberts' (2014) Vision II of scientific literacy addresses scientific literacy as essential for society, referring to it as "science for citizenship" (2014, p. 546). Vision II takes a broader look at science when exploring scientific information, considering both the scientific and non-scientific perspectives.

Similarly, Fives et al. (2014) suggest that scientific literacy constructs include the ability to bring a balanced perspective to decision-making and understanding of the role of science during this process. The National Science Teacher's Association (Holbrook & Rannikmae, 2009) states that a scientifically literate person engages in responsible personal and civic action. The papers discussed demonstrate a prevalent belief that the function and purpose of scientific literacy has to do with making informed and intelligent decisions with the understanding that our lives, the society in which we live, and the physical world are intertwined.

Science learnt in school, and other formal educational settings can be detached from real-world applications, particularly science's implications on politics, morality, and ethics (Holbrook & Rannikmae, 2009). A scientifically literate person acknowledges these various implications of science. They consider the scientific evidence and the connections within societal contexts and apply these considerations when participating in discussions and making decisions about relevant scientific issues (Adeleke & Joshua, 2015; Gillies, 2020; OECD, 2019; Roberts & Bybee, 2014).

The skills (see Figure 1) categorized under Science and Society focus on science in the context of citizenship. The specific scientific facts and concepts needed for citizenship are fluid and depend on the individual's social and cultural background and societal context. Nonetheless, individuals can only be scientifically literate citizens if they understand what science is and what it is not. Procuring these rudimentary concepts is embedded within the third and final theme, Science Literacy

**Science Literacy**

Science literacy refers to scientific knowledge and understanding of scientific processes in our research. Colloquially, science literacy is often referred to as school science. The first two themes focused on having the motivation and ability to apply and understand scientific knowledge in everyday life. In addition to the first two themes, one must have a solid understanding of scientific processes, what counts as science, and knowledge of basic scientific facts to be scientifically literate (Holbrook & Rannikmae, 2009). Roberts' (2013; 2014) Vision I focuses on this aspect of scientific literacy: the foundations of science and understanding scientific knowledge itself. Early concepts of scientific literacy concentrated on this aspect of science disciplinary knowledge (Mun et al., 2015).

Science literacy, described here, centers on basic scientific concepts and understanding constituent theories and methods (Ministry of Education, 2007; Roberts & Bybee, 2014). One of the critical skills under this theme is recognizing what counts as science and distinguishing it from non-science (Holbrook & Rannikmae, 2009). Likewise is the ability to identify scientifically investigable questions and propose procedures to evaluate these questions using scientific methods (OECD, 2019). One must know the fundamental concepts, theories, principles, and standard practices that underpin scientific research and knowledge (Gormally et al., 2012; Naganuma, 2017; OECD, 2019). Understanding the scientific method is essential for evaluating scientific information encountered in everyday life. The *Ontario Science Curriculum Grade 1-8* (Ministry of Education, 2007) highlights this by stating that students should retain the "big ideas" (pg. 6) of science long after forgetting the details of what was studied.

All these skills and understandings are taught in conjunction with scientific material itself. The question that remains is: what scientific concepts are essential for a scientifically literate person to know and understand? Due to science and technology's fluidity, creating or finding a universal list of scientific content knowledge is not possible. We came across no scientific literacy definition that provided a list of the content required to be scientifically literate. Curriculums that delineate this content are created regionally because the relative importance of scientific concepts depends on regional, social, and cultural contexts. Therefore, scientifically literate individuals worldwide would not know the same science content, but they would possess the skills described in our three themes. The main competency in the science literacy theme is that individuals formally learn the foundational scientific knowledge, skills, and dispositions, which they then build upon in their continued, independent learning of science throughout their lives

***Working Definition of Scientific Literacy***

While conceptually, the "idea" of scientific literacy may seem sufficiently straightforward, as we have seen above, the conceptualization and definition of scientific literacy can be complex since the term is situated within the socio-politico-cultural milieu of human existence. This complexity is further demonstrated in the previous section, Themes of Scientific Literacy, and the number of competencies scientifically literate individuals should possess. Scientific literacy is also context-dependent and, therefore, can vary. For this study, we have created an operational definition of what it means to be scientifically literate. This definition provides an overview of the skills and competencies important for scientific literacy based on the literature. Our study will be referencing both the following operational definition and the more detailed thematic outline described in this literature review section.

Scientific literacy encompasses three main traits. First, the habits of mind required to be comfortable with, continue learning, and critique scientific issues which appear in everyday life (e.g., in the media). This also includes the ability to make informed democratic decisions regarding scientific issues. Second is the ability to recognize the interconnectedness of science and society, understand the moral, political, and ethical implications of science, and apply science to real-world decision-making. Third is science literacy, the ability to identify what counts as science, know the key concepts and principles of science, and understand the nature of science.

**Science and Media in the Digital Age**

Over the past two decades, online media associated with the digital age has changed our everyday lives and the way we communicate with each other. The internet has a constant presence in everyday life. We use it to communicate via email, stay updated with the latest news, listen to music, speak to friends and family, and more. Online media has allowed us to share information and connect with hundreds of individuals at a time from around the world. People's daily lives have changed drastically due to online media (Dani et al., 2010).

For instance, traditional media is considered unidirectional, where information flows in one direction to the public (Langhans & Lier, 2014). In contrast, the internet enables quick, widespread broadcasting and circulation of information in a multi-directional fashion. The internet provides easy access to and the ability to share information. In social media platforms such as Facebook and Twitter, the participatory culture model enables people to share and engage with others their thoughts, opinions, and assertions. For these reasons, the internet has facilitated the conception and propagation of multi-directional communication (Houston et al., 2015; Langhans & Lier, 2014)—a decentralized publishing process that allows for more citizen journalism (McIntyre, 2018).

The multi-directionality of information flow on social media can be problematic since the boundaries between fact, fiction, and opinion are often blurry (Brossard, 2013). Further, social media lacks gatekeepers (quality assurance mechanisms) that traditional media generally have to guard against misinformation and distortion of facts (Zha et al., 2018). For example, anyone can share thoughts, news, or information on social media. While it is easy to share truthful information, the opposite is also true. Due to the widespread access to the internet, nearly anyone can consume and produce content. Consequently, the quality and credibility of information on the internet generally tend to show significant variability compared to traditional media outlets (Langhans & Lier, 2014; Lazer et al., 2018). The lines between fact and opinion are also blurred due to the multi-directional communication in online environments (Brossard, 2013).

The lack of quality assurance in online spaces has helped increase the spread of online misinformation. A type of misinformation –called disinformation or *fake news* occurs when false information is intentionally disseminated (Sinatra & Lombardi, 2020). The spread of disinformation has risen in tandem with individuals' ability to access, consume, produce, and distribute information over the internet (McIntyre, 2018). Thus, it is not a surprise that the prevalence of disinformation production and consumption in our times is aptly called the *post-truth* era. The post truth era is a period which, according to Sinatra and Lombardi (2020), is characterized by people having inclinations to "disagree about evidence-based facts and rely on more personal beliefs and feelings rather than validated knowledge" (p. 2). Increases in disinformation online warrant the promotion of vetting processes of social media platforms to determine the credibility of shared information (Langhans & Lier, 2014; Lazer et al., 2018).

Moreover, these issues are not isolated to individuals using social media. Mainstream media sources such as news channels and newspapers are influenced by many of the same factors that social media is. Traditional news sources are moving online, and the boundary between social and mainstream media is blurring (Brossard, 2013; Rubin, 2016). Researchers have proposed several methods to limit the spread of disinformation online. These include empowering individuals to recognize disinformation through education (McIntyre, 2018; Scheufele & Krause, 2019) and flagging, filtering out, and blocking disinformation on major social media platforms using artificial intelligence, human content monitors, and fact-checkers.

***Online Science Communication***

Researchers from all fields are increasingly using social media platforms to disseminate their research to the public (Davies & Hara, 2017; Jang et al., 2017; Miller & Pardo, 2005). Concurrently, individuals rely heavily on these platforms to learn and make decisions about scientific issues which directly and indirectly affect them (Brossard, 2013; Reid & Norris, 2016). Indeed, the internet has augmented another dimension to science's public visibility (Jang et al., 2019) and empowered individuals of all educational backgrounds to learn about what was once referred to as "special knowledge" (Peters, 2013, p. 14103). The widespread propagation of science disinformation on social media platforms only undermines individuals' ability to effectively learn and make informed decisions important to them and the larger society.

How and where individuals get their information matters, as it can shape their perceptions and attitudes about scientific issues (Brossard, 2013; Wu et al., 2018). While many individuals get their information from various sources, including traditional and non-traditional media sources, including social media, a good portion of the public relies solely on social media platforms to get their information. However, in attempts to generate revenue and compete with social media's popularity and widespread usage, even traditional media sources tend to fall into the trap of populism by appealing to media consumers' appetite for reinforcing their personal beliefs and emotions. Further, it is imperative to note that science media content is often not communicated to the public by scientists but rather by journalists. Over the past decade, news outlets have allowed debates during which equal weight to both sides of controversial scientific arguments are presented. McIntyre (2018) suggests that news outlets do so to appear objective on such issues and not impose one stance on their viewers. While scientific debates may be fruitful, these debates often occur with non-expert members of the public regarding widely accepted scientific knowledge (Reid & Norris, 2016), such as with controversy around climate change (Fischer, 2014). Jang et al. (2019) describe this "journalist balance" as a "false balance" (p.111) because the erroneous portrayal of information that is widely accepted within the scientific community as debatable can hinder public acceptance of that information. Individuals are more likely to accept ideas that align with their beliefs and are unlikely to authenticate the information they encounter unless it contradicts their preconceptions (Lazer et al., 2018; Scheufele & Krause, 2019). Individuals are even more susceptible to scientific disinformation when they have no stance on the topic (Sinatra & Lombardi, 2020). These occurrences highlight the importance of and need for the science literacy portion of our operational definition of scientific literacy. A good foundation of basic scientific knowledge and processes aids in understanding new scientific concepts. Science communication experts must consider how journalism shapes individuals' learning and affects their understanding of scientific concepts (Maier et al., 2014). Further, recognizing the breadth of scientific literacy and the social and cultural contexts within a given society is important before communicating scientific information (Feinstein, 2015; Scheufele & Krause, 2019).

Online information is interconnected and creates a non-linear learning space (Brossard, 2013). Information on social media is consumed in conjunction with the comments and the respective tone of fellow information consumers (Brossard, 2013). Interactions can sometimes overshadow the quality of information presented (Scheufele & Krause, 2019). Hyperlinks are also a key feature of online communication. Information on the internet is interconnected, presenting a challenge to information consumers when learning online. Reading information in this context requires the ability to read and synthesize information from multiple sources. This process takes time and can be psychologically demanding (Sinatra & Lombardi, 2020). However, interconnectivity is not entirely a disadvantage. Some school-aged students have started to use social media to engage with each other and benefit from collaborative learning (Greenhow & Lewin, 2016).

Social media creates a space tailored to each user—algorithms on social media work to keep you on the site. These algorithms can influence what information you receive (Brossard, 2013). Your social media can become homogeneous, reducing the number of alternate views you encounter (Lazer et al., 2018). For example, suppose you believe that climate change does not exist and continue interacting with others and information that agrees with this stance. You will eventually rarely be shown information that conflicts with your ideas. People can opt to read only belief-consistent information (Scheufele & Krause, 2019), creating an “echo chamber” effect on their social media (McIntyre, 2018). This makes it difficult to determine which scientific information is trustworthy (Maier et al., 2014). Furthermore, people are more likely to accept messages as accurate instead of assuming it is misinformation; this is called “truth bias” (Rubin, 2016, p. 345). Therefore, it is important to consider how algorithms affect the scientific information received by the public (Brossard, 2013).

Overall, it is essential to understand the platform and context where the information is shared. Context can vary from person to person, so it is impossible to examine every participant in this case study's perspective. However, we can take a snapshot of the general Canadian population through surveys. We must understand how people in Canada receive scientific information and if they think the information they receive is trustworthy.

### Canadian Context

This section reviews the research literature and relevant surveys regarding the breadth of scientific literacy and science attitudes within the Canadian context. In 2014, the Council of Canadian Academies (CCA) examined the state of Canada's science culture. The resulting report included an examination of existing literature, a public survey commissioned by the CCA, and an analysis of programs and organizations that support the development of Canada's science culture. Further, the Ontario Science Centre (OSC) (2018) examined Canada's science attitudes by distributing the Canadian Science Attitudes Research online survey in 2015 and analyzing the results. The survey was conducted by Leger, a Canadian polling and market research firm, and was answered by 1501 Canadians.

The CCA (2014) and OSC (2018) indicated that Canadians generally hold positive views toward science. Canadians were reported to be leading in this area compared to 17 other countries (based on international reports) (Council of Canadian Academies, 2014). Moreover, the OSC (2018) found most people in Canada attribute their high quality of life to science and technology, which they believe are essential in solving the world's most critical issues. In contrast, both the CCA (2014) and OSC (2018) found that some people in Canada hold negative attitudes towards science. Furthermore, they also found that a significant number of Canadians believe that there is a mounting tension with science's role in society. Canada is not entirely free of debate when it comes to science. This finding is concerning, as participating in such discussions constitutes a large component of scientific literacy.

Another area of science culture Canada led was the public engagement of science. CCA (2014) reported that 93% of Canadians are engaged in new scientific discoveries, and there is a high level of participation in science and technology-related activities. Focusing on using science in decision-making, the OSC (2018) found that 61% use a balanced approach. This balanced approach refers to using personal experience and intuition with scientific facts and information to make decisions. The same survey respondents who used this approach considered themselves scientifically literate and more likely to have post-secondary education. This balanced approach aligns well with our operational definition of scientific literacy. The survey also found that 42% of respondents believed that the average Canadian should have more understanding of science.

The third overlapping survey topic between the two reports was how the Canadian public informally learns about science. The OSC (2018) had a detailed section of their survey asking respondents where they received their scientific information and how they trusted the sources. The top sources (in order) were schools, post-secondary schools, books and magazines, and finally, the internet. The survey showed a higher trust in scientists and professors than in information on the internet. Furthermore, the respondents trusted social media the least for accurate scientific information. In the OSC (2018) report, Canadians showed that they are concerned about how scientific findings are reported in the media, indicating that they are worried about encountering fake news when navigating scientific information. There is also disagreement over prominent scientific issues in Canada (e.g., climate change, vaccinations, etc.). The reports also recognized the success of Canada's science centres, museums, and science media programs. These informal learning opportunities have contributed significantly to science learning in Canada (Council of Canadian Academies, 2014). Unfortunately, the CCA (2014) also highlight that Canada lacks dedicated funding for informal science learning research, like the National Science Foundation in the United States. The CCA (2014) added that all levels of government in Canada show support for building Canada's science culture. Overall, Canadians in the OSC (2018) survey believed more funding should be dedicated to science and education.

One of the areas the CCA (2014) examined in depth more than the OSC was the science knowledge of Canadians. Consistent with PISA findings, Canadians have a strong understanding of the scientific method and science constraints. On the other hand, the report concluded that more than half of Canadians do not have enough scientific knowledge to debate prominent scientific issues. This finding is concerning, as participating in discussions about scientific issues is a large part of scientific literacy and making informed decisions.

One of the main components of scientific literacy is your habits of mind and beliefs about science. A portion of the OSC (2018) survey measured Canadians' science beliefs. The results were promising, as 79% of the respondents were comfortable with the tentativeness of science, and 94% agreed that science ideas could change with the advent of new research. Understanding science's tentativeness is a critical component of habits of mind in our working definition of scientific literacy. Furthermore, 59% agree that science is indefinite and is a cause for debate in the survey. While scientific debate can be healthy, this culture may have contributed to the 29% of the respondents thinking science ideas cannot be trusted because of the fluidity in science knowledge and the 43% believing science is a matter of opinion. Finally, reminiscent of the rising partisanship in science discussed earlier, 71% of respondents believed that science results could be used to support any position.

The reports provide insight into the state of science information consumption, understanding, and beliefs in Canada. This information will be important when analyzing the results of people in Canada's Twitter use regarding the COVID-19 pandemic. In addition to understanding Canada's science culture, we must also understand the Twitter platform's dynamics.

**Twitter Background**

In Canada, following Facebook and Pinterest, Twitter is the third most popular social media site (based on the number of visits) (Social Media Usage in Canada, 2020). Twitter is unique from the other leading social media sites as it is a "microblogging site" (Uren & Dadzie, 2015). When you initially register for Twitter, you create a profile. Once you have a registered account and profile, you can share posts (referred to as tweets) with a maximum of 280 characters and optionally attach photos, URL links, or videos. This action of posting is called tweeting. You can also *follow* other users, so other user tweets appear on your homepage (your Twitter Timeline). Alternatively, you can visit other users' Twitter profiles to view their tweets and additional user information. Each Twitter user profile contains a user ID/name unique to each user (in the format of @username), a profile name, an optional description (*bio*) about the user, and an optional user location. Both user bio and user location are open text fields in which the user inputs information. Their profile page displays the user's tweets chronologically (newest to oldest). Interactions on Twitter can take the form of resharing (*retweets*), liking (*favourites*) other users' tweets, and following other users to be updated on their home page of new posts. You can also reply to another person's tweet (equivalent to commenting on someone's post) and add your comments when you retweet another user's tweet (*quoting a tweet*). One can also interact with other users privately through chat.

To find tweets about specific topics or an individual, you can search on Twitter by entering a username, keyword, or *hashtag* (keywords in tweets denoted by beginning with the # symbol). Hashtags and keywords are the primary processes of categorizing tweets. Twitter's algorithm also provides users with what is trending on the platform based on their location, interests, and who they are following (Twitter, 2020f). You can curate your Twitter feed by adding topics of interest to your profile. The trending topics give users a snapshot of the latest news and topics of conversation at the time. These are typically found on the side of your Twitter timeline in the form of keywords or hashtags. This feature on Twitter is utilized to stay updated, provide updates to your followers, and discuss the latest news events with other users (Bruns & Burgess, 2012).

A unique feature of Twitter is the platform's open application programming interface (API). Twitter allows individuals and companies to collect a portion of public data from their site for marketing, developing applications, and research. Twitter has a developer user designation that individuals and companies use to access their API. To become a developer, Twitter requires you to go through a short application and approval process. Twitter's free stream API only allows access to 1% of Twitter's total volume (Chen et al., 2020). However, a more extensive access volume and historical data can be purchased from Twitter for a fee (Twitter, 2020c). While 1% of Twitter's total volume appears minimal, it can result in more than 1 000 000 tweets collected a day. Twitter also outlines in its privacy policy that researchers, companies, and individuals have access to their public data (Twitter, 2020d). All these factors, Twitter's popularity, and easily accessible data make it a popular platform for collecting data for research regarding public discussion and disseminating scientific information online.

Research on how COVID-19 information is disseminated online has been a prevalent topic during the past year. There has been an avalanche of research using Twitter due to the discussed characteristics of the platform. Many recent studies focus on how online environments spread misinformation (Kouzy et al., 2020; Krittanawong et al., 2020; Rosenberg et al., 2020; Shahi et al., 2020). These studies were prompted by the exorbitant amount of information spread and continues to be disseminated about COVID-19. Other study types include sentiment analysis and examining political accounts discussing COVID-19 (Crocamo et al., 2021; Leeds-Hurwitz, 2009; Rufai & Bunce, 2020). While Twitter is a single social media platform, it has proven a powerful tool for examining prominent social issues in online environments with few barriers to collecting data.

**Information During the COVID-19 Pandemic**

The speed and scope that Twitter and other social media platforms provide to disseminate information have made it an important communication method in disasters and crises. Health communication shares many of the same goals, challenges, and practices as science communication. However, health communication focuses on communicating information to citizens regarding their health and well-being. Health communication plays a vital role in times of disasters and pandemics. It is used to mitigate the impact of the crisis/illness on humans and society and save lives (Wilkins, 2005). Therefore, effective communication is critical. Health communicators help the public to make informed decisions about their health ( Lee, 2014). During the COVID-19 pandemic, public health officials released the most up-to-date information about how the virus spread and gave advice on protecting yourself and others. This goal was to help the public adopt self-protective behaviours, limit their exposures, reduce mortality, and contain the spread of the disease (Lee, 2014). The importance of effective knowledge translation is amplified more during times of pandemic, where making rational, informed decisions can be a matter of life or death. Public health experts and agencies are part of a more extensive system to communicate this information effectively. They work with the media, journalists, and the public to share vital health information (Chew & Eysenbach, 2010). Individuals rely on such systems for guidance on how they should respond to the health crisis and make informed decisions (Hilyard, 2014).

***The Role of Mass Media***

Health information online mirrors that of science communication. While social media is becoming a prominent tool in health communication, mass media still plays a crucial part in information distribution and interpretation. For example, during the Ebola Virus outbreak of 2014, news organizations were the prominent influencers on social media compared to individuals (user-generated content) (Househ, 2016). In the H1N1 pandemic in 2009, information disseminated on Twitter mostly came from credible sources. The public regularly used the platform to share opinions and perspectives (Chew & Eysenbach, 2010). News organizations are powerful influencers on public and government perceptions of health crises and events (Househ, 2016; Houston et al., 2015; Spence & Fuller, 2011). The way the media frames information can significantly impact the public's knowledge, attitudes, and behaviour regarding the crisis (Houston et al., 2015). The portrayal of risk in the media in relation to other social, political, and institutional contexts during pandemics and other crises can amplify or mitigate the individual's perception of risk and affect how they respond to the situation (Hilyard, 2014). As with other online scientific information, information is not consumed in isolation. When people process information, it is done in relation to their socio-cultural contexts, ontologies and epistemologies related to knowledge and knowledge production. Thus, it must be acknowledged that there is great variety in how information is produced, presented, and consumed.

Mass media serves as an information filter for individuals and can activate different emotions that affect information processing and the formation of opinions about the information. This occurrence is more apparent during pandemics when people have little background knowledge and experience (Lee, 2014). New organizations and journalists share public health officials' goals of saving lives and lessening the pandemic's impact (Wilkins, 2005). Much of the research on pandemic information dissemination has been done on traditional media. However, research has shifted to focus on new media in the past decade, specifically social media. Research on social media and its role during pandemics and disasters is still emerging (Houston et al., 2015; Zade et al., 2018).

***Using Social Media to Communicate Risk***

The internet, social media, in particular, is a relatively new tool being integrated into disaster response (Zade et al., 2018) and is generally the primary source of information during crises and disasters (Spence & Fuller, 2011). Social media's openness and accessibility allow individuals to gather and share information and opinions about health issues (Househ, 2016; Zade et al., 2018). This rise of social media for disseminating health information is welcomed by information consumers and producers (Strekalova, 2017) as it creates an empowered and connected society (Roberts et al., 2017).

Social media has many benefits when it comes to quickly distributing health information. Firstly, it is low-cost and easily scalable (Wang et al., 2019). It also allows for the rapid dissemination of information to reach a broad audience (Strekalova, 2017). The increase in mobile devices, internet, and social media use has also resulted in highly connected citizens (Roberts et al., 2017). The internet is now in our pockets. This mobility allows risk information to reach someone almost anywhere (Langhans & Lier, 2014). As discussed in the Science Communication section, social media employs multidirectional communication channels. This feature is helpful for health experts, as they can have a discussion directly with the public and participate in existing conversations (Houston et al., 2015; Langhans & Lier, 2014), allowing information to be quickly clarified, adjusted, and corrected in real-time (Langhans & Lier, 2014). Like science information consumption, health information consumers are now also contributors (Roberts et al., 2017), with the public having a more significant role in knowledge translation (Zade et al., 2018). While there are many benefits to using social media, we must also be aware of the risks of disseminating information during pandemics and health crises, particularly on social media platforms.

***Information and Uncertainty in Pandemics***

Health communication shares many of the same characteristics and challenges as online science communication. However, information during pandemics is presented to the public with a heightened sense of fear and anxiety. As with online scientific information, others' conversations and comments influence individuals' opinions, attitudes, and decision-making (Langhans & Lier, 2014). Experts used Twitter in the H1N1 pandemic to share health information, while the public used Twitter to share their opinions and perspectives (Chew & Eysenbach, 2010). Due to the ease of disseminating information online, too much information is available. Sometimes increasing the amount of information shared online can create more anxiety about the situation (e.g., the pandemic). This anxiety can happen when communication channels do not consider their audiences in relation to the information they are sharing (Strekalova, 2017).

When people are exposed to too much information, information overload can occur. Information overload happens when people do not have enough time or cognitive ability to process all the information available. Farooq et al. (2020), in an initial study of information during the COVID-19 pandemic, found an abundance of available information. This abundance can be detrimental. People can get fatigued, and their ability to interpret and consequently follow public health recommendations is hindered when health information and recommendations overload them (Farooq et al., 2020).

Individuals may be sharing their interpretations of the information without fully understanding it, amplifying the public's risk perception (Strekalova, 2017).

It is essential to understand information during pandemics, as they are life and death situations. There was a lot of scientific and medical uncertainty in the initial stages of the SARS epidemic and COVID-19 pandemic. The scientific process plays out in real-time, with new information continually being added and recommendations revised (Funk & Tyson, 2020; Wilkins, 2005). For example, medical professionals initially recommend not wearing masks, which then changed to recommend mask-wearing. Scientific literacy and an understanding of science's tentativeness and durability are vital for the public during these uncertain times. This high level of uncertainty presents a communication challenge for public health officials (Lee, 2014). Farooq et al. (2020) found that individuals were more likely to follow public health recommendations if they understood the reasoning and necessity of them. Lack of clear communication can have severe consequences, creating even more uncertainty and panic. Furthermore, people have difficulty making sense of risk messages even with clear communication due to the powerful emotions (e.g. stress) during pandemics (Hilyard, 2014).

Researchers have identified a unique phenomenon in extended public health crises, such as the COVID-19 pandemic. *Pandemic fatigue* during a long-term public health crisis can cause a demotivation to participate in protective behaviours (World Health Organization, 2020a). A variety of factors relating to a person's emotions, experiences, and perceptions cause this demotivation. Pandemic fatigue has nothing to do with being physically or mentally tired but rather a lack of motivation to invest the mental effort required to follow the pandemic mitigation recommendations (Badre, 2021). Over time the apparent threat of COVID-19 can decrease in individuals' minds. The perceived cost of participating in mitigation measures such as social distancing, isolating, working from home, lockdowns, etc., may feel like it outweighs the benefits.

Furthermore, in a long-term health crisis, situations such as pandemics start to feel normal, the threat becomes an everyday occurrence, and people may become complacent (World Health Organization, 2020a). Not much is known about pandemic fatigue and how it affects social media usage or usage of scientific literacy. Due to these challenges, information overload and pandemic fatigue, online media's use for information dissemination during pandemics is a concern for researchers and communicators.

### *Emerging Research on the COVID-19 Pandemic, Misinformation, Twitter, and Scientific Literacy*

The following section outlines some of the early research published regarding how information about COVID-19 is being communicated to and received by the public. As highlighted previously, in the COVID-19 pandemic, there is a concern about the amount of misinformation shared in online spaces (World Health Organization, 2020b). Researchers have explored how individuals navigate, disseminate, and interpret COVID-19-related information online. In addition, they are investigating how the spread of misinformation affects individuals' self-protective behaviours and different interventions that can be used to combat the information spread.

The WHO's September 2020 statement regarding the infodemic called for experts and other officials to create a plan to manage the abundance of information available (World Health Organization, 2020b). The researcher who coined the term infodemic, Eysenbach, wrote a paper in response to this need for a plan. In the article, Eysenbach (2020) discussed four levels of information; science, policy/health care practice, news media, and social media. Social media has the largest amount of information that is unfiltered. One of the main issues they highlighted was how information is disseminated between the four levels. There is very little scientific misinformation at the science level. However, when that information eventually gets to the social media level, knowledge translation factors significantly affect sharing of scientific information. Therefore, Eysenbach (2020) suggests a focus be put on facilitating accurate knowledge translation and encouraging knowledge refinement at each level of information. They also highlight the need to build *eHealth Literacy*, "the ability to seek, find, understand, and appraise health information from electronic sources and apply the knowledge gained to addressing or solving a health problem" (Eysenbach, 2020, p. 4). As described in this paper, eHealth Literacy is an applied version of our operational definition of scientific literacy, focusing specifically on online health information. Eysenbach's (2020) paper concludes with a discussion about the need to monitor online information to counteract misinformation as it occurs.

Complementary to this research on the infodemic, researchers have examined COVID-19 discussions on Twitter. Some research has focused on sentiments surrounding the COVID-19 vaccine (Lyu et al., 2021), and other research has focused on COVID-19 misinformation on Twitter (Bridgman et al., 2020). Studies released in the past year regarding COVID-19 vaccinations examine sentiments in the early days of the COVID-19 vaccine release. As of November 2021, it has only been one year since the first COVID-19 vaccine was announced and less than a year since widespread vaccination programs were implemented (Zimmer et al., 2021). One of these early studies found that discussions regarding the COVID-19 vaccine followed news cycles, and trust in COVID-19 vaccines increased as the pandemic progressed (Lyu et al., 2021).

In examining misconceptions regarding COVID-19 on Canadian Twitter, Bridgman and their team (2020) found social media is increasingly being relied on for news. In their investigation, they discovered high levels of misinformation circulated on Twitter, while the information in news media contained high-quality information. They also found that increased exposure to the misconceptions being shared on Twitter was associated with lower amounts of social distancing. Furthermore, social media exposure was associated with increased exposure to misinformation (Bridgman et al., 2020). Another study examining Twitter and COVID-19 misinformation revealed that unverified accounts on Twitter produced more misinformation than unverified accounts and that accounts with more followers shared less misinformation (Kouzy et al., 2020). The same study also found that the tweet quality did not change with the amount of engagement (likes and retweets) (Kouzy et al., 2020).

In science education research, preliminary studies examine how to incorporate COVID-19 into science instruction and equip students with the necessary skills to navigate the COVID-19 pandemic. One study discusses *critical STEM literacy,* which integrates scientific and mathematical literacy aspects into one competency (Braund, 2021). Braund (2021) highlights the importance of mathematical literacy during the COVID-19 pandemic because of the abundance of information presented graphically. For example, case counts and vaccine distribution dashboards often show data as a line graph. As discussed earlier, clear communication of information is an essential element in mitigation measures used to prevent the spread of COVID-19. Therefore, it is critical that individuals can accurately interpret the information being presented graphically. Braund's (2021) study highlights the need for transdisciplinary learning. In the first section of this literature review, we emphasized the importance of defining scientific literacy. This is an example of why researchers need to do so. Braund's (2021) definition of critical STEM literacy is essentially the same as our interpretation of scientific literacy because our operational definition includes mathematical literacy within the science literacy trait.

This brief overview of the current research being published regarding COVID-19, Twitter, misinformation, and scientific literacy highlights the timeliness of our study. We have examined multiple factors discussed in these preliminary studies concerning scientific literacy use on Twitter during COVID-19. Furthermore, our study's definition of scientific literacy incorporates many aspects cited in the papers to combat and equip individuals with the necessary skills to navigate information about the COVID-19 pandemic. Thus, demonstrating that our research complements the current research being conducted in this area.

## Chapter 3 – Methodology

### Overview

The overarching research question driving our case study examines the nature of scientific literacy usage in Canada on Twitter when navigating, discussing, and disseminating information about the COVID-19 pandemic. We also proposed a secondary question regarding the factors that affect scientific literacy usage and trends in scientific literacy usage online. We examined tweets that discussed the COVID-19 pandemic to answer the research questions. Due to the technical nature of our data collection methods, we have included a glossary of technical terms and their definitions in Table 2**.**

**Table 2**

*Glossary of Technical Terms*

| Term | Definition |
|---|---|
| Application Programming Interface (API) | A computer system that connects two different computers, programs, or applications |
| Hydrating/Hydrated (Tweet) | The process in which a Tweet ID is used to collect the complete details of the associate tweet by connecting to and downloading the data from the Twitter API. A tweet with its text and metadata is considered hydrated |
| Metadata | Data about other data that can appear in many different forms. Tweet metadata includes descriptive data about the tweet itself, included user, creation data, associated links, likes, retweets, etc. |
| Open-source software | Software for which the copyright license allows the user to edit and distribute the software code, often available free of charge to users |
| Tweet | "A message posted to Twitter containing text, photos, a GIF, and/or video." (Twitter, 2021a) |
| Tweet ID | Unique 64-bit unsigned integers assigned to each object (Tweet, Message, User, etc.) on Twitter use to reference Twitter's API (Twitter, 2020e) |
| Twitter | A microblogging and social media platform |

**Table 2 (continued)**

*Glossary of Technical Terms*

| | |
|---|---|
| Twitter User Verification | Twitter's method of authenticating Twitter accounts of public interest (often celebrities, major organizations, and brands). Accounts are identifiable by the blue checkmark that appears beside their username. (Twitter, 2020a) |

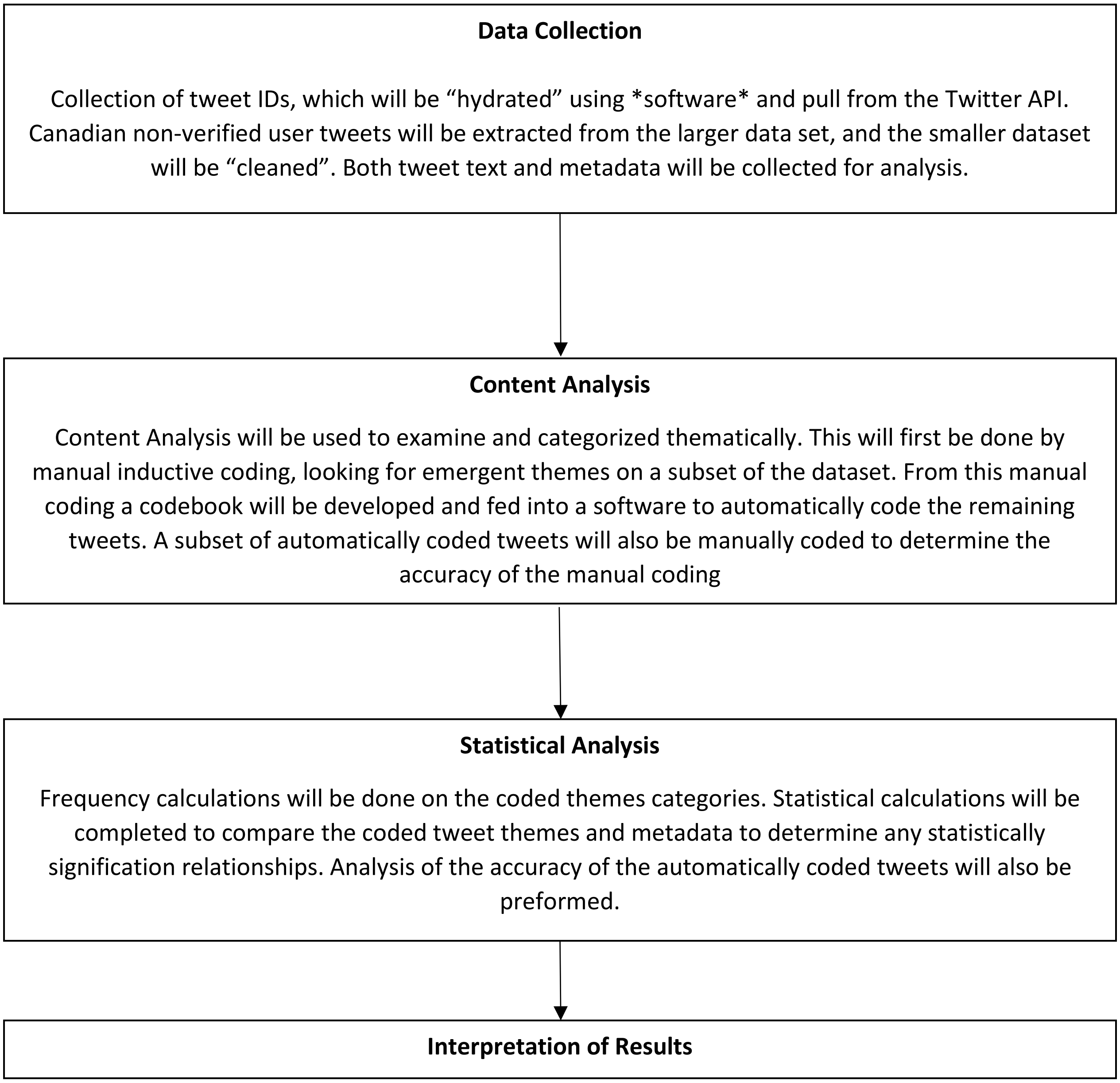
We collected the tweets in the form of *Tweet IDs* and downloaded them from an online repository of COVID-19 Tweet IDs. Tweet IDs are a unique string of numbers assigned to each "object" (e.g., tweet, message, user, etc.) and identify objects in the Twitter API (Twitter, 2020e). We employed a qualitative research design by collecting data in the form of tweets and their metadata. We performed a content analysis to categorize the tweets into themes. To further examine our qualitative results more in-depth, we conducted some statistical calculations to understand thematic trends, frequency of coded themes, and factors affecting scientific literacy use online. Figure 2 outlines each step in the research design.

**Data Collection**

Tweets and their metadata extracted from the Twitter API are the primary data source for our case study. We used an open-source program called Hydrator to access the API and extract the data (Documenting the Now, 2020)—a process referred to as *hydration.* To collect data from the Twitter API using the Hydrator program, we first needed a list of Tweet IDs referencing the tweets we wanted to include in our data set. The Hydrator program used these Tweet IDs to locate the full tweet text and metadata on the Twitter API. The program then downloaded this information and saved it to the user's computer.

**Figure 2**

*Research Design*




In our case study, we collected Tweet IDs from a COVID-19 Tweet ID Repository located on GitHub. The repository contains an "ongoing collection of Tweet IDs associated with the novel coronavirus COVID-19 (SARS-CoV-2)" (Chen, 2020, sec. Read Me). On January 28, 2020, Chen et al. (2020) began collecting tweets that contained specific keywords and accounts primarily sharing information about COVID-19 (e.g., WHO, Centre for Disease Control), most of them very popular on Twitter at the time. The researchers discuss leveraging Twitter's search API to collect tweets from January 21, 2020. Data collection was still ongoing and is updated weekly as of November 2021. The data set released only contains Tweet IDs instead of each tweet's complete text and metadata to comply with Twitter's Terms of Service. It is international and multilingual but is skewed towards English tweets (approx. 67%) because all keywords are English (Chen et al., 2020). As the pandemic has evolved, they have added more keywords and accounts to the list, with the most recent keywords added on July 7, 2020 (v2.72) as of November 2021 (Chen, 2020). A complete list of the keywords and accounts appears in Appendix B**:** COVID-19 Tweet ID Repository Keywords. Until June 15, 2020, Tweets were obtained from the Twitter API stream using the Python Library Tweepy (Chen et al., 2020). From v2.0 onwards, data collection was done using Amazon Web Services (AWS). No collection parameters were changed, but there was an increase in Tweet IDs gathered and shared after June 15, 2020. This change did not cause any gap in data collection (Chen, 2020).

***Data***

After the completion of data collection, we had two datasets. One contains a list of Tweet IDs collected from the COVID-19 Tweet ID repository. The second is a hydrated dataset containing tweet text and metadata and is the subsection of the tweets associated with the collected Tweet IDs. The metadata collected includes the tweet's language, type of tweet (i.e., retweet or original), the tweeter's profile information (user information), likes and retweets, and the time the tweet was sent. We used the hydrated dataset for further analysis. The hydrated dataset contains the tweets and their metadata in two different file formats, JSONL and CSV. The days to be hydrated were randomly chosen based on a sampling method described later in this section. The following few subsections will detail delimitations for our data cleaning, our data cleaning methods, and the analysis process.

**Delimitations**

We have several delimitations to deal with the dataset's size and obtain the necessary data to answer research questions. These delimitations guide the data cleaning process to obtain a dataset that fits our study parameters. First, we only examined English tweets discussing the current COVID-19 pandemic shared by people who identify as being from Canada or living in Canada in their Twitter bio account location during the study period. The selection of English-only tweets is because the data set is skewed towards the English tweets, and it is the language spoken by our research team and most people in Canada. The term Canadian in this study refers to anyone who identifies as residing in or from Canada in their Twitter account location, not just Canadian citizens. There is no way on the Twitter platform to discern one's citizenship. Therefore, we have chosen to use the self-identification of the Twitter user's location from their Twitter bio.

This study looks at the nature of individuals' scientific literacy online. Therefore, we avoided the analysis of tweets coming from organizational bodies (e.g., Health Canada, CTV News, etc.) by analyzing only non-verified Twitter accounts. Verification is Twitter's way of authenticating a user account. Users with this designation are typically public figures, government, and media organizations (Twitter, 2020a). We further separated retweets from original tweets. Chew and Eysenbach (2010) stated that retweets could skew the sample by resharing the same popular post or spam. We also did this separation to help stop the influence of Twitter bots. Therefore, our study only examines the original tweets. All the delimitations discussed aided in filtering the tweets from the large dataset that did not match the study parameters.

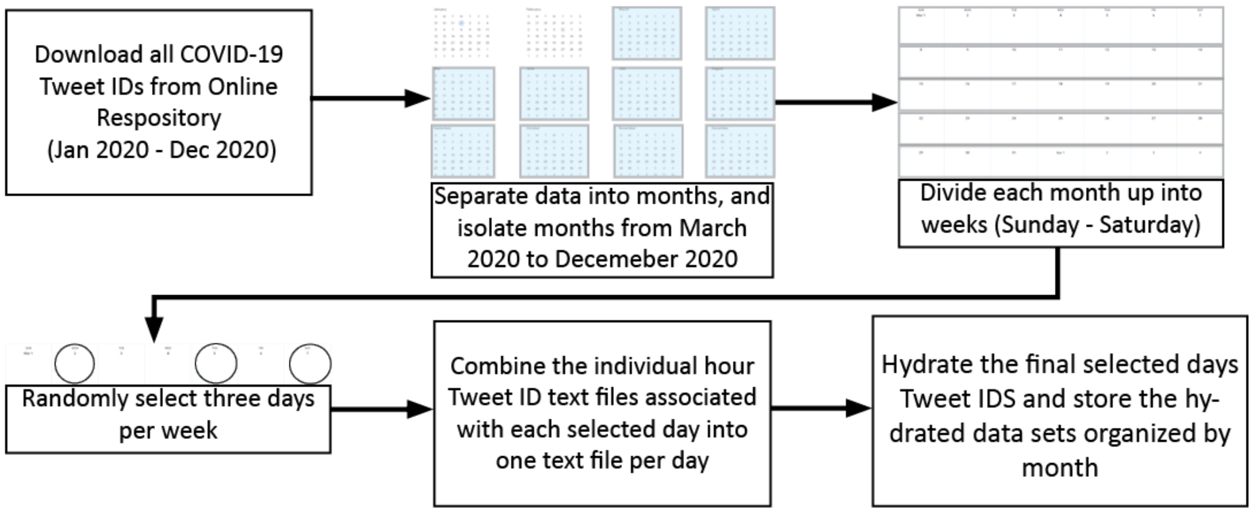
**Sampling Procedure**

Due to the dataset's size and nature, it is not feasible to hydrate and analyze every Canadian tweet sent between March 2020 and December 2020. A total of 2 022 616 140 tweets (v. 2.72) are in the COVID-19 Twitter Data repository (Chen, 2020). In preliminary testing, a data set with approximately one million Tweet IDs took about half an hour to hydrate. While a dataset with approximately seven million Tweet IDs took a day to hydrate. The limiting factor for hydrating tweets is the Twitter API rate limit. Twitter only allows users to pull a certain number of tweets from their API every 15 minutes. The limit changes depending on what type of Twitter developer account one uses and what they are trying to pull from the Twitter API. The application, Hydrator, manages our rate limits and stops and starts collecting data from the API as needed (Documenting the Now, 2020). Due to the time required to hydrate the tweet IDs, a sampling procedure was necessary to obtain a subset of tweets through hydration before data cleaning.

We employed a multi-stage sampling procedure to determine which proportion of data to collect and analyze in the content analysis – both manual and automatic portions. Riffe et al. (2019) describe the stratified sampling method we used to determine the initial Tweet IDs to be hydrated. We first split the data into months (e.g., March, April, May, June, etc.). From there, we broke each month down into weeks. Kim et al. (2018) found that *simple random sampling* (SRS) is more efficient at sampling Twitter data than an alternative method called constructed week sampling. Simple random sampling involves selecting data not based on specific days of the week because there is an equal chance of obtaining relevant data every day. This method does not always work well for traditional media, as on some days, such as the weekend, newspapers and news broadcasts are not as prevalent. Social media does not follow these conventional media cycles based on days of the week. Social media has little variation in the amount of discussion and sharing of information from day to day. Following this, SRS picked three days from each week to be hydrated, cleaned, and analyzed. SRS also determined the tweets for manual coding with each day. Figure 3 outlines this sampling process.

**Figure 3**

*Sampling Procedure Outline*




We downloaded and cleaned 125 days' worth of Twitter data from the Twitter API between March 1st, 2020, to December 31st, 2020. A list of days chosen using SRS can be found in Appendix C. We took a sampling of tweets from one day per month of our timeframe to create our pilot coding dataset. This dataset was used to develop topic codes and train our primary coder for consistency. The pilot coding data set contained 1000 tweets. After the pilot coding, 1600 tweets were randomly selected from one day per week (50 tweets/day) of our timeframe to create a final dataset of tweets for manual coding.

**Data Cleaning**

The data cleaning's primary goal is to isolate English tweets from users located in Canada from the data set. While Twitter allows users to *geo-tag* their tweets with an exact location, over 97% of users choose not to do this (Twitter, 2021b). For this study, account location, provided by the user on their public profile, determined the user's location. The account location is a free-form field, meaning that users do not have to use a geo-referenced place or only use a particular format for a location name (Twitter, 2020b). A call for student programmers (both Undergraduate and Graduate) was sent out in mid-October 2020 to aid in the data preprocessing and cleaning. A total of 28 programmers responded, and we selected three programmers to collaborate on the data processing portion of this study.

The three student programmers used test sets of data (April 23, 2020, and October 1, 2020) to develop a Python program that cross-references the account location field with a list of known Canadian locations and their common short forms. The same program removes unnecessary data columns for the data analysis, verified users, and random characters in the tweet text produced during the hydration process (text preprocessing). Retweets and original tweets are also separated into two separate files. The final cleaned data is stored in a CSV file format. In the end, two programs were compared, and the best parts of each of the codes were incorporated into the final data cleaning program. We used this final code to clean all 125 days of hydrated data.

***Ethics***

In accordance with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans document (Canadian Institutes of Health Research, 2018), this research is exempt from the Research Ethics Board Review. Twitter data falls under the category outlined in Article 2.2.b "in the public domain and the individuals to whom the information refers have no reasonable expectation of privacy" (Canadian Institutes of Health Research, 2018, p. 15). Twitter's privacy policy outlines that its API is publicly accessible, "most activity on Twitter is public," and that users who publicly post content are allowing Twitter to "disclose information as broadly as possible, including through our APIs" (Twitter, 2020d, sec. 1.2). The COVID-19 Tweet ID Repository is released to the public for non-commercial research use (Chen et al., 2020), and complete data for each tweet is obtained using the Tweet IDs and Twitter's API. We relayed this information to an Ethics Officer at Western University, who confirmed that this research is exempt from the Research Ethics Board Review. A copy of this exchange can be found in Appendix A.

## Data Analysis

Qualitative content analysis was the primary analysis method for this study. We conducted additional statistical calculations to examine various trends and patterns in the data using chi-squared with phi and Fischer's exact test (2-sided). For example, we looked at the geographical trends of the tweets. The method used in this analysis adapts and builds on those used in Chew and Eysenbach's (2010) paper, *Pandemics in the Age of Twitter: Content Analysis of Tweets during the 2009 H1N1 Outbreak*. In which they examined the trends and content of tweets during the H1N1 outbreak.

### *Content Analysis*

We used content analysis to examine the main research question: What is the nature of Canadians' scientific literacy usage on social media when discussing, sharing, and disseminating information about the COVID-19 pandemic? Researchers often refer to Twitter data as "big data" (Kim et al., 2018). The most accurate coding method is manual coding by trained coders. However, manually coding an entire Twitter data set can be time-consuming and costly (Kim et al., 2013). Automatic/Computer-based coding techniques can quickly code an extensive data set but lack accuracy. Machine learning and natural language analysis have come a long way; however, computer programs cannot understand human language's nuances (Kim et al., 2018; Riffe et al., 2019). For these reasons, a hybrid approach, using manual and automatic coding techniques, is the preferred method when performing content analysis on Twitter data (Riffe et al., 2019). Our research attempted to utilize the hybrid approach to conduct the content analysis portion of the data analysis. A single trained coder completed the manual coding. We used NVivo, a qualitative data analysis software, for the automatic part of the hybrid approach. NVivo is a qualitative research tool used for content analysis, literature review, and other qualitative and mixed-method research techniques. It has various auto-coding features, including pattern-based auto coding (NVivo, 2021), which we employed for our automated content analysis

**Manual Coding**

We manually coded a total of 2 600 tweets. This data set of manually coded tweets acted as our pilot coding file for NVivo to base its pattern-based auto coding on (NVivo, 2021). We used this manually coded dataset to develop a codebook utilizing a combination of deductive and inductive coding techniques. Coding was a generative process, with codes refined throughout the codebook development process. A total of four coders manually coded a pilot coding data set to create the codebook: the primary coder, SJ, and three secondary coders, AP, MA, and JJ. The pilot coding dataset consisted of 1000 tweets (100 tweets/month) from the 2 600 tweets in the manual coding dataset. Manual coding was done in six stages. First, the primary coder, SJ, determined the prominent discussion topics using the pilot coding dataset and inductive coding techniques. Second, the group of four coders condensed discussion topics into general categories. Third, training for coding the topic and scientific literacy (including traits of scientific literacy) was done using the 100 tweets from December 2020 in the pilot coding dataset. Finally, AP, MA, and JJ were assigned 300 out of the remaining 900 tweets to code from the dataset. SJ coded all the remaining 900 tweets with topic and scientific literacy codes. The coding was compared between the secondary coders and the primary coder to assess the reliability of the primary coder. Additional discussions were held to negotiate any disagreements, and additional training was held as necessary. Finally, after verifying SJ's reliability as a coder, SJ coded the remaining 1 600 in the manual coding dataset.

After completing the initial inductive coding for tweet topics using the pilot coding dataset, 37 unique discussion topics were found. We categorized the 37 topics of discussion into nine coding categories (combating the pandemic, humour, impact/effect, information, personal, politics, spread, social, and other/not applicable). After an initial coding session using the nine codes, we determined that there was still a lot of overlap, and the codes could be condensed further. We condensed the discussion topics into three general codes: consequence, response, and politics. We also found that some tweets collected did not explicitly discuss the pandemic or pandemic-related issues. These tweets were coded as not applicable (N/A). A definition of the three topic codes used and examples can be found in Table 3. We did not use tweets coded as not applicable in our subsequent analysis, as this did not pertain to discussions around COVID-19.

**Table 3**

*Topic Codes*

| Topic | Description | Examples |
|---|---|---|
| Consequence | Consequences of the COVID-19 pandemic for all aspects of life and society. This can include the impact it has on the economy, education, health, healthcare, social interactions, personal experiences, education, entertainment, and jobs. Discussion of the spread of the virus, deaths caused by the virus or due to the pandemic in general. ***Uncontrolled phenomena due to the pandemic.*** | "3 people in their 20s have died so far from COVID-19 in Alberta, province says \| CTV News https://t.co/c5dAazHVrE"<br><br>"Pandemic-induced â€˜nestingâ€™ fuels Home Depot and Loweâ€™s salesâ€"Why itâ€™s likely toÂ continue https://t.co/ZNa3f3SiF3 |
| Response | Tweets about how society is responding or not responding to the pandemic. This category refers to ***purposeful responses*** **or ways society is working to combat and adapt to the pandemic.** Things in this category could include social distancing, mask wearing, lockdowns, vaccines, testing, quarantine, treatment options, school closures, travel restrictions, cleaning routines, information sharing, information seeking, individual response, government response, and how businesses are adapting.<br><br>*Note:* A response is always tied to an effect of the pandemic. | "@YoniFreedhoff Think people have been asked, pleased with and begged to listen. Many clearly are not ..shut it all down, mass testing / tracing done âœ….. letâ€™s save the ones that care .. Put us back on CERB for that time .. #COVIDzero #smotherthespread https://t.co/6uvhLb1gXV" |
| Politics | Discussion of political figures, prominent company figures (e.g. Jeff Bezos), leaders in society, or media inner workings including criticism of their decisions surrounding the pandemic. **This category is for tweets that focus on the politics behind the pandemic and less of**. | "@fordnation @Sflecce And next it will be Ontario because of you two. https://t.co/zp8kDG1CP9 |

**Table 3 (continued)**

*Topic Codes*

| | | |
|---|---|---|
| | **the response or effect related to the pandemic itself.** Key words to look for are names of politicians and other public figures/entities | |
| N/A | Tweets that are clearly discussing something other than the COVID-19 pandemic but share similar keywords allowing it to be picked up in the search. This category also includes tweets whose topic of discussion could not connected to COVID-19 in general. | "@scottjohnson The other flu (not corona, not covid-19) this year resists conventional treatment and tends to come back to bounce between family members for 3 to 4 months. It is virus like however most family members will say they have really bad allergies instead of seeing a doctor." |

We further separated the tweets assigned a topic code into three categories; tweets that display scientific literacy, tweets that display a lack of scientific literacy (no scientific literacy), and not applicable. These codes were deductively created based on our operational definition of scientific literacy found in Chapter Two. Table 4 displays a description of these codes and examples.

**Table 4**

*Scientific Literacy Codes*

| Code | Description | Example |
|---|---|---|
| Scientific Literacy | Tweets that demonstrate one or more of the traits of a scientifically literate individual as outlined in Figure 1. | "@mustafahirji @NRPublicHealth The reason you are not seeing local cases is because you are NOT TESTING POSSIBLE CASES?! Flatten the curve won't happen with community transmission that is CURRENTLY OCCURRING, but you aren't TESTING. Continue to IGNORE WHO rec to TEST TEST TEST" |
| Lack of Scientific Literacy | Tweets that discuss claims regarding the COVID-19 pandemic in a manner that conflicts with the traits of a | "Wake up Victoria and wake up Canada! It not about health, it's all about control. With a 99.9 survival rate, it's a plandemic not a pandemic. https://t.co/dJg4bnSAFR" |

**Table 4 (continued)**

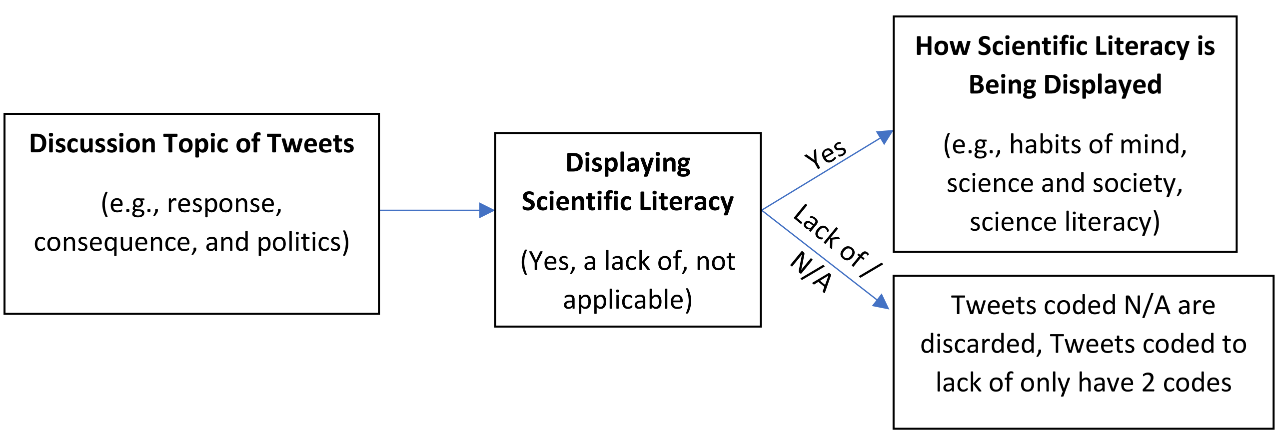
*Scientific Literacy Codes*

| | | |
|---|---|---|
| | scientifically literate individual. These traits are outlined in Figure 1. | |
| N/A | Neither displays traits of scientific literacy nor a lack of scientific literacy. Often describe one's personal experience during the pandemic. | "In need of volunteers to make face masks! We have kits with enough material to make 20 masks. If you're interested and have a sewing machine, please sign up here: https://t.co/aIvfU11DtP We're hoping to create more child-size and youth-size masks!<br><br>#COVID19 #Volunteering #PAFNW" |

Finally, we categorize the tweets coded to scientific literacy to one or more of the three scientific literacy traits. Our operational definition of scientific literacy includes these traits, habits of mind, science and society, and science literacy. Tweets could be coded to one or more of the traits. For example, if a tweet displayed qualities from both habits of mind and science literacy traits, it would be coded to habits of mind and science literacy. Figure 4 displays the coding process.

**Figure 4**

*Development of Codebook*



When comparing our pilot data set codes between the primary coder and the secondary coders, we found the most discrepancy when categorizing the scientific literacy traits. We determined that this discrepancy could be explained by the constructs' interconnectivity and the difficulty in defining them. This will be further discussed in Chapter Five. Even though there was a divergence between the primary and secondary coders, the primary coder was consistent with their coding assignment. Therefore, after the pilot coding and training, the primary coder, SJ, was considered reliable enough to code the rest of the manual coding dataset.

**Automated Coding**

We uploaded 2 600 manually coded tweets into NVivo for the “Auto-coding using existing coding patterns” (Auto-Coding Wizard) feature and the 125 days of Canadian tweets downloaded from the Twitter API. NVivo Windows Release 1 contains a coding enhancement feature that automatically codes data sets based on existing coding patterns (NVivo, 2021), which we used for our content analysis. NVivo uses these manually coded passages of text to compare to the one it is coding. If the coded content is similarly worded in the pilot code, then the content is coded to that code (NVivo, 2021). It can also be used with iterative dataset collection, such as Twitter data, and works best with thematic coding. NVivo also allows the user to review and adjust the auto coding.

Each of the 125 datasets (days) took 15+ minutes to import to NVivo. Before we could import all the 125 Twitter dataset files (one file per day), our NVivo file was corrupted and would not open. The number of references (in this case, tweets) was too large for NVivo to handle. We then pivoted and uploaded only one day of data per week in our timeframe (41 days of data). NVivo was able to import all the 41 Twitter dataset files. These files were then coded using the Auto-Coding Wizard feature on NVivo. After the coding process, the number of references became too great again for NVivo to handle, and very little analysis could be completed without NVivo crashing. Finally, we limited the number of tweets to 1000 tweets/week, pulling data from the same 41 days uploaded previously. After switching to a more powerful computer (Computer B in Table 5) and reducing the number of references, NVivo functioned semi-successfully. Table 5 outlines the specifications of the computers used in our analysis and NVivo's minimum and recommended computer specifications.

**Table 5**

*Computer Specifications*

| Computer | RAM | Operating System | Processor | Processor Details |
|---|---|---|---|---|
| A | 16 GB | Windows 10 Pro | Intel Core i7-1065G7 | 1.30 GHz (Base)<br>3.40 GHz (Turbo)<br>Quad-Core |
| B | 32 GB | Windows 10 Pro | Intel Core i7-10700F | 2.90 GHz (Base)<br>4.80 GHz (Turbo)<br>Octa-Core |
| NVivo Recommended | 8 GB (also consider 16 GB) | Windows 8.1 or later | N/A | 3.0 GHz Quad-core or Faster |
| NVivo Minimum | 4 GB | Windows 8.1 | N/A | 2.0 GHz Dual-core |

NVivo's auto-coding feature has different threshold levels for the similarity between text passages. These levels range from one (less) to four (more) and can be set by the user (NVivo, 2021). We put our threshold to the recommended level of two. After NVivo assigned a topic code to each tweet (any tweets not coded to a topic of discussion were considered not applicable), we removed any intersecting codes, so each tweet only had one topic code assigned to it. Following this, we used the auto-coding feature again to code the tweets assigned a topic code to code the tweets to a scientific literacy category. Similarly, any tweet not assigned a scientific literacy code was considered not applicable. One of the main warnings/errors NVivo produced during this process was the inconsistent language of the pilot coding references. This is expected as a wide variety of writing styles are used on

Twitter to present the same ideas. Furthermore, short forms and colloquialism are often utilized in Tweets, making it more difficult for NVivo to identify patterns in our pilot coding.

To calculate inter-rater reliability between the primary coder, SJ, and NVivo, we needed to extract all the tweets coded to scientific literacy and no scientific literacy from NVivo to an Excel sheet. This had to be done by manually identifying and pulling the tweets coded by NVivo from the original datasets uploaded. NVivo does have the functionality of being able to code the same tweets it automatically codes manually. It then can calculate the interrater reliably within the program. However, due to the size of our dataset, NVivo could not complete this operation. NVivo continued to crash every time we attempted to code a reference previously categorized as scientific literacy or no scientific literacy by NVivo. SJ manually reviewed all the tweets coded by NVivo and coded them to the applicable code (scientific literacy, not scientific literacy, or not applicable). The percentage agreement was then calculated between SJ and NVivo.

NVivo auto-code wizard, set to the threshold level two, coded an average of 15 tweets/1000 tweets to scientific literacy. In comparison, our manual coding data sets had an average of 103 tweets/1000 tweets coded to scientific literacy. The percent agreement for tweets coded to scientific literacy between SJ and NVivo was 54%. Out of the 200 tweets used for the percent agreement coded to scientific literacy by NVivo, 107 (54%) were verified to display scientific literacy, 12 (6%) showed a lack of scientific literacy, and 81 (40.5%) were not applicable. The percent agreement for tweets coded to no scientific literacy between SJ and NVivo was only 4%. Out of the 27 tweets coded to no scientific literacy by NVivo, only 1 (4%) displayed a lack of scientific literacy, 3 (11%) displayed scientific literacy, and 23 (85%) were not applicable.

NVivo's auto-coding function used to assess the scientific literacy in Twitter data did a very poor job at identifying tweets. We also suspect many tweets in the dataset of approximately 41 000 tweets should have been coded to scientific literacy, or no scientific literacy was missed by NVivo. Due to the extremely poor results in the percent agreement calculations. We choose not to use the data from NVivo in our analysis. Therefore, our analysis was completed using only 2 600 manually coded tweets.

***Analysis of Trends***

After completing the content analysis, we used statistical analysis to explore our content analysis results further. We used SPSS and Excel to conduct our statistical analysis. The five variables that we considered for an association with scientific literacy usage are the tweet's topic, location of the user in Canada, the date the tweet was shared, the number of followers the user had (follower count), and the total number of tweets the user shared to date (status count) of tweet examined. The importance and implications for these variables and their relationship with scientific literacy usage on Twitter are further discussed in Chapter Five. The user locations were grouped into provinces. Tweets were also grouped into the months (March to December 2020) they were shared. Finally, due to the extensive range of follower and status counts, we grouped follower and status counts into categories as well. We examined potential associations between the above variable and scientific literacy codes using a chi-Squared with phi or Fischer's exact two-sided test. Frequency counts were also calculated during our analysis process.

***Trustworthiness of Study***

We employed various techniques at each preparation stage in our study to establish trustworthiness. We have discussed the majority of these techniques in-depth above but will highlight them in this section for clarity. The three phases we will be discussing come from Elo et al.'s (2014) article *Qualitative Content Analysis: A Focus on Trustworthiness*. Beginning with the preparation phase, we used a large unstructured Twitter data set. We initially collected more data than possible to analyze for our study from a sizeable saturated data set. Based on social media research methodology research, we choose two suitable sampling techniques for our particular type of data. Furthermore, we employed random number generator programs in Excel and Python to eliminate human error and subjectivity when performing simple random sampling.

In our methodology's organizational phase, we employed both inductive and deductive techniques. We used a methodological approach when coming up with our a priori codes. Our code books for tweet topic was determined through multi-stage analysis of a sample of our data preformed by multiple coders. The process was iterative. We continually paired down topics until there was little to no overlap in our final three topics. In our codebook, we have definitions and examples for each code. The scientific literacy codes were developed deductively through an extensive literature review. The codes were tested on a pilot coding dataset by multiple coders before being used for the final content analysis. The testing of our codebooks was done in collaborative meetings with our four coders. The codes were created as a group and verified before the primary coder used them for analysis. To ensure consistency with coding, three secondary coders trained the primary coder. Each discrepancy between the coders was discussed and evaluated before assigning a final code to the tweet in the pilot testing/training phase. Additionally, when performing the content analysis, the primary coder reviewed each of the assigned codes of the 2 600 tweets at least two times—ensuring that the codes assigned were as accurate as possible based on our code books.

In the reporting phase, we provide an overview of the results in the following section and more detailed descriptive of the data in each stage in Appendix B and Appendix C. Throughout our data collection, analysis, and final recording of result, we kept each iteration of the dataset. We did not delete any data in the process, and we have records of our original dataset downloaded from the repository. Moreover, we retained a copy of each data set at every sampling stage, coding, analysis, and data visualization for reference. The original dataset we used is also freely available for any researcher to download and analyze similarly. Finally, we ensured trustworthiness overall by providing detailed descriptions and explanations regarding each stage in our methodology, from data collection to analysis.

## Chapter 4 – Results

Our results were found by analyzing 2 600 manually coded tweets. The following sections outline the results from our content analysis and statistical tests, and visual representations of our data.

### Scientific Literacy Coding Results

Out of the 2 600 tweets examined, we found that 10% ($n$ = 269) displayed scientific literacy, meaning they demonstrated at least one scientific literacy trait. A lack of scientific literacy was found in 2.4% ($n$ = 63) of the tweets coded. The remaining 87% ($n$ = 2268) of tweets were deemed neither to demonstrate scientific literacy nor a lack of scientific literacy and were coded as not applicable.

The tweets displaying scientific literacy were further broken down into scientific literacy traits. Scientifically literate tweets utilized a variety of combinations of the scientific literacy traits, ranging from one to all three. Of the 269 scientific literacy tweets, the habits of mind trait was found in 158 of the tweets, the trait science and society in 172 of the tweets, and the science literacy trait found in 107 tweets. Table 6 outlines the number of tweets categorized to each combination of scientific literacy traits and examples of tweets coded to different combinations. In total, 38% ($n$ = 101) of the tweets utilized only one of the scientific literacy traits, 36% ($n$ = 98) used a combination of two of the scientific literacy traits, and 26% ($n$ = 70) utilized all three of the scientific literacy traits. This resulted in approximately two-thirds (63%) of the tweets examined displaying a combination of two or more of the different scientific literacy traits.

**Table 6**

*Scientific Literacy Traits Breakdown*

| Scientific Literacy Trait Combination | % of Tweets Displaying Trait(s) | Example of Tweet |
|---|---|---|
| Habits of Mind | 13 (*n* = 36) | "@CP24 I'm guessing neither He or his so called "experts" ever read. This news is over a week old now. The WHO changed their direction & is urging countries NOT to use a LOCKDOWN as a primary measure of controlling COVID. https://t.co/FsEFN5HgWt" |
| Science and Society | 13 (*n* = 36) | "AODA is law.<br>Cities must be accessible to all.<br>Plexi glass and arrows are barriers to those with vision impairments.<br>Guide dogs are not trained in social distancing.<br>Accessibility is a right for all. #AODA" |
| Science Literacy | 11 (*n* = 29) | "@BuddyJayQ @RexChapman What a dummy this guy is.<br>The U.S. has 8.8 x the population of Canada (328m to 37m) and yet they have 22x the deaths from COVID-19. Wake up from your coma and learn some friggin math. Just like a Trumper to use testing numbers." |
| Habits of Mind, Science and Society | 8 (*n* = 20) | "Iâ€™ll wear a mask anytime to prevent another system wide shutdown of the economy. No one likes wearing a mask but to protect our way of life? Anytime. https://t.co/4hlWVwV94j" |
| Habits of Mind, Science Literacy | 12 (*n* = 32) | "Uh oh. "The latest epidemiological modelling by B.C. health officials shows recent contact rates in the province are at 65 per cent of normal â€" hovering near the threshold for a potential rebound of new cases of #COVID19" – which is 60% #bcpoli #masks4all https://t.co/Tf7qEFipV1" |
| Science and Society, Science Literacy | 17 (*n* = 46) | "@CPHO_Canada The govt can #FlattenTheCurve by implementing centralized aggressive testing and bypass the provinces with the Emergencies Act" |
| Habits of Mind, Science and Society, and Science Literacy | 26 (*n* = 70) | "@JohnTory @cityoftoronto @ChiefPeggTFS @Toronto_Fire @TPFFA Covid numbers continue to climb. When is the city going going to roll things back again? It's time to take action and go back to phase 1 to curb the spread. It's time to shut non-essential businesses down again." |

## Analysis of Trends and Factors Association to Scientific Literacy

### *Tweet Attributes*

The first tweet attribute we examined was the tweet topic of discussion (tweet topic). Out of the 2 600 manual coded tweets, 423 (16%) were coded to consequence, 394 (15%) coded to politics, 1005 (37%) coded to response, and 778 (30%) were not applicable. We only examined the tweets coded to the first three topics (consequence, politics, and response) for scientific literacy. Table 7 breaks down the tweets coded to scientific literacy and no scientific literacy by topic. A Fischer's exact test (2-sided) was used to measure the relationship between the tweet topic and scientific literacy/no scientific literacy. A strong relationship was found between the tweet's topic and if it uses scientific literacy or not, $p = 0.00$, $\phi_c = 1.00$.

The relationship between the topic and scientific literacy usage and all the following relationships were examined using Fischer's exact test, and chi-squared was used to test the independence of the two variables. The strong relationship here indicates that topic and scientific literacy usage are dependent or correlated. However, Fischer's exact test does not tell us the direction of the connection (i.e., which one is the independent variable and the dependent variable), only that the usage of scientific literacy and the topic is being discussed are connected. A lack of a relationship would indicate that the two variables are independent or not correlated.

**Table 7**

*Scientific Literacy Coded Tweets Separated into Topics*

| | **Scientific Literacy** | | **No Scientific Literacy** | |
|---|---|---|---|---|
| **Topic** | ***N*** | **%** | ***N*** | **%** |
| Consequence | 68 | 16 | 6 | 1 |
| Politics | 29 | 7 | 18 | 5 |
| Response | 172 | 17 | 39 | 4 |

To explore this relationship more in-depth, we investigated how topics were distributed within the scientific literacy and no scientific literacy codes compared to the whole dataset of applicable tweets. The distribution of tweets into topics for each category can be found in Figure 5. Furthermore, we also examined the tweet's topic in relation to the utilization of scientific literacy traits. This breakdown can be found in Table 8. A chi-squared test with phi used to measure the strength of the relationship indicated that there is a strong relationship between tweet topic and the utilization of scientific literacy traits, $\chi^2(1, N = 269) = 12.387, p = 0.015, \Phi = 0.215$.

**Figure 5**

*Distribution of Topics coded to Tweets categorized as Scientific Literacy, No Scientific Literacy, and All Applicable Tweets*

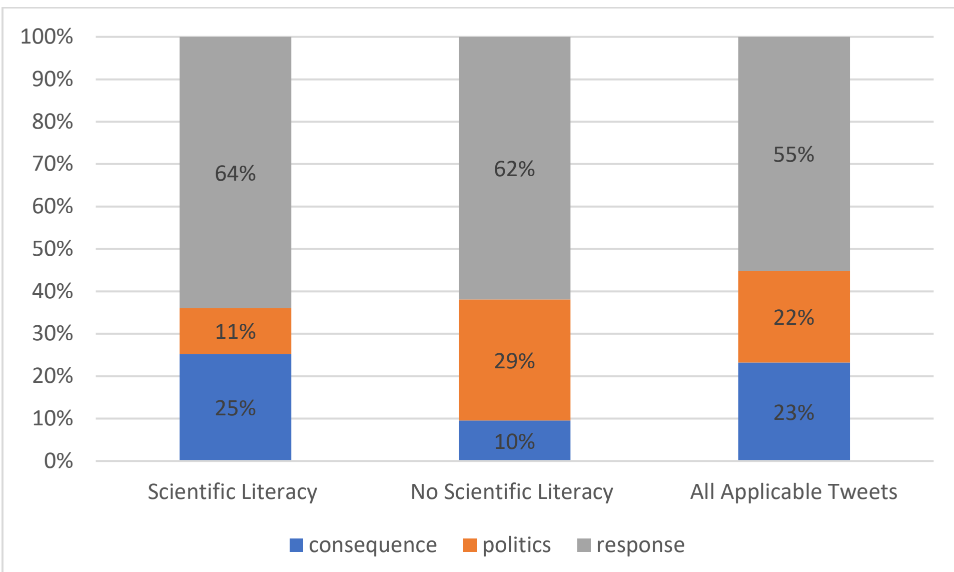



**Table 8**

*Scientific Literacy Trait Usage by Topic*

| | One Trait | | Two Traits | | All Traits | |
|---|---|---|---|---|---|---|
| **Topic** | ***N*** | **%** | ***N*** | **%** | ***N*** | **%** |
| Consequence | 27 | 28 | 32 | 33 | 9 | 13 |
| Politics | 9 | 9 | 14 | 14 | 6 | 9 |
| Response | 65 | 64 | 52 | 53 | 55 | 79 |

The second attribute of the tweets we examined in relation to scientific literacy was the date when the tweet was shared. Table 9 and Figure 6 display the frequencies and percentages of scientific literacy identified each month. A chi-squared test with phi was used to examine the relationship between the two variables. There was no dependent relationship found between scientific literacy usage and the month the tweet was shared, $\chi^2(9, N = 332) = 0.618$, $p = 0.618$.

**Table 9**

*Scientific Literacy Coded Tweets Separated into Months*

| | Scientific Literacy | | No Scientific Literacy | |
|---|---|---|---|---|
| **Month (Total Tweets)** | ***N*** | **%** | ***N*** | **%** |
| March (300) | 29 | 9.7 | 6 | 2.0 |
| April (250) | 21 | 8.4 | 2 | 0.8 |
| May (250) | 22 | 8.8 | 5 | 2.0 |
| June (250) | 24 | 9.6 | 3 | 1.2 |
| July (300) | 38 | 12.7 | 6 | 2.0 |
| August (200) | 21 | 10.5 | 5 | 2.5 |
| September (300) | 33 | 11 | 10 | 3.3 |
| October (250) | 26 | 10.4 | 11 | 4.4 |
| November (250) | 31 | 12.4 | 8 | 3.2 |
| December (250) | 24 | 9.6 | 7 | 2.8 |
| **Average** | 27 | 10.3 | 6 | 2.4 |
| | (*SD* = 4.09, *CV* = 0.66) | | (*SD* = 1.37, *CV* = 0.93) | |

***User Attributes***

The first user attribute relationship examined was the user's locations and the tweets that displayed scientific literacy. Figure 7 and Table 10 display how the tweets coded to scientific literacy of respective user locations are distributed across Canada. It is shown as percentages of the total number of tweets collected from each location. Not all provinces and territories are represented in our data set. A breakdown of the number of tweets collected and coded to scientific literacy and no scientific literacy for each location can be found in Table 10.

**Figure 6**

*Usage of Scientific Literacy over a 10-Month Period*

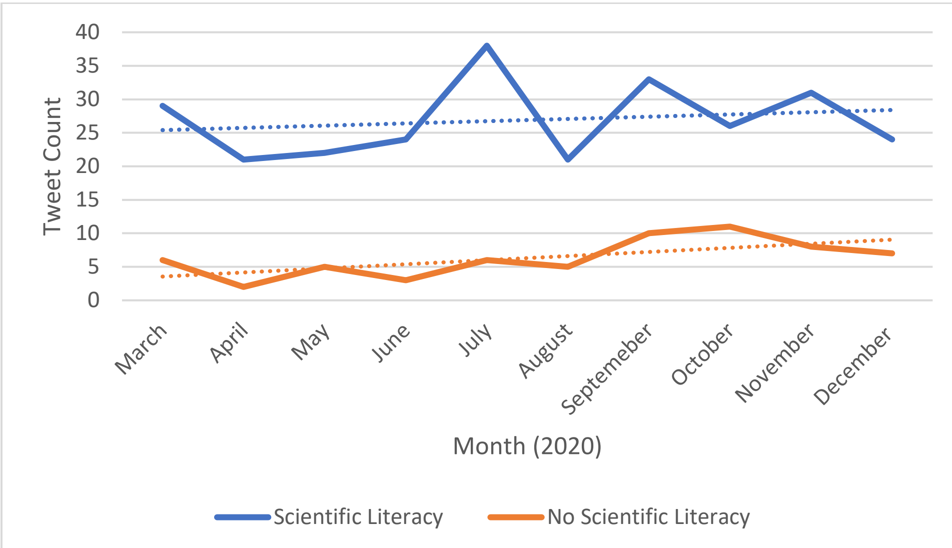



**Table 10**

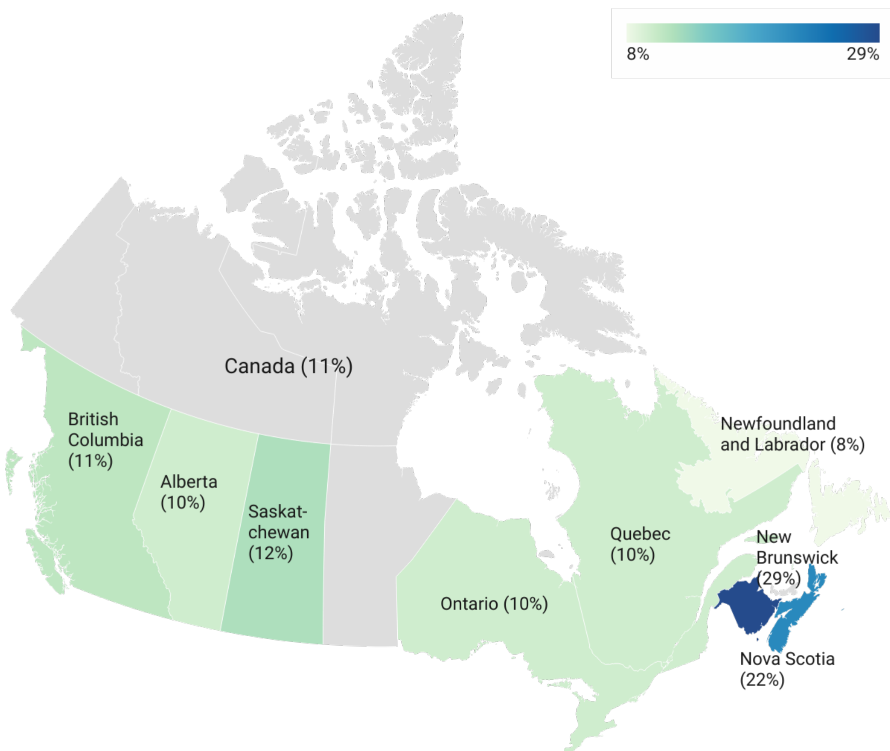
*Scientific Literacy Tweets Broken Down by Location*

| | # Tweets Collected | | Scientific Literacy | | No Scientific Literacy | |
|---|---|---|---|---|---|---|
| **Location** | ***N*** | **% (Dataset)** | ***N*** | **%** | ***N*** | **%** |
| British Columbia | 322 | 12 | 34 | 11 | 7 | 2 |
| Alberta | 318 | 12 | 32 | 10 | 9 | 3 |
| Saskatchewan | 33 | 1 | 4 | 12 | 2 | 6 |
| Manitoba | 16 | 0.6 | 0 | 0 | 0 | 0 |
| Ontario | 1254 | 48 | 125 | 10 | 25 | 2 |
| Quebec | 48 | 2 | 5 | 10 | 1 | 2 |
| New Brunswick | 7 | 0.3 | 2 | 29 | 0 | 0 |
| Nova Scotia | 18 | 0.7 | 4 | 22 | 0 | 0 |
| Newfoundland and Labrador | 13 | 0.5 | 1 | 8 | 0 | 0 |
| Canada (unspecified) | 571 | 22 | 62 | 11 | 19 | 3 |

The other two user attributes examined concerning the utilization of scientific literacy were status count and follower count. Table 11 displays the scientific literacy usage regarding the number of statuses a user has sent. Table 12 shows scientific literacy usage regarding the user's total number of followers. We examined both relationships using Fischer's exact test (2-Sided), which found no association between status count and scientific literacy usage ($p$ = 0.59) and follower count and scientific literacy usage ($p$ = 0.565). We used Fisher's exact test (2-Sided) to measure the relationship between user location and scientific literacy usage in Canada. We found no association between the two variables, $p$ = 0.832.

**Figure 7**

*% of Tweets Displaying Scientific Literacy Usage Across Canada*




The other two user attributes examined concerning the utilization of scientific literacy were status count and follower count. Table 11 displays the scientific literacy usage regarding the number of statuses a user has sent. Table 12 shows scientific literacy usage regarding the total number of followers the user has. We examined both relationships using Fischer's exact test (2-Sided), which found no association between status count and scientific literacy usage ($p = 0.59$), and follower count and scientific literacy usage ($p = 0.565$).

**Table 31**

*Scientific Literacy Usage by Status Count Range*

| | Scientific Literacy | | No Scientific Literacy | |
|---|---|---|---|---|
| **Follower Range** | ***N*** | **%** | ***N*** | **%** |
| <500 | 18 | 7 | 4 | 6 |
| 500-1000 | 14 | 5 | 2 | 3 |
| 1000-2000 | 16 | 6 | 9 | 14 |
| 2000-4000 | 37 | 14 | 6 | 10 |
| 4000-8000 | 36 | 13 | 6 | 10 |
| 8000-16000 | 38 | 14 | 11 | 17 |
| 16000-32000 | 39 | 14 | 10 | 16 |
| 32000+ | 59 | 22 | 14 | 22 |
| Unknown | 12 | 4 | 1 | 2 |

**Table 42**

*Scientific Literacy Usage by Follower Count Range*

| | Scientific Literacy | | No Scientific Literacy | |
|---|---|---|---|---|
| **Follower Range** | ***N*** | **%** | ***N*** | **%** |
| <500 | 133 | 49 | 32 | 51 |
| 500-1000 | 30 | 11 | 12 | 19 |
| 1000-2000 | 39 | 14 | 11 | 17 |
| 2000-4000 | 28 | 10 | 2 | 3 |
| 4000-8000 | 18 | 7 | 3 | 5 |
| 8000-16000 | 9 | 3 | 1 | 2 |
| 16000-32000 | 6 | 2 | 1 | 2 |
| 32000+ | 6 | 2 | 1 | 2 |

## Chapter 5 – Discussion

The following section will discuss the results of our analysis found in the previous chapter. This study aimed to explore the nature of scientific literacy usage in Canada on Twitter when navigating the prominent scientific issue, COVID-19. We used the following research questions to guide our analysis and interpretation of the results; (1) What is the nature of scientific literacy usage in Canada on Twitter when navigating, discussing, and disseminating information about the COVID-19 pandemic? (2) What are the trends and factors affecting the usage of scientific literacy in Canada on Twitter? Two main takeaways from the data analysis were that scientific literacy traits are primarily used in combination when discussing COVID-19, and there is a strong relationship between scientific literacy usage and the topic being discussed. These results will be further explored in the following sections of this paper.

### Nature of Scientific Literacy Usage on Twitter

First, we will explore our primary research question; what is the nature of scientific literacy usage in Canada on Twitter when navigating, discussing, and disseminating information about the COVID-19 pandemic? We considered what aspects and how scientific literacy was being employed in the tweets. It is important to remember that determining the scientific literacy usage of a single tweet does not accurately assess the overall scientific literacy abilities of the user. We sought to understand more about how scientific literacy is represented on Twitter by analyzing the discourse on the platform. Someone who is scientifically literate, such as a science communicator, may not demonstrate scientific literacy in every tweet they share. This was shown in many tweets collected ($n = 2268, 87\%$).

Another element that we had to be aware of when assessing the scientific literacy of tweets was the evolution of knowledge regarding the science behind COVID-19 and the pandemic. Scientists and officials' recommendations changed over time. As described in the habits of mind component of scientific literacy, a scientific literate person understands that science is tentative and can adjust their understanding of a topic as new information emerges. While we could not track individuals' changes in tweeting habits over time, we did consider this change in knowledge when determining if a tweet displayed scientific literacy or not.

### *Scientific Literacy is Nuanced*

Scientific knowledge occurs in personal and social contexts (AAAS, 2009; Naganuma, 2017; OECD, 2019). As these contexts change, it is possible for how scientific literacy is displayed to vary. We considered this in our analysis by recognizing that the science and public protection behaviour changed throughout the first 10-months of the pandemic. For example, at the pandemic's beginning, a scientifically literate tweet could include something like "The govt can #FlattenTheCurve by implementing centralized aggressive testing and bypass the provinces with the Emergencies Act" (March 18, 2020). While towards the end of the pandemic, scientific literacy was being displayed in discussions of personal mitigation efforts, for example:

> "I can't see it happening. There are far too many people who claim covid is nothing to worry about. If they won't wear masks, why in the world would they accept a vaccine? My estimate is 30% of the population will actually take the vaccine. Not a fact, just my opinion."
>
> (December 13, 2020)

This is to say, consistent with the literature, a scientifically literate person adjusts their behaviour and understanding based on new information. We found this reflected in the scientifically literate tweets in our dataset.

The methodology chapter stated that we had the most considerable discrepancy between the primary and secondary coders when assigning scientific literacy traits (habits of mind, science and society, and science literacy) to tweets. Through further discussions to agree on coding scientific literacy traits, we determined that the discrepancies were due to the nature of the scientific literacy traits themselves. The three traits of a scientifically literate person work together to form well-rounded scientific literacy abilities. The traits overlap and are intertwined and thus are often used together to support one another. For example, to interpret and critique scientific findings presented in the media (habits of mind), one must often understand fundamental scientific principles and interpret representations of scientific findings (science literacy).

Due to the interconnectedness of the scientific literacy traits, one could argue that any tweet employing scientific literacy utilizes all the traits. Furthermore, the conciseness of the tweets also presented a challenge when performing coding for scientific literacy traits. For our study, we wanted to focus on the main traits displayed. When coding the scientific literacy traits, we found that some of us picked up the more subtle representation of traits than others. This led to wider discrepancies. We determined that when we categorize scientific literacy traits, coding consistency is important. Therefore, we decided that since our primary coder was consistent, they were reliable.

However, it needs to be stated that quantifying what traits tweets are exhibiting and in what specific combination is less important than the fact that the tweets display some form of scientific literacy. While the statistical data is interesting, the qualitative understanding of the tweets is more important due to the uncertainty of what scientific literacy traits are employed. In our analysis, we decided to group the traits into how they were being represented (e.g., one trait, two traits, or all traits) versus the specific trait themselves. We did this grouping to help reduce the subjectivity in determining what traits individual tweets were displaying and focus on the number of scientific literacy traits displayed.

***Holistic Usage of Scientific Literacy***

We found that 63% of the tweets displaying scientific literacy demonstrated the use of two or more scientific literacy traits. This indicates a tendency for a holistic usage of scientific literacy versus just one part of it. Holistic usage (i.e., a tweet displaying all scientific literacy traits) was often portrayed in tweets as simple as "I wear a mask to protect others" or "#MasksSaveLives." Tweets such as these demonstrate that ways to mitigate COVID-19 are scientifically investigable phenomena (science literacy), that there is trust in science/scientists, and it is used in personal decision making (habits of mind), and finally, there is an understanding of how science is applied to real-world situations and how science is connected to society (science and society). This example shows that online discussions and comments do not have to be extensive to employ scientific literacy holistically.

We also need to consider that tweets labelled as only displaying one trait could have also been subtilty employing other scientific literacy traits not immediately apparent to our coders (as discussed previously). Scientific literacy usage ranged in length and topic, from discussions on government-mandated lockdowns and findings from scientists to personal mitigation efforts such as mask-wearing. This vast range of representations indicates that scientific literacy is apparent in many forms on Twitter when discussing the COVID-19 pandemic.

***Representations of a Lack of Scientific Literacy***

Identification of tweets displaying a lack of scientific literacy was straightforward, as they often stated incorrect information or disagreed with scientific evidence. Tweets showing a lack of scientific literacy (coded to no scientific literacy) were less subtle in how they represented it than tweets displaying scientific literacy. Some tweets that lack scientific literacy discussed the false notion that governments planned or created the pandemic. In contrast, others focused on criticizing scientifically-backed mitigation efforts. Often the misinformation shared was not as nuanced as expected, and most individuals with a basic level of scientific literacy could identify it as misinformation. Examples of such tweets are:

> "@realDonaldTrump Trump won bidden cheated! This is god I have sent you the angel of death! The virus was created by the pope and to destroy the lives of all non-Christians and to build hate against the Chinese so they can start a war! Trudeau have billions of dollars hidden in China I know." (December 23, 2020)

> "A hundred percent we got SCAMMED by this PANDEMIC which was a SCAM-DEMIC and this SCAM-DEMIC has been forced down on us whether we believed in it or not and now OUR RIGHTS and FREEDOMS are being taken away by MAYORS like @BonnieCrombie @patrickbrownont @JohnTory" (July 4, 2020)

> "@brianlilley Cases mean nothing... even the deaths are not extraordinary, there was never a pandemic.. general rule is 7% of the population perish in a pandemic, thatâ€™s 2.7 MILLION Canadians.. we are at a shade over 9000 right now...most of whom would have succumbed to the seasonal flu.." (September 14, 2020)

While these tweets can be reasonably straightforward to identify as misinformation, other tweets could be more challenging to identify without some background knowledge of the science behind COVID-19. As seen in tweets discussing hydroxychloroquine and the lack of government approval for the drug that could "end COVID-19". Or in other tweets that misinterpret the science behind PCR testing for COVID-19. For example:

> "@globeandmail Covid19 testing is a scandal & not fit for purpose. False positives & false negatives are high; you can test positive for up to 83 days & I cannot even find what cycle value is being used. With the same sample, a 20 cycle could = a healthy person, 40 cycle=a pandemic." (August 8, 2020)

Misinformation was and continues to be a concern for scientists, science communicators, and educators alike. With the lack of gatekeepers on social media platforms, such as Twitter, misinformation can be shared easily (Zha et al., 2018). However, we found that significantly more tweets displaying scientific literacy were shared than ones showing a lack of scientific literacy. Only 2.4% of our dataset contained tweets that we identified as lacking scientific literacy. Our small-scale study demonstrates that while we hear about misinformation being exceptionally prominent on social media, it might not be typical as correct information being shared. Our study may appear to conflict with the results from Bridgeman et al.'s (2021) study examining Canadian Twitter, which found high levels of misinformation circulating on Canadian Twitter. However, it should be noted that we did not specifically examine the presence of misinformation. Instead, we examined how people employed scientific literacy through tweets. Which is not necessarily equivalent to the accurate sharing of information or not. Misinformation surrounding the COVID-19 pandemic threatens public health and can endanger lives (World Health Organization, 2020b). Therefore, efforts to mitigate misinformation being spread are still vitally important.

**Trends and Factors of Scientific Literacy Usage on Twitter**

Our secondary research question, which addressed the trends and factors affecting the usage of scientific literacy in Canada on Twitter, led us to explore user and tweet attributes. This data was drawn from each tweet's metadata or found through inductive coding methods. The data gives us more context about the Twitter user who shared the tweet and information about the tweet itself. We choose to examine the following factors; when the tweet was shared, the topic of the tweet, location of the user as specified in the bio, number of tweets the user has shared (status count), and number of followers the user who shared the tweet has (follower count). Unfortunately, due to the nature of our data, we cannot identify a direction of association between scientific literacy usage and these factors if there is a relationship. However, we can offer a possible explanation for why a particular phenomenon occurred or did not occur.

### *Usage of Scientific Literacy Over the Ten Months*

Two prominent phenomena are cited in the literature as affecting an individual's decision-making ability during a pandemic. At the beginning of the pandemic, individuals are at risk of information overload. Lots of new information is coming at consumers at once. In an early study of the COVID-19 pandemic, Farooq et al. (2020) found an abundance of information available, which could fatigue individuals' ability to interpret information and follow public health recommendations. As the pandemic progressed, a new phenomenon was recognized, aptly named pandemic fatigue. Pandemic fatigue occurs overtime during a prolonged public health crisis, such as the COVID-19 pandemic, and a decrease in motivation to partake in protective behaviours (World Health Organization, 2020a). This behaviour is because as individuals become used to the pandemic, the threat decreases, restrictions cause people to feel that they have little control over their lives, and individuals' risk assessment changes (World Health Organization, 2020b). For example, an individual can feel that "the cure is worse than the disease."

We sought to see if these two phenomena's effect was identifiable in our Twitter data. In particular, we wanted to see if information overload and pandemic fatigue influence the usage of scientific literacy on Twitter. Statistical tests used to determine if there was a relationship between the usage of scientific literacy and the lack of scientific literacy over the ten months found no association. Meaning, that our dataset did not show any difference in the use of scientific literacy over the ten months.

Since our study only examines a relatively short period of the still ongoing pandemic, we cannot conclusively determine that information overload and pandemic fatigue do not exist on Twitter. A possible explanation for our results could be that information overload occurred over our entire dataset, resulting in us seeing approximately the same amount of scientific literacy usage throughout. Additionally, since pandemic fatigue occurs slowly, the ten-month period could not have been long enough to be fully apparent to a large portion of the population. Thus, our dataset would not have been large enough to pick up a significant number of tweets influenced by pandemic fatigue. A larger dataset over a longer timeframe needs to be examined to fully confirm the existence or lack of information overload and pandemic fatigue.

***Tweet Topics and Scientific Literacy Usage***

We examined the topic of tweets to see if what was being discussed about the pandemic affected and how scientific literacy was being displayed. Exploring the tweet's topic allows us to see if what aspect of the pandemic is being discussed can influence how people interpret scientific information. Out of all the tweets we examined (including ones marked not applicable for scientific literacy), the most common topic of discussion was response (37%), followed by consequence (16%) and politics (15%). Health and science communication literature highlight social media to spread information about self-protective behaviours during crisis and disasters (Farooq et al., 2020). Response or the discussion of how people were combating and reacting to the pandemic is the most common topic of discussion is confirmation of this. Furthermore, when examining only the tweets that display scientific literacy or a lack of scientific literacy, response was also the most common topic of discussion, 64% and 62%, respectively.

The more interesting results came when examining the usage of scientific literacy when discussing consequences and politics. The tweet topic and usage of scientific literacy were the only statistically significant relationship found. Of the tweets that displayed scientific literacy, 25% discussed consequences, and 11% discussed politics. The opposite happened with tweets that showed a lack of scientific literacy, with 10% discussing consequences and 29% discussing politics. These results should be investigated further in a more in-depth study on discussion topics and scientific literacy.

However, a possible reason for this occurrence can be explained by the post-truth phenomena. Examination of early pandemic responses shows that partisanship and polarization about the pandemic are found among the public and politicians in the United States. In Canada, researchers found that the pandemic was presented in the same way among different political parties and politicians (Funk & Tyson, 2020; Merkley et al., 2020). At the same time, while Canadian politicians were united on the pandemic response (at least as evident in the early months of the pandemic), it did not stop individuals from sharing tweets about United States politics and being influenced by the United States' response. We found many tweets that discussed the then United States president, Donald Trump, and his response to the pandemic. It also should be noted that the United States presidential election, which featured pandemic response as a prominent part of candidate's platforms, occurred in November 2020 at the end of the ten months investigated in our study.

The partisanship occurring in the United States surrounding the pandemic may have affected individuals' usage of scientific literacy on Twitter. As described in the post-truth era, people sometimes rely more on emotions and personal beliefs than validated scientific knowledge (Sinatra & Lombardi, 2020). Pandemic fatigue could also play a role in this phenomenon, in which people are relying more on their possible biased individual experience of the pandemic and its lack of severity. Individuals may feel that the pandemic is not as much of a threat as politicians are making it out to be, and they then feel the need to share tweets that criticize the government's response to the pandemic (i.e., lockdowns, mask mandates, etc.).

On the other hand, individuals sharing tweets displaying scientific literacy focus on discussing consequences could be because they understand the severity of the pandemic even if it is not apparent in their personal experiences. The science and society trait plays a role in this explanation, as scientifically literate individuals understand how science is applied to real-world life. For example, we found tweets that discussed results from scientific studies examining the long-term effects of COVID-19. While the risk of COVID-19 infection may appear low, the long-term consequences increase the importance of mitigating COVID-19. Understanding the implications of the pandemic also often requires reading and interpreting the mathematical representations of case counts and the spread of COVID-19, which falls under the science literacy trait of a scientifically literate person (Braund, 2021). Sharing case counts and statistics was another common theme among tweets discussing consequences. The lack of discussion of the politics around the pandemic in tweets displaying scientifically literate traits can be explained by an understanding of the interdisciplinary nature of science. At first glance, the government's response to the pandemic may seem incorrect. Still, scientifically literate individuals consider all facets of decision-making around scientific issues as they know that science and technology have many implications, including political, moral, ethical, and social implications. The pandemic highlighted this as politicians tried to balance the response with its stress on the economy (i.e. lockdowns) (Braund, 2021). Therefore, scientifically literate tweets may be less likely to criticize or discuss government response when considering these aspects.

We also found a strong relationship between the combination of scientific literacy trait usage (e.g., one trait displayed, two traits displayed, or all traits displayed) and the tweet's topic. As discussed previously, assigning and quantifying scientific literacy traits to tweets can be subjective. The more important factor is whether the tweet employs any scientific literacy traits. However, we will briefly discuss an explanation for this strong relationship (apart from the subjectivity of coding). Our analysis found that a more significant number of tweets displaying all traits discussed the pandemic's response (One Trait – 64%, Two Traits – 53%, All Traits – 73% discussed response). This could be because understanding and employing mitigation strategies often need scientifically literate individuals to use all three traits. For example, you need to understand the science behind why the mitigation efforts are being used (i.e., masks protect others from you by limiting the spread of droplets) – science literacy, the comfort and trust in science and scientists to follow recommendations – habits of mind, and finally apply the science to your everyday life in real-world situations (i.e., wearing a mask) – science and society. These explanations are only hypotheses of what phenomena could cause this strong relationship between scientific literacy usage and the topic of discussion. Further studies should be conducted to examine this occurrence and better understand what is happening.

### *Other Factors Affecting Scientific Literacy Usage*

Three additional factors were examined to see if they had a relationship to scientific literacy usage. All three showed no relationship to scientific literacy usage in statistical tests. The first was the location. We decided to examine location due to the socio-cultural contexts varying from province to province. Furthermore, the pandemic affected and was handled by provinces differently, as demonstrated by the "Atlantic Bubble" (Nova Scotia, New Brunswick, PEI, and Newfoundland and Labrador) formation in June 2020 (Communications Nova Scotia, 2020). Our results showed that location was not a factor in the use of scientific literacy, with each location (including Canada in general) displaying scientific literacy in approximately 10% of tweets collected from that location. This percentage matches the percentage of tweets that show scientific literacy in the dataset (10% of the 2600 tweets examined).

Three outliners to the 10% average are New Brunswick (29%), Nova Scotia (22%), and Manitoba (0%). These percentages can be easily explained by the number of tweets sampled from these locations. We only collected seven tweets from New Brunswick and 18 from Nova Scotia, so a small number of tweets displaying scientific literacy from those provinces will result in a large percentage of total tweets collected. We also only collected 16 tweets from Manitoba, and most likely, by pure chance, we did not collect any tweets displaying scientific literacy. Furthermore, it needs to be mentioned that our location comes from the free-form text field of the user bio, which is not the exact location of each Twitter user. Therefore, we can conclude from the data that scientific literacy is displayed at the same rates in tweets across Canada.

The last two factors examined were the number of user tweets (status count) and the number of followers (follower count). We were interested in seeing if tweeting frequency affects who displays scientific literacy in their tweets. Furthermore, analyzing the follower count allowed us to see if a user's popularity affected scientific literacy usage. Unsurprisingly, there was no relationship between these two factors and the display of scientific literacy in tweets. These results aligned with the literature, as no researchers have found any connection between these factors and the quality of information shared. Scientific literacy is a skill that someone can have regardless of their social media habits, as it applies to all aspects of everyday life.

**Limitations**

Our study has several limitations, some of which we have mentioned in previous chapters. Many of the limitations we encountered were due to the nature of our dataset and data. There is only so much you can pull from one 260-character maximum tweet. Some tweets were so short in length that we could not identify what they were discussing without further context. The type of language used on Twitter also presented challenges. Tweets often are not grammatically correct and use many different short forms. This sometimes hindered our ability to understand what the tweet was discussing. The inconsistency in language also challenges artificial intelligence software when learning from and further identifying other related tweets.

Moreover, our dataset only provided the tweet themselves. They did not always include the context of the tweet. It was often difficult to understand what the person was saying in the tweet without the context of the discussion on Twitter, which leads to another limitation in our study. Science communication researchers identify that the context and comments can affect how someone interprets the information (Brossard & Scheufele, 2013). We could not examine how this could affect the usage of scientific literacy on Twitter due to how we downloaded tweets from the Twitter API. An additional challenge due to our dataset's nature was accurately identifying what tweets originated from Canada. Likely, some tweets associated with a user location in Canada were not sent by someone who lives in Canada. There are no restrictions on what you put in the location section of the user bio. We also found that some users had multiple locations listed when initially parsing the entire dataset.

Furthermore, unless a user included a province or country in their location, we could not confidently say they were from Canada, so we did not use those tweets. The short form of Canada (CA) is also the short form of California, so some cities from California had the potential to be included in our more extensive dataset. Fortunately, we were able to verify that of 2 600 manually coded tweets, none of them referenced a location in California. Also, only using the metadata provided by the Twitter API limited the descriptive data we could get from each Tweet. There was no way to accurately determine a Twitter user's bio's age, gender, educator, occupation, and other standardly examined variables. Therefore, we could not investigate the relationship of any of these variables with scientific literacy.

While this study looks at individuals' usage of scientific literacy online, it is impossible to completely isolate all organizational accounts (e.g., government, business, news media, charity, groups, etc.). By removing verified accounts from the data set, influential organizations were not included in the data set, such as the Government of Canada, Health Canada, CTV News, and CBC News. Removal of verified accounts also removes prominent figures, such as celebrities and politicians. However, this was not an issue for this case study, as the focus is on the average person located in Canada.

The most significant limitation of our study was the size of our dataset. In the beginning, we decided to employ a combination of manual and automatic coding techniques as suggested by other social media researchers. We chose to use NVivo as it is a commonly used qualitative analysis software by social science researchers that includes the feature to auto-code data. Unfortunately, NVivo had issues handling all the data we collected. Furthermore, when we imported a dataset of a more reasonable size, the inter-rater reliability was too poor to include it in our analysis. Therefore, we could only have a small portion of over 1 000 000 + tweets we initially collected. Our small dataset limits our ability to confidently say that our results are generalizable to all Canadian Twitter.

**Future Directions**

Following the discussion on our study's limitations, we will discuss possible future directions for our research. The first thing that we would suggest is to increase the number of tweets examined. We used the text-based classification (auto-coding based on existing codes) feature in NVivo. However, many other relatively new programs found in Google Developer Apps, Microsoft Power Platform, and other paid services should be explored for Twitter data research. Another option to expand the dataset size that can be analyzed is to use crowdsourcing to code the tweets.

We choose to examine Canada because it is where we are located, and there is a lack of research on how Canadians navigate scientific issues online. However, due to the global use of Twitter, this research methodology could be expanded to other locations as scientific issues are often context-specific issues. COVID-19 offers a unique situation where the same scientific issue affected the entire world. Different regions and countries' pandemic responses were vastly different. Exploring individuals' scientific literacy on Twitter within different socio-cultural contexts will help further understand how scientific literacy is employed in online spaces.

Finally, we were unable to research how conversations and surrounding comments affect the interpretation of scientific information. Researchers in the future could explore this variable in relationship to scientific literacy on Twitter by following a similar research design except sampling their Twitter data from specific conversations on Twitter, for example, collecting tweets from the replies of a popular post about COVID-19. Thus, giving a better understanding of how conversations affect scientific literacy usage online.

# Chapter 6 – Conclusions

Our case study is an interdisciplinary study that examined discussions surrounding the COVID-19 pandemic on Twitter. We investigated how individuals in Canada on Twitter displayed scientific literacy usage by exploring tweets shared during the first ten months of the COVID-19 pandemic (March 2020 – December 2020). Our research was guided by two research questions: (1) What is the nature of people in Canada's scientific literacy usage on Twitter when navigating, discussing, and disseminating information around the COVID-19 pandemic? (2) What are the trends and factors affecting people in Canada's usage of scientific literacy on Twitter. Our study aims to add to the emergent research in science communication, health communication, and science education fields on how individuals navigate and interpret scientific issues online. With a greater understanding of how individuals navigate and disseminate scientific issues online, we can better equip individuals with the necessary skills to combat misinformation.

The internet has become a breeding ground for misinformation. Science communicators, health communicators, and education researchers are examining how to combat this misinformation. The leading solution is education, specifically scientific literacy, and the ability to critically think about the information they encounter online. Scientific literacy has been studied extensively in formal learning environments. However, the relationship between scientific literacy and informal learning environments, such as social media, is less understood. This study expands on these studies by examining learners of varying ages' communication in an online informal learning environment, looking at how people are enacting scientific literacy outside the school environment. Our exploratory case study sought to help fill this research gap by providing insight into how people in Canada use scientific literacy on Twitter.

We found that scientific literacy is displayed in approximately five times more tweets than those that showed a lack of scientific literacy. Scientific literacy usage is not associated with location, follower count, status count, and when the tweet is shared. However, we suggest that further studies should examine a more extensive period of the COVID-19 pandemic to confirm whether information overload and pandemic fatigue affects scientific literacy usage on Twitter. We did find an association between the tweet topic and scientific literacy usage. Specifically, tweets containing a lack of scientific literacy discussed politics more than tweets displaying scientific literacy. One possible explanation is that discussions of politics often appeal to individuals' emotions versus focusing on scientific fact, as described in post-truth era research. When discussing politics, individuals may be more likely to focus on emotional responses versus their scientific knowledge. Therefore, science and health communicators should be aware of this cognitive dissonance when they present information about COVID-19 and other scientific issues relating to politics online.

Furthermore, we found that all aspects of scientific literacy are used on Twitter. Our content analysis results indicated that individuals adjust their response to COVID-19 issues as new information is presented. This demonstrates that individuals on Twitter are comfortable with science, understand scientific knowledge, and apply it to their own lives. The prevalence of scientific literacy compare to a lack of scientific literacy on Twitter provides hope for the online scientific community. Our small-scale results demonstrate that scientific literacy is one of the main ways people in Canada navigate scientific information on Twitter.

Insights found in our case study can aid in evaluating and developing curriculums that reach their goals of creating scientifically literate citizens. Furthermore, we wish to provide Canadian scientific communicators and educational researchers with a clearer idea of how science and health information is communicated in their own country. As currently, only a minority of current research is being done in a Canadian context. Finally, Twitter data, particularly datasets related to COVID-19, is becoming increasingly abundant and available for all researchers. We hope researchers can use our case study to learn from, expand on, and explore scientific literacy on Twitter in their contexts.

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## Appendix A: Ethics Review Exemption

**Figure 1**

*Confirmation of Research Ethics exemption*

**Samantha Jewett**

**From:** Katelyn [redacted]
**Sent:** October 27, 2020 7:47 PM
**To:** Samantha Jewett
**Cc:** Anton Puvirajah
**Subject:** RE: Research Study Ethics Inquiry

Hello Samantha,

Thank you for your email, and for so thoroughly searching out the applicable information.

One question I have is how do you have access to this github repository? Is it publicly accessible too? If so, I can confirm that based on what you have described, this project – relying solely on publicly available information – is exempt from REB review in accordance with TCPS2 (2018) Article 2.2.

If you'd like to discuss further, please let me know.

Best,
Katelyn

**Katelyn** [redacted]
Human Research Ethics Officer
Western Research
[redacted]

***Supporting scholars through collaboration, communication, and service.***

*PLEASE NOTE: For the most part, Western Research is working remotely until further notice. We appreciate your patience for any delays in responding to requests as we navigate through this transition. COVID-19 information as it relates to research at Western can be found at* https://www.uwo.ca/coronavirus/research.html

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**From:** Samantha Jewett <sjewett2@uwo.ca>
**Sent:** Monday, October 26, 2020 2:01 PM
**To:** Katelyn [redacted]
**Cc:** Anton Puvirajah <apuvira@uwo.ca>
**Subject:** Research Study Ethics Inquiry

1

Dear Katelyn [redacted]

I am a 2nd year Masters of Education student preparing to submit my research proposal within the next few months. My research involves me collecting and analyzing tweets from the Twitter API that discuss COVID-19. I will be collecting the Tweet IDs from the following repository: https://github.com/echen102/COVID-19-TweetIDs. I will then use these IDs to access the tweets' content and metadata through an open source program and the Twitter API.

From my understanding, after attending an ethics seminar with UWO Research Ethics, reading through the TCPS2, and similar studies, ethics approval is not required for my research. I just wanted to confirm that this is the case as I move forward writing and submitting my research proposal.

I have copied the section of the TCPS2 I am referring to and a link to Twitter's privacy policy at the end of this email. I have also CC'd my supervisor in this email.

Thank you,

Samantha

**Samantha Jewett**
MA Graduate Student
Faculty of Education, Curriculum Studies
Western University
[redacted]

**The TCPS2 Document States in Article 2.2 pg. 15-16**

*Public domain with no expectation of privacy*

REB review is also not required where research uses exclusively information in the public domain that may contain identifiable information, and for which there is no reasonable expectation of privacy. For example, identifiable information may be disseminated in the public domain through print or electronic publications; film, audio or digital recordings; press accounts; official publications of private or public institutions; artistic installations, exhibitions or literary events freely open to the public; or publications accessible in public libraries. Research that is non-intrusive, does not involve direct interaction between the researcher and individuals through the Internet, and where there is no expectation of privacy does not require REB review. REB review is not required for cyber-material, such as documents, records, performances, online archival materials, or published third party interviews to which the public is given uncontrolled access on the Internet and for which there is no expectation of privacy.

Exemption from REB review for this type of information is based on the information being available in the public domain, and that the individuals to whom the information refers have no reasonable expectation of privacy. Information in the public domain may, however, be subject to copyright and/ or intellectual property rights protections or dissemination restrictions imposed by the legal entity controlling the information.

There are situations where REB review is required. There are digital sites in the public domain where there is a reasonable expectation of privacy. Privacy expectations may be outlined in the sites' terms of use. When accessing identifiable information in digital sites, such as online groups with restricted membership, the privacy expectation of contributors of these sites is much higher. Research involving information from these types of sources shall be submitted for REB review (Article 10.3).



**Twitter's Privacy Policy outlines that their API is publicly accessible, allowing individuals and companies to access a percentage of it.**
**See https://twitter.com/en/privacy Section 1.2 Public Information.**

## Appendix B: COVID-19 Tweet ID Repository Keywords

**Table 1**

*COVID-19 Tweet Repository Keyword List Adapted From Chen (2020, sec. Keywords)*

| Keyword | Date Added | Keyword | Date Added | Keyword | Date Added |
|---|---|---|---|---|---|
| Coronavirus | 1/28/2020 | Kungflu | 1/28/2020 | stayhome | 3/19/2020 |
| 14DayQuarantine | 3/14/2020 | lock down | 3/16/2020 | stayhomechallenge | 3/16/2020 |
| canceleverything | 3/13/2020 | lockdown | 3/16/2020 | staysafestayhome | 3/18/2020 |
| CDC | 1/28/2020 | N95 | 1/28/2020 | trump pandemic | 3/18/2020 |
| China | 1/28/2020 | Ncov | 1/28/2020 | trumppandemic | 3/18/2020 |
| china virus | 3/18/2020 | outbreak | 1/28/2020 | wear a mask | 6/28/2020 |
| chinavirus | 3/18/2020 | pandemic | 3/12/2020 | wearamask | 6/28/2020 |
| chinese virus | 3/16/2020 | pandemie | 3/31/2020 | Wuhan | 1/28/2020 |
| chinesevirus | 3/16/2020 | panic buy | 3/14/2020 | Wuhancoronavirus | 1/28/2020 |
| Corona | 1/28/2020 | panic buying | 3/14/2020 | Wuhanlockdown | 1/28/2020 |
| corona virus | 3/2/2020 | panic shop | 3/14/2020 | | |
| coronakindness | 3/15/2020 | panic shopping | 3/14/2020 | | |
| coronapocalypse | 3/13/2020 | panicbuy | 3/14/2020 | | |
| Coronials | 3/13/2020 | panic-buy | 3/14/2020 | | |
| COVD | 3/12/2020 | panicbuying | 3/14/2020 | | |
| covid | 3/6/2020 | panicshop | 3/14/2020 | | |
| COVID__19 | 7/9/2020 | panic-shop | 3/14/2020 | | |
| covid19 | 3/6/2020 | PPEshortage | 3/19/2020 | | |
| covid-19 | 2/16/2020 | quarantinelife | 3/16/2020 | | |
| covididiot | 6/28/2020 | quarentinelife | 3/19/2020 | | |
| covidiot | 3/26/2020 | saferathome | 3/19/2020 | | |
| COVID－19 | 3/8/2020 | sars-cov-2 | 3/6/2020 | | |
| DontBeASpreader | 3/16/2020 | sflockdown | 3/16/2020 | | |
| DuringMy14DayQuarantine | 3/14/2020 | sheltering in place | 3/18/2020 | | |
| Epidemic | 1/28/2020 | shelteringinplace | 3/18/2020 | | |
| epitwitter | 3/28/2020 | Sinophobia | 1/28/2020 | | |
| flatten the curve | 3/18/2020 | Social Distancing | 3/13/2020 | | |
| flattenthecurve | 3/18/2020 | SocialDistancing | 3/13/2020 | | |
| GetMePPE | 3/21/2020 | SocialDistancingNow | 3/13/2020 | | |
| InMyQuarantineSurvivalKit | 3/14/2020 | stay at home | 3/19/2020 | | |
| Koronavirus | 1/28/2020 | stay home | 3/19/2020 | | |
| kung flu | 6/28/2020 | stay home challenge | 3/16/2020 | | |

**Appendix C: Summary of Tweets Collected and Coded**

**Table 1**

*SRS Selection of Days of Tweets to Hydrate*

| March 2020 | April 2020 | May 2020 | June 2020 | July 2020 | August 2020 | September 2020 | October 2020 | November 2020 | December 2020 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 2 | 1 | 2 | 2 | 1 | 3 | 1 | 1 |
| 2 | 10 | 5 | 4 | 4 | 3 | 2 | 7 | 4 | 2 |
| 4 | 11 | 8 | 6 | 7 | 6 | 5 | 8 | 5 | 4 |
| 8 | 14 | 10 | 9 | 9 | 10 | 8 | 9 | 9 | 5 |
| 9 | 15 | 12 | 11 | 11 | 12 | 9 | 14 | 11 | 7 |
| 18 | 17 | 14 | 12 | 12 | 14 | 11 | 16 | 12 | 12 |
| 20 | 18 | 18 | 16 | 15 | 16 | 14 | 17 | 17 | 13 |
| 21 | 19 | 21 | 20 | 17 | 18 | 17 | 19 | 20 | 17 |
| 23 | 20 | 22 | 24 | 19 | 22 | 19 | 20 | 21 | 19 |
| 25 | 21 | 26 | 25 | 22 | 24 | 20 | 23 | 22 | 21 |
| 27 | 26 | 27 | 27 | 23 | 26 | 21 | 25 | 26 | 23 |
| 29 | 27 | 29 | 29 | 27 | 27 | 26 | 29 | 28 | |
| 30 | 28 | | | | | 30 | 31 | | |
| 31 | 29 | | | | | | | | |

**Table 2**

*Dates and Number of Tweets Collected*

| Date | # Tweets | Date | # Tweets |
|---|---|---|---|
| 2020-03-04 | 50 | 2020-07-27 | 100 |
| 2020-03-08 | 50 | 2020-08-06 | 50 |
| 2020-03-18 | 100 | 2020-08-14 | 50 |
| 2020-03-23 | 50 | 2020-08-26 | 100 |
| 2020-03-29 | 50 | 2020-09-01 | 50 |
| 2020-04-10 | 50 | 2020-09-08 | 50 |
| 2020-04-14 | 100 | 2020-09-14 | 100 |
| 2020-04-20 | 50 | 2020-09-21 | 50 |
| 2020-04-29 | 50 | 2020-09-30 | 50 |
| 2020-05-02 | 50 | 2020-10-08 | 50 |
| 2020-05-12 | 50 | 2020-10-14 | 50 |
| 2020-05-22 | 100 | 2020-10-19 | 100 |
| 2020-05-29 | 50 | 2020-10-25 | 50 |
| 2020-06-04 | 50 | 2020-11-01 | 100 |
| 2020-06-12 | 50 | 2020-11-09 | 50 |

| | | | |
|---|---|---|---|
| 2020-06-20 | 50 | 2020-11-17 | 50 |
| 2020-06-24 | 100 | 2020-11-26 | 50 |
| 2020-07-04 | 50 | 2020-12-01 | 50 |
| 2020-07-09 | 50 | 2020-12-07 | 50 |
| 2020-07-17 | 50 | 2020-12-13 | 100 |
| 2020-07-22 | 50 | 2020-12-23 | 50 |
| | | Total | 2600 |

**Table 3**

*Number of Tweets Coded to Each Topic*

| Topic | Total Tweets |
|---|---|
| consequence | 423 |
| politics | 394 |
| response | 1005 |
| N/A | 778 |
| Total | 2600 |

**Table 4**

*Number of Tweets from Each Location*

| Province/Location | Total Tweets |
|---|---|
| Canada | 571 |
| Ontario | 1254 |
| Alberta | 318 |
| British Columbia | 322 |
| New Brunswick | 7 |
| Quebec | 48 |
| Manitoba | 16 |
| Newfoundland and Labrador | 13 |
| Nova Scotia | 18 |
| Saskatchewan | 33 |
| Total | 2600 |

**Table 5**

*Number of Tweets Collected Sorted into Follower and Status Ranges*

| Range | Follower Tweet Count | Status Tweet Count |
|---|---|---|
| <500 | 1153 | 169 |
| 500-1000 | 394 | 119 |
| 1000-2000 | 370 | 169 |
| 2000-4000 | 278 | 254 |
| 4000-8000 | 200 | 375 |

**Table 5 (continued)**

*Number of Tweets Collected Sorted into Follower and Status Ranges*

| | | |
|---|---|---|
| 8000-16000 | 118 | 367 |
| 16000-32000 | 48 | 381 |
| 32000+ | 39 | 616 |
| unknown | 0 | 150 |
| AVERAGE | 3002 | 35651 |
| MEDIAN | 638 | 10389 |

**Curriculum Vitae**

| | |
|---|---|
| **Name:** | Samantha Jewett |
| **Post-secondary Education and Degrees:** | University of Waterloo<br>Waterloo, Ontario, Canada<br>2014-2019 B.Sc |
| **Related Work Experience** | Teaching Assistant<br>Western University<br>2019-2020 |
| | Part-Time Math Teacher<br>Oxford Learning Eastbridge<br>2020 - 2022 |
| | Outreach Assistant<br>The Royal Astronomical Society of Canada<br>2020-2021 |
| | Education and Outreach Coordinator<br>The Royal Astronomical Society of Canada<br>2022 – |

**Conference Presentations:**

Jewett, Samantha. "Scientific Literacy in the Digital Age." Round Table Presentation presented at the Robert Macmillan Symposium in Education, Western University, March 2020.

Jewett, Samantha, Anton Puvirajah, Mohammad Azzam, and Jingrui Jiang. "Examining the Nature of Science Understanding through Canadian's Tweets about COVID-19." Ignite Presentation presented at the NARST Annual International Conference 2021, April 8, 2021.

Jewett, Samantha, Antonn Puvirajah, Mohammad Azzam, and Jingrui Jiang. "Examining Canada's Scientific Literacy Through COVID-19 Tweets". Paper Presentation presented NARST Annual International Conference 2022, March 27, 2022

Jewett, Samantha, Anton Puvirajah, Maede Nouri, Ben Morgenstern, Mohammad Azzam, and Jingrui Jiang. "Examining Canada's Science Understanding through COVID-19 Tweets." Presented at the Robert Macmillan Symposium in Education, Western, March 25, 2021.