WHOSE JOB IS IT ANYWAYS?

A study of attitudes and perspectives among Canadian science communicators with a comparison to global practices

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ABSTRACT

Science communication is essential in sharing and discussing scientific research with people outside of specialized scientific audiences. Diversity among science communicators, researchers, and audiences is evident on both a local and global scale, necessitating training programs that serve to enhance communication skills, thereby improving overall communication effectiveness. This study seeks to enhance our understanding of science communication in Canada, including barriers and challenges the field currently faces. An online questionnaire was conducted to compare attitudes and approaches of Canadian communicators from various backgrounds, fields, and disciplines including scientists, journalists, podcasters, online content creators, and artists. Most Canadian science communicators had a background in science (rather than journalism or communication), had limited training in communications prior to starting their careers, and indicated that scientists in particular should be trained in science communication. Diversity was listed as both a positive aspect of Canadian science communication, and a challenge needing to be overcome (specifically that diversity is still lacking). The findings suggest that greater emphasis on communication training is needed, especially for young, early career scientists, and that equity, diversity, and inclusion were important. Gaps in knowledge were identified regarding the accessibility of science communication, as well as the impact of older practices such as Indigenous oral histories. A better understanding of the Canadian science communication landscape can help to design and enhance training, support, and outreach initiatives, for improved public engagement with science across the country.

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LIST OF ABBREVIATIONS

2SLGBTQQIA+	Two-Spirit, Lesbian, Gay, Bisexual, Transgender, Queer, Questioning, Intersex, Asexual, and all other sexual orientations and genders
ABCSSS Islands	Dutch-speaking Caribbean islands of Aruba, Bonaire, Curaçao, Saba, Sint Maarten, and Sint Eustatius
ACFAS	*Association canadienne-français pour l'avancement des sciences* [French-Canadian Association for the Advancement of Science]
ACS	*Association des communicateurs scientifiques du Québec* [Quebec Science Communicators Association]
BBC	British Broadcasting Corporation
BIPOC	Black, Indigenous, and/or Person of Colour
CASC	Canadian Association of Science Centres
CBC	Canadian Broadcasting Corporation
CBS	Colombia Broadcasting System
CCSC	Canadian Council of Science Centres
CEGEP	*Collège d'enseignement général et professionnel* [College of general and professional teaching]
CSWA	Canadian Science Writers Association
COVID-19	Coronavirus disease 2019
GMO	Genetically modified organism
NBC	National Broadcasting Company
PCST	Public Communication of Science and Technology
SWCC	Science Writers and Communicators of Canada
STEM	Science, Technology, Engineering and Mathematics
TELI	Technical Literacy Society in Germany
USA	United States of America
WWII	World War II

CHAPTER 1: INTRODUCTION

1.1 Science Communication: A Field on the Rise

Science communication is an important field focused on sharing scientific information with people outside of specialized scientific settings (Burns et al., 2003). Both interdisciplinary (integrating work from more than one defined discipline) and multi-disciplinary (collaboration between, rather than integration of, various disciplines) in nature, science communication draws on a variety of fields including sociology, psychology, and communication (among many others) to engage, persuade, and support better decision-making by disseminating accessible scientific information to various audiences (Burns et al., 2003; Gascoigne et al., 2010; Gascoigne et al., 2020; Priest, 2010; Schiele & Landry, 2012).

Globally, science communication is a diverse field that involves governments, academic institutions, independent organizations and associations, museums, science centres, and individual practitioners, such as journalists, educators, researchers, and artists. Science communicators work to promote engagement with and understanding of science and technology among various members of the public (Burns et al., 2003; Priest, 2010) through various media, including print (e.g., books, newspapers, magazines), online (e.g., blogs, video content, podcasts, social media), and broadcast (e.g., television and radio) media as well as artistic endeavors such as theatre, painting, and sculpture. Though this diversity of processes may ensure that scientific information is being shared through unique and creative means, it can also create community-based divisions by discipline or practice, language, culture, and geography (Davies et al., 2021; Gascoigne et al., 2010;

Gascoigne et al., 2020; Gerber et al., 2020; Priest, 2010; Rauchfleisch & Schäfer, 2018). Diversity is valuable for expanding access to science communication, in such a way that variation in practices and attitudes between regions and/or science communication groups can ensure that culturally relevant communications are being produced (Canfield et al., 2020; Dahlstrom, 2014; Djonko-Moore et al., 2018; Hunter-Doniger et al., 2018; Taylor and Dewsbury, 2018). However, fragmentation and separation in the science communication community could hinder the spread of information between communicators, leading to reduced efficacy of communications and audience engagement (Canfield et al., 2020; Márquez & Porras, 2020).

There are five main goals of science communication including sharing information with non-experts to build excitement about science and some of its findings, increasing appreciation of the approaches and results of scientific research, educating people about specific scientific issues, influencing attitudes, opinions, and behaviours including policy preferences and consumer choices, and seeking solutions to societal issues through engagement with diverse audiences (National Academies of Sciences, Engineering, and Medicine [NASEM], 2017). While the goals of science communication often vary from one communicator to the next, a common goal is to elicit a personal response to science such as awareness, enjoyment, interest, opinion (forming, reforming, or confirming science-related attitudes), or understanding (Burns et al., 2003). Generally, science communication aims to improve people's social, environmental, and economic standing by helping them to navigate complex scientific issues like climate change and COVID-19 (Gascoigne et al., 2020; Howell & Brossard, 2021). With the potential to positively influence various aspects of society including people's views and actions (Bauer et al., 2007), science communication is a critical tool used to bring scientific findings on health, the environment, technology and more to the public in an efficient, effective, accessible, and understandable manner.

In order to be effective, science communication relies on people's receptivity to new ideas and discoveries (Scheufele, 2013; Scheufele, 2014; Wynne, 1992). This receptivity, based on an individual's trust in science, is inherently affected by social identities such as age, ethnicity, gender, political ideology, race, religion, and socio-economic status (Gauchat, 2012; Perry et al., 2021; Rainie, 2017; Scheufele, 2013; Scheufele, 2014; Wynne, 1992). Receptivity often decreases when scientific findings conflict with one's social identities (especially moral, ethical, or social values, religious beliefs, and long-held views) and when ethical and political questions are raised (NASEM, 2017). For example, in the United States, attitudes towards scientists have become increasingly polarised with politically conservative individuals demonstrating greater levels of distrust regarding such "controversial" topics as climate change and vaccinations (Mann & Schleifer, 2020; Perry et al., 2021). Similarly, politically left-leaning individuals worldwide have shown high levels of distrust regarding genetically modified organisms (GMOs), especially in food production (Blanke et al., 2015).

1.2 What Drives Science Communication? Science Literacy to Science and Society

Science communication has historically been guided by one of two general paradigms: science literacy or public understanding of science (Bauer et al., 2007). Historically, science literacy focused on a public deficit of knowledge (Jenkins, 1994; Bauer et al., 2007) while public understanding of science focused on attitudes towards science (Bauer et al., 2007; Collins & Bodmer, 1986; Royal Society, 1985).

The so-called “deficit model” of science communication, popularized from the 1960s through the mid-90s, assumed the public lacked knowledge and/or understanding about science and needed educating (Bauer et al., 2007; Sturgis & Allum, 2004). The model suggested that knowledge, or lack thereof, was the dominant factor affecting people’s attitudes and behaviours toward science and science-based issues (Bauer et al., 2007; Dudo & Besley, 2016; Sturgis & Allum, 2004). While knowledge may be a factor, it is by no means the only factor influencing people’s attitudes and behaviours (Allum et al., 2008). One’s culture, socioeconomic status, socio-political values, trust (or more often a lack thereof), perception of risk, and cues from mass media all influence a person’s attitudes, perceptions, and behaviours regarding science (Bauer et al., 2007; Brossard et al., 2005; Dudo & Besley, 2016; Ho et al., 2008; Scheufele & Lewenstein, 2005; Sturgis & Allum, 2004).

While increasing knowledge and understanding is not unimportant, dialogical interactions with scientists who are willing to engage and listen are more likely to generate positive attitudes towards science and its practitioners (Bauer et al., 2007; Sturgis & Allum, 2004). The new "dialogue” or “engagement” model explicitly acknowledges non-scientific forms of knowledge (i.e., cultural and experiential) with the goal of learning through sharing various views, values, experiences, and concerns (Reincke et al., 2020). It emphasizes the need for strategic, audience-centred approaches to communication including tailoring one’s message so it can be well received by different individuals, demonstrating active listening, and building relationships (Besley et al., 2018; Nisbet & Scheufele, 2009; Reincke et al., 2020; Sturgis & Allum, 2004). Over time, the process should be "self-enhancing" as relationships are built and strengthened by sharing, listening, and learning (Reincke et al., 2020).

Today, science literacy encompasses more than its historical definition of understanding science, its practice, production, aims, and general limitations and, as a result, is used synonymously with public understanding of science (Jenkins, 1994; Laugksch, 2000; Snow & Dibner, 2016). Science literacy has become less rigid, expanding to include three key dimensions: civic, digital media, and cognitive. These dimensions help identify and categorize the skills necessary to be science literate in the 21st century (Howell & Brossard, 2021).

"Civic science literacy" represents the more classic definition of the term, focusing primarily on individual competence in science (Howell & Brossard, 2021; Snow & Dibner, 2016). This dimension typically encompasses understanding scientific knowledge (e.g., basic facts, concepts, and vocabulary), scientific practices (e.g., hypothesis formulation and testing, probability versus risk, correlation versus causation), and science as a social process (e.g., peer review processes, funding and conflicts of interest, places for discussion and critique) (Howell & Brossard, 2021; Laugksch, 2000; Miller, 1998; Snow & Dibner, 2016). Civic science literacy also includes an understanding of how science relates to society (Howell & Brossard, 2021). In a sense, science and society are interdependent with societal factors, like economics, politics, and social priorities, influencing who participates in science and where that science is focused, while science affects the way people live their lives, and the decisions they face (Howell & Brossard, 2021). This first dimension of science literacy focuses on increasing the general public's scientific knowledge in an effort to increase support for science and technology (Laugksch, 2000).

The digital media dimension moves beyond general understanding of science and its production, focusing on how to evaluate science that is presented by the media (Brossard & Scheufele, 2013; Howell & Brossard, 2021). This dimension combines two interwoven notions, digital literacy, the ability to participate in society by consuming, and producing, information online through digital technologies like a smartphone or computer (Chase & Laufenberg, 2011; Koltay, 2011; Njenga, 2018), and media literacy, the ability to access, understand, assess, and create media and content (Koltay, 2011; Tisdell, 2008). "Digital media science literacy" also includes one's ability to understand how scientific information travels through online media systems (Howell & Brossard, 2021).

Lastly, "cognitive science literacy" allows people to use scientific information they have found and assessed to make informed decisions (Howell & Brossard, 2021). Cognitive literacy (*aka* metacognition) is the awareness of personal thought processes and how they shape our conclusions (Hofer & Sinatra, 2010; Israel et al., 2005; Tomlin, 2014). In essence, cognitive science literacy allows individuals to recognise personal biases as they interact with scientific information and media (Howell & Brossard, 2021; Kraft et al., 2015). This awareness can help people avoid falling prey to misinformation, especially when it fits their pre-existing beliefs and worldviews (Howell & Brossard, 2021; Mercier, 2017). As a whole, science literacy allows people to understand, appropriately assess and apply the science they interact with every day.

Together, the various dimensions of science literacy provide a toolkit of skills that improve one's ability to identify misinformation and thereby resist its influence (Craft et al., 2017; Howell & Brossard, 2021; Kahne & Bowyer, 2017; Guess et al., 2020; Mercier, 2017). Rather than a strict "deficit" or "dialogue" dichotomy, models and methods of effective science communication can be viewed on a continuum with varying degrees of public participation which coexist (Trench, 2008). As a result, we see a spectrum of science communications from one-way dissemination approaches (like articles, videos, and podcasts) to two-way "dialogue" and multi-way participation approaches (like town halls, conferences, and citizen science projects), with various art-science media meant to provoke discussion through exploration (such as Science Gallery and storytelling like science fiction) filling in the more fluid space between. Ultimately, it is important to employ the methods that match the goals associated with the communications being produced (Einsiedel, 2008; Kappel & Holmen, 2019; Schiele, 2018; Trench, 2008).

Recently, the field has started to view science communication through the "frame of culture" perspective, that is, by focusing on the experiential and emotional aspects of science communication (Davies et al., 2019b). More specifically, science communication as a means of societal expression or "collective meaning-making" (Davies et al., 2019b). From ancient myths to modern story-based podcasts, television shows, and movies, humanity has used storytelling to understand the world around them (Davies et al., 2019b; Kaiser et al., 2014; Linett, 2013). For example, science fiction as a specific genre, has managed to bring science into mainstream (popular) culture by making science more interesting and accessible, sparking curiosity about science and the future of scientific discovery

(Anderson, 2022; Davies et al., 2019b, Quintanilla, 2024). Fictional narratives may also serve to contextualise the implications of science for society, thereby helping people make sense of its nature, role and potential and may be used as powerful tools when trying to influence societal attitudes and behaviours (Davies et al., 2019b; Kirby, 2017; Moyer-Gusé & Dale, 2017).

1.3 Around the World in 80 Years: A Brief History of Science Communication

It can be argued that science communication is as old as science itself, evolving over time to address changes in science and various sociopolitical landscapes. Due to the evolutionary nature of the field, it can be difficult to pin down specific "eras" for science communication (Gascoigne et al., 2020). While evidence of science communication can be found throughout the 19^{th} and early 20^{th} century (known then as science vulgarisation or popularisation), it was primarily practiced by scientists, science enthusiasts, and social reformers (Gascoigne et al., 2020; Nielsen, 2022; Schiele, Liu, & Bauer, 2021). Moreover, due to conflict, national security concerns over military-related scientific advancements being disclosed to foreign enemies, and structural changes resulting from World Wars I and II, scientists were discouraged from communicating with the public, thus disrupting science communication practices at the time (Gascoigne et al., 2020).

In most countries, science communication didn't experience significant growth until the post-war period, with marked change occurring between the 1970s & 1990s with governmental involvement and support (Gascoigne et al., 2020; Schiele, Liu, & Bauer, 2021). The growth in science communication was often linked to increases in higher education among the general public, as well as integration of science into a nation's economy (Gascoigne et al., 2020; Nielsen, 2022). This growth, both as a practice and field of research, has been bolstered by the creation of dedicated conferences (e.g., the *Association canadienne-française pour l'avancement des sciences* [Acfas] Conference first held in 1933), networks (e.g., the International Network on Public Communication of Science and Technology [PCST] formed in 1989), and academic journals (e.g., *Public Understanding of Science* first published in 1992; the *Journal of Science Communication* first published in 2002; and the *International Journal of Science Education, Part B: Communication and Public Engagement* first published in 2011), as well as the opening of science centres or museums and, most recently, the creation/offering of dedicated courses at universities worldwide. While these courses are mostly offered through communications related faculties/disciplines such as arts, social science, journalism, and media, some are now offered through faculties of science, medicine, and environmental studies. However, the inclusion of science communication curricula in higher education has lagged cultural acceptance of the discipline (Besley et al., 2015; Brownell et al., 2013; Mercer-Mapstone & Kuchel, 2015; Oliveira et al., 2024; Pace et al., 2010). While science communication is seen as valuable, specifically for communicating science to the public, training trails behind (Rubega et al., 2021). Canada, more specifically, has been slow to develop courses and programs specific to science communication with the first science communication qualification, a graduate diploma at Laurentian University, only on offer since 2005 (Riedlinger et al., 2012). However, other science communication and science journalism programs have continued to emerge since at an increasing rate.

Over time, science communication communities of research and practice have emerged and evolved in almost 40 countries and regions including Africa (Rasekoala, 2022), Australia (Metcalfe & Gascoigne, 2012), Canada (Riedlinger et al., 2019), Latin America (Aguirre Rios & de Regules, 2022), and the United States (Menezes et al., 2022; Scrimshaw, 2019) along with several European and Asian countries (Gascoigne et al., 2020). The development of science communication, as both a practice and field of study, in each specific country or region varies, depending on how it started, how the standards of practice and availability of communications, as well as the number of practitioners and researchers, have grown and changed over time, and which groups or individuals have historically practiced or held influence in the field.

Various factors may have contributed to the growth and development of science communication as a professional field in particular. One such factor is the emergence of science education and outreach institutions, organizations, and programs. This includes the creation of science centres, national science weeks, festivals, and fairs (Gascoigne et al., 2020; Schiele et al., 2012; Schiele et al., 2021). For the most part, these defined spaces for society to interact with science have only been around since the mid-1900s, with most being introduced after 1975 (Gascoigne et al., 2020). The growth of these social spaces indicates a rise in the popularity of science with the public and the state. As public interest in science increases, so does the need for high quality science communication. Based on web searches of science communication programs offered around the world, most are currently offered in North America (44%) followed by Europe (25%), Oceania (12%), and South America (11%), approximately. The United States alone accounts for over a quarter of programs (around 28% globally), while Canada by comparison, accounts for less than half of those offered in the USA (about 12% globally).

Another factor contributing to increased interest in sharing science with the public is the proliferation of science in the media. Science writing and journalism took off in the 1960s and 70s, as evidenced by the increase in science writing associations and awards available specifically for science communication (Gascoigne et al., 2020; Schiele et al., 2012; Schiele et al., 2021). Associations for science writers and journalists have emerged in 33 countries worldwide, the first was formed in the late 1920s (Germany's *Technish Literarische Gesellschaft* [Technical Literacy Society or TELI] founded in 1929), while most were formed after 1960 (Gascoigne et al., 2020). The creation of these associations is important as it indicates the emergence of a profession and that a substantial number of writers and journalists are specializing in science (Gascoigne et al., 2020).

Looking at science in broadcast media, while several scientific radio programs existed prior to 1949 (e.g., Brazil's *Radio Sociedade* first aired in 1923; BBC's *The Stream of Life* first aired in 1925; NBC's *National Farm and Home Hour* first aired in 1928; CBS's *Adventures in Science* first aired in 1938; Radio-Canada's *Radio-Collège* first aired in 1941; and Radio Barcelona's *Los progresos científicos* [Scientific Advances] first aired in 1941), science programming largely increased post-WWII (with programs such as BBC's *Science in Action* on air since the 1950s, CBC's *Quirks & Quarks* on air since 1975, and Echo of Moscow's *Granit nauki* [Granite of Science] on air since 1997) (Gascoigne et al., 2020). Television programming was quick to follow, with most televised science programs (e.g., The Royal Institution's *Christmas Lectures* airing as early as 1936; CBC's *The Nature of Things* first airing in 1960; and BBC Television's *Horizon* first airing in 1964) being introduced between the 1940s and early 1970s (Gascoigne et al., 2020).

The creation of specific and specialized university-level trainings in science communication, a factor indicating the growth and development of science communication as an academic field, began in the 1960s, specifically in the United States and the Philippines (Gascoigne et al., 2020). These initial offerings kicked off a wave of specialized courses, certificates, degrees, and diplomas, both at the bachelor's and graduate level, in over 35 countries from the late 1970s to the present day, mostly in arts, journalism or communications, with a few in science (Gascoigne et al., 2020; Trench, 2012). Specific graduate programs (master's and PhD level), many of which are offered in science, have only begun to be offered more recently (the majority post-2000s), indicating the newness of science communication as an academic field (Gascoigne et al., 2020; Schiele et al., 2012). Canadian science communication academic curricula more specifically have been slow to develop, with most programs emerging after 2005 (Oliveira et al., 2024; Riedlinger et al., 2012; Riedlinger et al., 2020). The number of programs has increased rapidly in recent years, with more activities, modules, whole courses, programs, and degrees being offered across the country (Daoust-Boisvert, 2022; Oliveira et al., 2024; Qaiser, 2019).

Since the 1990s, the internet and online media has grown exponentially, and the rise of social media throughout the early 2000s has only served to bolster the spread of information online (Iyengar & Massey, 2018). In the last 30 years, science communication has shifted to online media (Allan, 2011; Brumfield, 2009; Fahy & Nisbet, 2011; Iyengar & Massey, 2018; Riedlinger et al., 2019), including short- and long-form video content, blogs, audio content (such as podcasts), and social media on a variety of platforms such as Facebook, Instagram, Spotify, TikTok, Twitter (now X), and YouTube. While these diverse channels allow news and information regarding important scientific topics to be easily disseminated, they have also allowed misleading content such as fake news (false/fabricated information presented in a way that emulates news media and is meant to spread lies), misinformation (false/misleading information spread regardless of intent, often as a result of ignorance or error), and disinformation (false/misleading information shared with the express intent to deceive or manipulate) to flourish (Iyengar & Massey, 2018; Lazer et al., 2018).

In the current media landscape, it can be difficult to determine which sources are trustworthy, especially as content is polarized on many issues such as climate change and vaccines (Rainie, 2017). Furthermore, as we search for information that aligns with our knowledge and world views, algorithms learn from our actions and recommend us more of the same things, which serves to reinforce our confirmation bias (Iyengar & Massey, 2018; Lazer et al., 2018; Tufekci, 2015). This only serves to amplify personal biases pushing us towards the extremes (Lazer et al., 2018; Tufekci, 2015). As a result, partisan animosity and bias have grown significantly leading to increased polarization and societal fragmentation (Iyengar & Massey, 2018; Lazer et al., 2018), as evidenced by incidents such as the Canadian border blockades (The Canadian Press, 2022) and trucker convoy to Ottawa in protest of COVID-19 related public health requirements regarding vaccination, masking, and lockdowns (Osman & Fraser, 2022). These are prime examples of how a lack of digital and cognitive science literacy can influence society in a negative way. Being able to recognize one’s biases (and understand how algorithms may push us into echo chambers of potential misinformation) can help people assess the information that is being presented to them, especially in a digital space (Howell & Brossard, 2021; Mercier, 2017). Being able to assess the quality and reliability of sources, especially online, will make it easier to resist the influence of misinformation (Craft et al., 2017; Howell & Brossard, 2021; Kahne & Bowyer, 2017; Guess et al., 2020; Mercier, 2017).

In this rapidly evolving media environment, where misleading content abounds, it is important to consider and analyze the efficacy of current science communication practices. To do this we first need to understand who is communicating science and how they are doing so.

1.4 An Ecosystem of its Own: The Diverse Landscape of Science Communication

Science communication continues to grow and change, with participants ranging from a vast array of individuals and organizations with a variety of backgrounds including social sciences, arts, health science, natural sciences, and technology joining the field which was previously dominated by writers and journalists (Gascoigne et al., 2020; Metcalfe & Gascoigne, 2012; Rauchfleisch & Schäfer, 2018; Schiele & Landry 2012). As such, the discipline has evolved, centring on the more nebulous paradigm of "science and society" focused not only on sharing knowledge or improving attitudes towards science, but also on the trust (or lack thereof) between scientists and the public (Bauer et al., 2007; Miller, 2001; Miller 2008?).

Currently, it appears that, in North America, scientific findings are predominantly communicated to the public by scientists (Besley, 2015; Riedlinger et al., 2019), especially as the number of science journalists has dwindled (Riedlinger et al., 2019). Mostly as a result of increased financial strain due to increased competition for audiences from other (predominantly online) sources, specialty and investigative reporting such as science news (which takes a lot of time and effort to produce), is often seen as expendable by editors

(Allan, 2011; Brumfiel, 2009). With fewer specialized journalists being employed by traditional media outlets, fewer science stories are being reported (Brossard, 2013; Scheufele, 2013; Scheufele & Krause, 2019). Furthermore, when science is covered, it is often by reporters who spend most of their time writing about other non-scientific topics such as business, fashion, politics, and sports (Scheufele, 2013; Scheufele & Krause, 2019). As a result, science communication is effectively being pushed out of traditional print media and moving to online forums where they have seen greater success (Allan, 2011; Brumfield, 2009; Fahy & Nisbet, 2011; Iyengar & Massey, 2018; Riedlinger et al., 2019).

By contrast, practitioners in Argentina have predominantly focused on communication through journalism over the last 15 years with recent professional diversification into public relations for government and scientific institutions, while those in Australia have historically come from media and communications backgrounds (e.g., media officers, public relations officers, librarians, scientific editors, and science journalists) (Cortassa & Rosen, 2020; Metcalfe & Gascoigne, 2012). Ultimately, science communication has developed in the historical, cultural, and social contexts of various countries (Gascoigne et al., 2020), likely contributing to regional variations in practice. These varied contexts have led to the development of a diverse global field.

1.5 Screaming into the Void: Evidence of Fragmentation in Science Communication

Encompassing immense diversity within the field, science communication is important, not only as a profession, but also as a field of research. While it can be argued that science communication is as old as science itself, science communication research remains relatively new, only emerging in the last 40-50 years alongside the creation of science and technology ministries and certain science-focused publications (Gascoigne et al., 2010; Gascoigne et al., 2020; Schiele & Landry, 2012; Schiele et al., 2021). While practitioners come from a variety of backgrounds, researchers typically hail from the realm of social sciences and communications (Davies et al., 2021; Gerber et al., 2020; Miller, 2008; Priest, 2010).

However, in Australia, research has split over time into two facets: "science and society" for those with backgrounds in the humanities, arts, and social sciences, and "science communication" for those with natural science backgrounds (Metcalfe & Gascoigne, 2012; Metcalfe & Gascoigne, 2017). While there has been a general shift back to social science disciplines, the division remains (Metcalfe & Gascoigne, 2017). A similar division in the European science communication community has arisen between individuals from scientific versus social science-related disciplines (Gerber et al., 2020; Miller, 2008). Though in this case, practitioners typically have high levels of science education (Miller, 2008), while researchers generally belong to the social sciences (Davies et al., 2021; Gerber et al., 2020; Miller, 2008). As a result, many communicators do not interact with the literature (Gerber et al., 2020; Miller, 2008). This separation, between those who study and those who practice science communication, undermines the overall goal of science communication research, to improve communication efficacy.

Furthermore, a recent study of the European science communication landscape shows a variety of deep community-based divisions such as discipline, culture, geographic location, and language (Davies et al., 2021; Gascoigne et al., 2010; Gascoigne et al., 2020; Gerber et al., 2020; Miller, 2008; Priest, 2010). This has the potential to spark animosity through increased intergroup competition for audience attention and differing opinions or attitudes on who should be communicating science and how. Furthermore, having distinct pockets of knowledge, held apart from other researchers or practitioners threatens the continued growth and development of the field and jeopardizes accessibility of quality communications.

1.6 A Tale of Two Cultures: Science Communication in the Canadian Context

Science communication in Canada is as diverse and dynamic as its population, with a unique history of dual development within a dominant Francophone culture in Quebec and a dominant Anglophone culture in the rest of the country (Riedlinger et al., 2020; Schiele et al., 2012). First colonized by France in 1534, Canada (then known as Nouvelle France) was ultimately ceded to Great Britain in 1763. While over time, anglophone culture has become dominant in the country, with over 200 years of French rule, French culture was well established in the region, specifically Quebec, though pockets also exist throughout the country in every province and territory (Statistics Canada, 2021).

It is difficult to parse Quebec's history from more general Canadian science communication in the early 19th century, as science communication in Canada arose (mostly) from learned societies in Quebec (such as the Historical Society of Quebec and the Natural History Society of Montreal), involved in everything from newspaper articles to public lectures and demonstrations (Riedlinger et al., 2020; Schiele et al., 2012; Schiele et al., 1994). It would take until after confederation in 1867, for national organizations that promote scientific progress and invest in research, such as the Royal Society of Canada

(1882) and the National Research Council of Canada (1916), to be founded (Riedlinger et al., 2020).

1.6.1 A Brief Timeline of Science Communication in Anglophone Canada

Professional science journalism and media in Canada grew in the years following the Second World War, as science and science communication (then popularization) separated one from the other (Lewenstein, 1992; Schiele et al., 2012). New popularizers emerged following WWII through the 1950s and 60s as mass media such as newsprint, publishing, radio, and later television grew with CBC Television's *The Nature of Things* and its French-language equivalent *Aux frontières de la science* both airing in 1960 as well as CBC Radio's *Quirks and Quarks,* first airing in 1975 (Council of Canadian Academies, 2014; Riedlinger et al., 2020; Schiele et al., 2012). With a shift away from "popularization" and more towards science communication, science journalists, acting as translators and mediators between scientists and the public, founded the Canadian Science Writers Association (CSWA) in 1970 (Schiele et al., 2012; Riedlinger et al., 2020).

Starting in the 1970s, it became clear that national development of science and technology had close ties to economic development (Schiele et al., 2012). However, it would take until the release of the 1985 Bodmer Report, for Canada to truly become concerned with promoting science literacy amongst its people (Bodmer, 1985; Schiele et al., 2012). This concern led to the implementation of various policies to support research, stimulate scientific careers, and encourage information sharing with the public (Schiele et al., 2012).

With the rise of the internet and online media through the end of the 20th century into the 21st, the landscape of science communication in Canada underwent rapid change, as science communication largely moved online (Rieldinger et al., 2019; Riedlinger et al., 2020). Today, not including popular science radio shows (like *Quirks and Quarks*) which are often available in podcast form, Canada produces over 75 independent science podcasts in a range of topics including general science, natural sciences, nature, earth sciences, life sciences, and astronomy (Canadian Podcast Awards, 2024). Science blogs have flourished since the early 2000s, along with independent online organizations like *Science Borealis*, *Hakai Magazine*, and *The Conversation Canada* launched in the 2010s (Science Borealis, 2024; Hakai Magazine, n.d.; The Conversation Canada, 2024). Social media, specifically Twitter (now X) and Instagram are two of the most popular platforms for science communication in Canada, with over 300 communicators posting between the two platforms (Barata et al., 2018; Riedlinger et al., 2019; Riedlinger et al., 2021). To reflect changes in their membership and the landscape of science communication in the country, CSWA recently changed their name to the Science Writers and Communicators of Canada (SWCC) (SWCC, 2017).

Other important players in the Canadian science communication landscape, science centres and museums, have been working to communicate science in Canada for decades. The Canada Science and Technology Museum, Canada's first museum dedicated to science and technology opened in the late 1960s with origins tracing back through the National Museum of Canada (1927-1968) to the Geological Survey of Canada's first museum (opened 1843) (Canadian Museum of History, n.d.). Around the same time, Canada opened its first interactive science centre, the Ontario Science Centre (1969), inspired by and modelled after the hands-on, interactive nature of science centres like the Exploratorium in San Francisco (Riedlinger et al., 2020). Today, the Canadian Association of Science Centres (CASC), previously the Canadian Council of Science Centres (CCSC, established in 1985), represents over 50 science centres, museums, aquariums, planetaria, zoos, and other spaces dedicated to public understanding and appreciation of science and technology (CASC, 2024). Unfortunately, government support for science communication has decreased since the beginning of the 21st century, which has forced the field to rely more heavily on industry, universities, and independent research institutions for support (Riedlinger et al., 2020).

Dedicated formal training and research in science communication emerged in Canada in the early 2000s with the establishment of a multidisciplinary graduate diploma offered through a partnership between Science North and Laurentian University (Riedlinger et al., 2020). This was followed by the establishment of the first undergraduate degree at Mount Saint Vincent University in 2010, and the first master's degree at Laurentian University in 2017 (Riedlinger et al., 2020). Today, there are over 25 different science communication programs offered at 20 different universities across Canada predominantly in science faculties.

Canadian academics are some of the most productive publishers in science communication, ranking among the top five along with the United States, United Kingdom, Germany, and Australia (Riedlinger et al., 2020). With over 60 papers published in dedicated science communication journals between 1994 and 2015, Canadians are the fifth most prolific contributors (Barata et al., 2018). Canadian researchers also publish more popular science in newspapers and magazines than researchers elsewhere in the world (Bentley et al., 2011). However, scientists maintain that the impact of their science is not being seen as policymakers fail to incorporate science when making decisions (Besley and O'Hara, 2018).

1.6.2 A Brief Timeline of Science Communication in Quebec

Unlike for anglophone Canada and many other countries, WWII did not serve as a catalyst for science communication in Quebec (Riedlinger et al., 2020). As a result of the strong educational influence of the Catholic Church, Quebec would lag behind the rest of Canada until the "Quiet Revolution" in the late 1950s and early 60s (Schiele et al., 2012). During this time, the government carried out a wide range of reforms, including expanding civil services, nationalizing hydroelectric utilities and other natural resources, conferring women the rights to pursue higher education and work, bolstering healthcare, and promoting French in the workplace (Dickinson & Young, 2003). One of the most important reforms was the government's overhaul of the education system. Through the establishment of the Ministry of Education, the government took control of the education system from the Catholic Church, created the public CEGEP system, and established the Université du Québec network (Dickinson & Young, 2003). Emerging in the interwar period as part of a movement for sociopolitical, cultural, and economic emancipation, the *Association canadienne-française pour l'Avancement des Sciences* (ACFAS) [French-Canadian Association for the Advancement of Science], founded in 1923, worked to promote scientific research and teaching (Riedlinger et al., 2020; Schiele et al., 2012).

Active mobilization of the scientific community in Quebec throughout the Great Depression ensured not only the preservation, but ultimately the expansion of science communication initiatives (Riedlinger et al., 2020). This involved the creation of the *Cercles des Jeunes Naturalistes* [Circles of Young Naturalists] in 1931, the first ACFAS conference in 1933 (Gingras, 2023), and the construction of the Zoological Garden of Quebec City. However, government support for science, and its communication in Quebec, would only arise in the 1960s following the election of a liberal government and their overhaul of the education system (Dickinson & Young, 2003; Riedlinger et al., 2020; Schiele et al., 2012). Scientific research was prioritized, along with science fairs and French-language science magazines like *Québec Science* (first published in 1962 under the title *Le Jeune Scientifique*) (Riedlinger et al., 2020).

Following the election of the Parti Québécois in 1977, science communicators in the province separated from the CSWA to form the *Association des communicateurs scientifiques du Québec* (ACS) in preparation of Quebec's independence which was ultimately rejected in the 1980 referendum (Riedlinger et al., 2020). L'Agence Science-Presse, a press agency dedicated to science communication was founded the following year and launched its own magazine (Riedlinger et al., 2020). The new government allocated more resources to scientific research both at university and in industry and invested in scientific leisure such as Montreal's *Maison des sciences* [House of Science], and the *Semaine des Sciences* [Science Week] (Riedlinger et al., 2020).

The 1980s marked a shift in government attitude, bringing science to the forefront as, like elsewhere in the world, the provincial government became interested in the public communication of science and technology (PCST) (Pitre, 1994; Riedlinger et al., 2020). By the late 80s, the government began supporting PCST magazines, organizations, and events as well as temporary and traveling science exhibitions (Riedlinger et al., 2020). This dedication to science communication continued through the 1990s with the opening of several science museums including the Montreal Biosphere, the Botanical Garden Complex, the Armand Frappier Museum, and the Cosmodome (Riedlinger et al., 2020). Following the defeat of the second independence referendum in 1995, drive for nation-building dwindled and with it state involvement in science communication (Riedlinger et al., 2020).

1.6.3 Like, Comment & Subscribe: Social Media & Canadian Science Communication

Two distinct cultures of science communication, Francophone in Quebec, and Anglophone in the rest of the country, persist in Canada's social media science communication landscape. While English Canadian communicators have rapidly created a strong presence online, French-Canadian communicators have largely maintained their traditional media (print, radio, and television), struggling to break into the English-dominated sphere of social media (Riedlinger et al., 2020; Riedlinger et al., 2021).

In general, Canadian science communicators on social media tend to be young women with scientific backgrounds in a biological science field such as ecology, conservation biology, cell/molecular biology, and neuroscience (Riedlinger et al., 2019; Riedlinger et al., 2021). Social media communicators are paid less, sometimes not at all, for their activities, have fewer years of experience communicating science, and more than likely have formal science training compared to their counterparts in traditional media (Riedlinger et al., 2019; Riedlinger et al., 2021).

As social media has become an increasingly important tool for science communication, government support for the field has dwindled at both the provincial and federal level (Boon, 2017; Riedlinger et al., 2020). In fact, most funding for science communication focuses on either training for scientists or activities for children, while online communicators and communications directed towards adults operate without support (Riedlinger et al., 2021). For science communication to continue to grow and develop in Canada, greater funding and research is needed, especially with regards to science communication practices associated with Indigenous science, as well as women, BIPOC (Black, Indigenous, and/or Person of Colour) and 2SLGBTQQIA+ (Two-Spirit, Lesbian, Gay, Bisexual, Transgender, Queer, Questioning, Intersex, Asexual, and all other sexual orientations and genders) individuals in STEM (Riedlinger et al., 2021).

1.7 Rationale, Objectives & Research Questions

Today, Canada is an incredibly diverse country; with just under 37 million people, immigrants account for almost a quarter of the national population (Statistics Canada, 2023). There are over 200 different languages spoken in Canada including over 60 different Indigenous languages (Statistics Canada, 2023). The most common languages (other than English and French), include various Chinese dialects (predominantly Cantonese and Mandarin), Punjabi, Spanish, Arabic, and Tagalog (Statistics Canada, 2023). This diversity extends to provincial, territorial, and national culture, which is influenced not only by colonisation and immigration, but by the culture of neighbouring regions both within and outside of Canada (Riedlinger et al., 2020; Schiele et al., 2012). Given the diversity of the Canadian population, it is critical that science communicators take this multiculturalism into consideration to communicate effectively with their audience. As a result, it is important that science communicators remain connected to promote knowledge sharing practices that work for diverse audiences.

This project seeks to build on recent research and update the Canadian landscape by investigating Canadian science communicator attitudes towards their field. With evidence of fragmentation in the European science communication landscape (Davies et al., 2021), and the effect of the culture wars on science communication in the USA (Mooney, 2011) I will explore whether similar differences exist in Canada. The data collected will serve as a baseline for future research into Canadian science communication. This research will increase our understanding of this developing field, contributing to more effective dissemination of scientific knowledge, enhanced educational programming, science-based policy decisions, and public understanding around critical issues such as health care, technology, and the environment (Nielson, 2010; Scheufele, 2013; Somerville & Hasool, 2011). This research may also have implications for science communication training allowing for enhanced communicator education.

The main objective of this research is to obtain a deeper understanding of how science communication in Canada is perceived by those working in the field. Through questionnaire responses of participants from the Canadian science communication community, our aims are to determine whether regional and/or group variation exists in Canada. To do this, I look to answer the following questions:

- Who is communicating science worldwide? Who is being trained to communicate science?

- Are there regional differences in who is conducting/being trained in science communication around the world?
- Who is communicating science in Canada?
- How does the field in Canada compare to elsewhere in the world?
- How do different groups or individuals view their role in science communication?
- Do these groups or individuals actively tailor their messages to different audiences? If yes, how many audiences and which ones?
- How do they view the intended goals their work? Political, social, educational or other?
- Why do they think communicating science to the public is important?
- What are their relationships like with other groups/individuals (i.e., scientists, journalists, government, research organizations, etc.)

I predict that the questionnaire responses will provide an accurate perspective of the attitudes prevalent in the current science communication landscape. Through qualitative and quantitative analyses, I aim to determine whether differences exist between groups of Canadian science communicators, and what effects these potential differences may have on the development of this field moving forward.

CHAPTER 2: METHODS

2.1 Science Communication in the International Context

To develop a preliminary outline of the current landscape of science communication in the global context, worldwide approaches to science communication were reviewed via information online. Searches were conducted using both scholarly journal search engines such as Google Scholar and Omni as well as non-scholarly search engines like Google Advanced Search. Scholarly searches were conducted to gather background information on regional approaches (where such research exists), while non-scholarly searches focused on identifying different science communication organizations and training opportunities for evaluation and comparison. Searches were conducted using Boolean search strings such as:

- "Science communication" AND organization;
- "Science communication" AND program; and
- "Science communication" AND Canada.
    - "Canada" was substituted with other countries and regions/continents such as Africa, Australia, Europe, North America, United Kingdom, United States, etc.
    - "Science communication" was substituted with similar terms like "science writ*" and "science journalis*".
    - "Program" was added on to by including terms such as Certificate, Diploma, Graduate, Masters, PhD, and Workshop

Due to a limited understanding of languages other than English, French, and Spanish, articles and websites with no available translation into one of these three languages were excluded. This information bias affected the collection of data for certain regions, specifically Eastern Europe, Asia, and Africa. Given the time and resources available for the project, full, certified translations of foreign websites and journal articles were not feasible for this study.

Other than the primary inclusion/exclusion criteria of language, organizations were included/excluded based on regional coverage. To adequately compare science communication approaches between countries or regions, it was important to sample organizations that cover the appropriate regional scale. Some organizations were too large, covering multiple continents (e.g., the Network for the Public Communication of Science and Technology [PCST Network]), while others were too small, covering singular cities (e.g., New York City Science Communication [NYCSciComm]). Both types were excluded as their scope would be too large (or too small) to detect regional differences at the scale of the current study. This also helped limit duplicate samples and overrepresentation of certain groups as national and international organizations often represent smaller, local associations.

The information gathered by country/global region on science communication training program target audiences and organization membership served as proxy data for the overall science communication landscape in each region. This information was used to assess whether the target participants of Canadian science communication differed from those of other countries/regions.

Once a list of programs and organizations was generated, entries were categorized based on their target audience (science, arts/non-science, both/either, or unspecified) or student/trainee membership (scientists, science communicators, science writers, journalists, and uncertain) as well as by country and/or continent.

2.2 Identifying Potential Participants in Canada

Canadian science communicators were identified through web searches using Google and Google Advanced Search using keywords 'science communication', 'science communicator', 'science writer', 'science journalist', and 'science artist' along with 'Canada' or 'Canadian'. The Science Writers and Communicators of Canada's (SWCC) "Mapping the new landscape of science communication in Canada" list of individuals using social media to communicate science in Canada (SWCC, 2018), was also used in generating the list.

Altogether, over 300 Canadian science communicators were identified. Most individuals were found on social media platforms such as Twitter (now X) and LinkedIn as well as by personal websites or professional profiles on employer websites such as museums, newspapers, or online media. This list was narrowed down to 209 by verifying individuals who were currently active in the field, were Canadian or had been active in Canada for several years, and had some form of contact information readily available. Given the diverse nature of the science communication landscape, individuals were also chosen to ensure representation from a variety of backgrounds and fields/disciplines such as scientists, journalists, podcasters, online content creators, and artists.

The identified individuals were invited to complete an online questionnaire (Appendix A). The questionnaire was designed to compare respondents' attitudes and approaches to science communication and explore how and why they got into the field. The questionnaire was comprised of three different types of questions. Questions one to three were multiple choice, questions four and five were rankings, and questions six through eleven were short answer. At the end of the questionnaire, respondents were asked to provide the names of other science communicators they felt should be contacted to also take part in the questionnaire. As a result, 15 additional people were invited to complete the questionnaire, for a total of 224 potential participants. After the initial questionnaire invitation, two follow-up reminders were sent. Responses were collected from September 2022 to February 2023 with reminders sent in October 2022.

The first question asked respondents to categorise their work in the field of science communication and offered a selection of categories of common specializations including science writing, science journalism, science centres/museums, podcasting, and art. Respondents were also able to provide alternative categories in their answer. Science communication was included as a category to test whether practitioners like, use, and identify with that particular identifying label.

The underlying goal of science communication can vary from one communicator to the next. Q5 asked respondents to rate the importance of certain purposes of science communication including increasing public understanding of science, sharing important information about personal and public health, promoting environmental sustainability, and increasing civic engagement. Respondents were also allowed to provide alternative purposes for their science communication activities.

One objective of this study is to understand whether scientists are encouraged and/or expected to play an active role in science communication. In an open-ended question, I asked respondents whether it is important for scientists in particular to be trained in science communication (Q6). It was also important to understand how respondents viewed the state of science communication in Canada. I asked respondents whether science was being communicated effectively and why or why not (Q7). To better understand the respondents' backgrounds, questions 8 and 9 asked about their educational credentials and experiences as well as their pathway to a career (or hobby) in science communication. The last open-ended questions asked respondents to reflect on how the field of science communication may have changed over the course of their career (Q10), and what their experience has been like communicating science in Canada (Q11).

2.3 Data Analysis

Quantitative data analysis was conducted using Microsoft Excel (version 16.66.1) and Rstudio Version 2022.7.2.576 (Rstudio Team, 2022) running R Version 4.2.3 (R Core Team, 2023). More specifically, Excel and the *stats* package (which is a part of R) were used to generate descriptive statistics and comparisons using chi-square tests while the *tidyverse* (Wickham et al., 2019) and *ggsignif* (Ahlmann-Eltze & Patil, 2021) packages were used for data visualization. Due to the nature of the data collected, non-parametric tests were used for analysis, specifically Pearson's chi-squared test of independence (for questions 2 and 3) and Kruskal-Wallis and Mann-Whitney *U* tests (for questions 4 and 5). Responses were arranged into contingency tables of counts per category prior to analysis. Results were significant at an α level of 0.05.

Multiple *post hoc* comparisons were made when initial tests (either chi-squared or Kruskal-Wallis) suggested at least one response variable category differed from the others. For questions 2 and 3, *post hoc* pairwise comparisons between categories were also conducted using Pearson's chi-squared tests. For questions 4 and 5, *post hoc* pairwise comparisons between categories were conducted using Mann-Whitney *U* tests.

The Bonferroni correction was applied to pairwise *p*-values before comparison to α (0.05) for ease of interpretation. This correction was applied as it reduces both the familywise Type I error rate (probability of incorrectly rejecting the null hypothesis at least once when making multiple comparisons) and the per-family Type I error rate (expected number of Type I errors that occur during multiple comparisons) (Frane, 2015; Klockars & Hancock, 1994).

As this project was exploratory in nature, qualitative analysis conducted on opinion-based open-ended questions (questions 6, 7, and 10) followed the *grounded theory* of "discovery from data" to group responses into clusters and to gather meaningful insights from them (Glaser & Strauss, 1999). To follow this approach, responses were systematically examined in an iterative process which gave rise to the emergence of analytical categories and subcategories for answers to each question, that were then refined through another iterative process.

CHAPTER 3: RESULTS

3.1 Science Communication Programs Around the World

Science communication is a global field with at least 265 programs offered in over 40 countries across 6 continents. Most of these programs are found in North America (n=115, 43%) and Europe (n=100, 38%), followed by Oceania (n=22, 8%) and South America (n=16, 6%), while Asia (n=6, 2.2%), and Africa (n=5, 1.8%) offered the fewest (Figure 1). Most programs were open to enrolment from individuals with a background in science (n=98, 37%), while less than ten percent of programs (n=24) were open to individuals with non-science backgrounds (such as arts, journalism, or communications) (Figure 2). Several programs were specifically open to individuals from either background (n=76, 29%) or were open to anyone (n=67, 25%; i.e., the websites indicated no specific qualifications, science or otherwise, to enroll) (Figure 2).

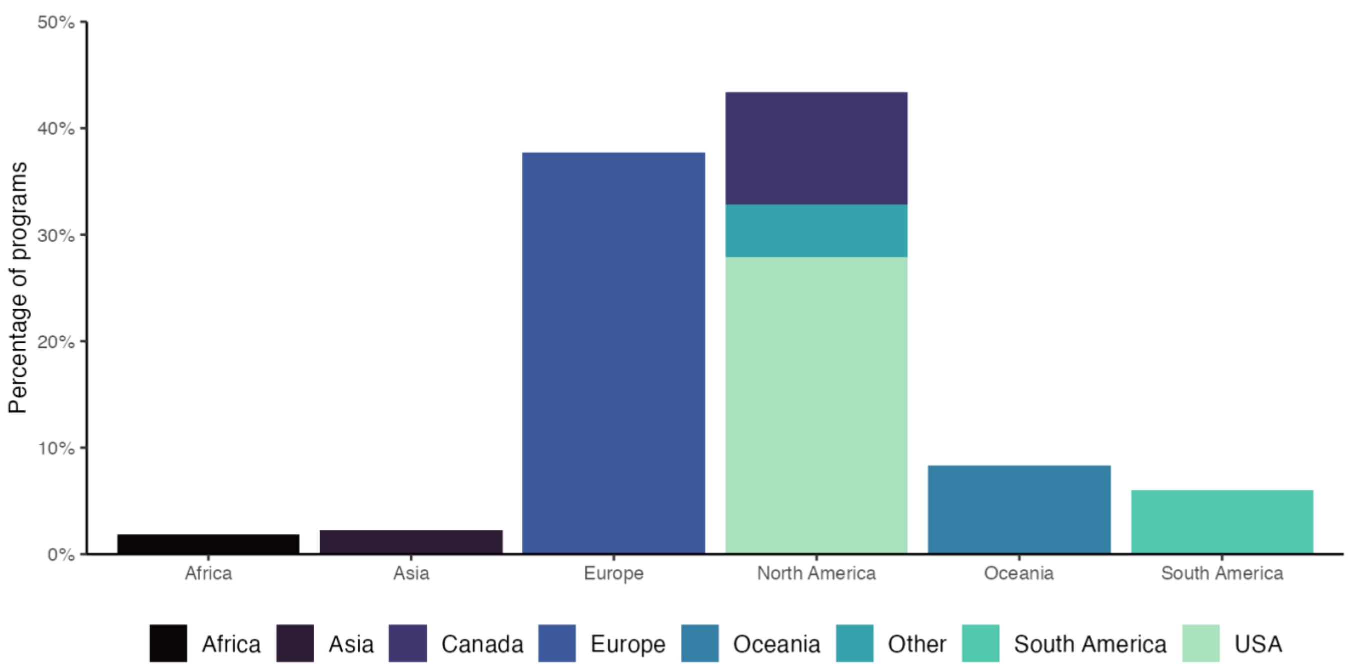

Figure 1. Percentage of global science communication programs offered by continent. Data retrieved from web searches using Google Advanced Search (number of programs = 265).

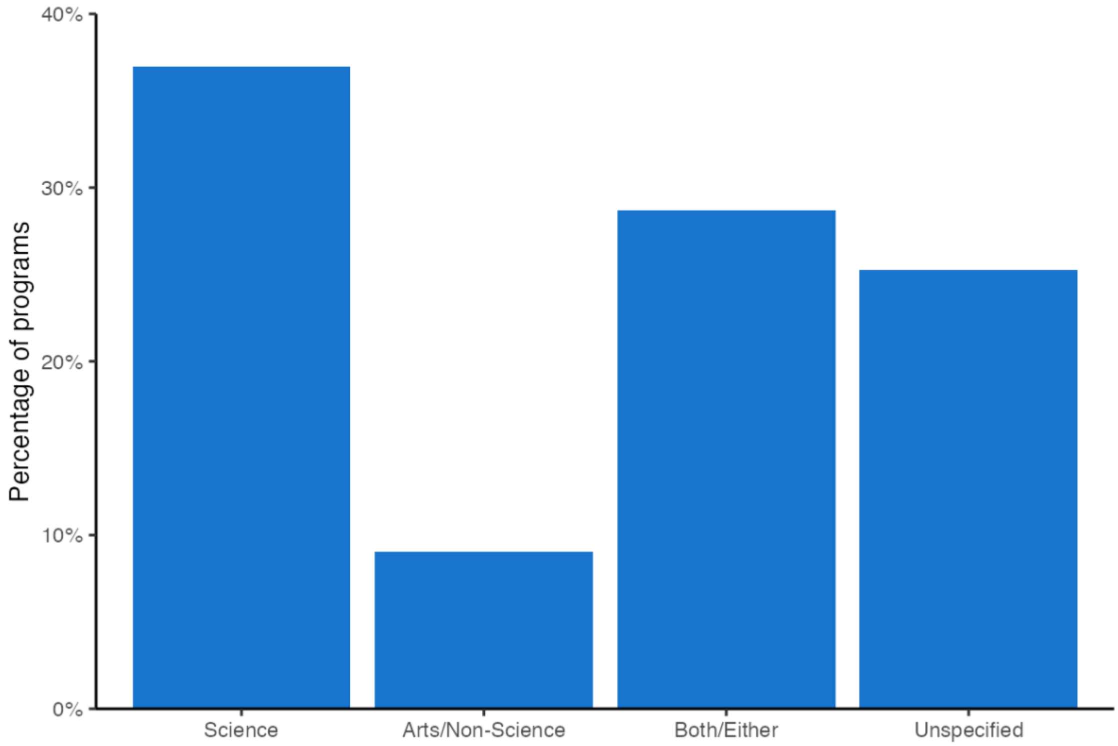

Figure 2. Percentage of global science communication programs by educational background of intended participants. Data retrieved from web searches using Google Advanced Search (number of programs = 265).

North America, Europe, and Oceania were found to offer more of their programs to individuals with a background in science specifically (45%, 36%, and 36% respectively) compared to Africa (20%, n = 1), Asia (4.5%, n=1), and South America (0%, Figure 3). Africa offers a proportionally higher amount of their programs to individuals specifically from non-science backgrounds (40%), while programs in South America do not restrict enrolment based on educational background (Figure 3).

Most programs identified were offered by universities (n=226, 85%), with the remaining fifteen percent offered by other organizations including charities/non-profits, societies/foundations, science centres/museums, individuals, and businesses. Most of the programs being offered by universities were graduate degrees (45%) followed by certificates (14%), the other 41% was made up of a variety of program types (such as undergraduate degrees, diplomas, minors, workshops, and single courses), however none accounted for more than 10% of all programs (Figure 4). Non-university organizations offered a variety of workshops (28%) and other training opportunities (59%) including fellowships, intensives, short programs, and online courses (Figure 4).

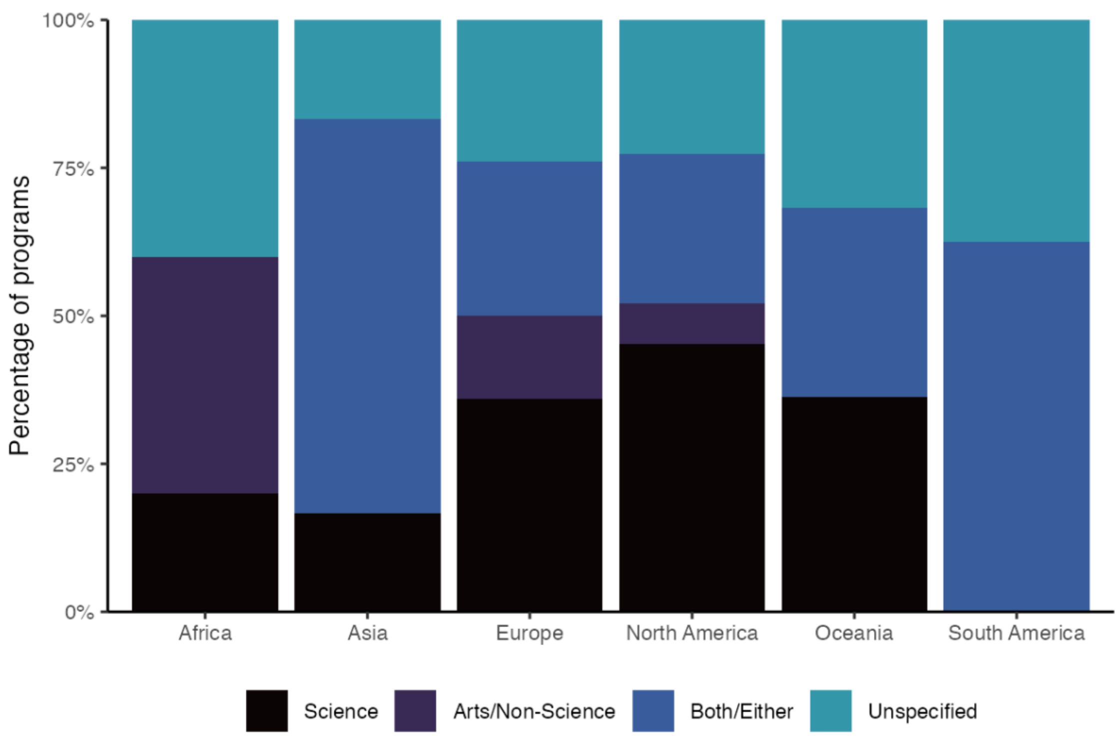

Figure 3. Percentage of global science communication programs by student/trainee background for each continent. Data retrieved from web searches using Google Advanced Search (number of programs = 265).

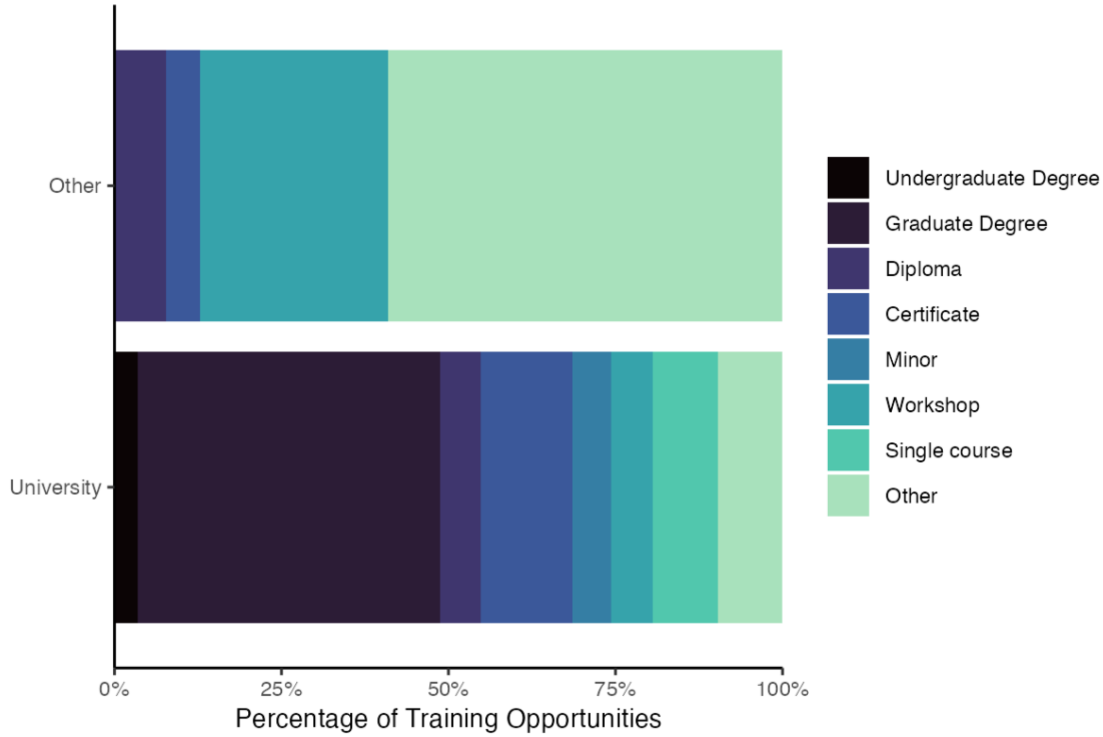

Figure 4. Percentage of global science communication training opportunities by organization and educational program type. Data retrieved from web searches using Google Advanced Search (number of programs = 265).

3.2 Science Communication in Canada is a Diverse Field

Of the 224 individuals contacted, a total of 54 Canadian science communicators elected to take part in the questionnaire (response rate of just over 24%). Respondents encompassed many unique roles in the field including artists (such as graphic designers and illustrators), government workers (both federal and provincial), science interpreters (working in science centres, museums, planetariums, and zoos), media professionals (including print, radio, television, and movie), research scientists and university professors, science communication consultants, science educators, writers (including bloggers), and other online content creators (including podcasts, videos, and social media).

When asked to categorise their work by selecting one or more of the provided categories (Figure 5), most respondents (65%) selected 2 or more categories. The most common response was science communication (85%), followed by science writing (44%), science journalism (22%), science centres/museums (20%), art (16%), and podcasting (13%) (Figure 5). The "other" category allowed respondents to provide alternative categories. "Other" responses included television and film, science education and outreach, research, science governance and policy, teaching and training science communication, and medical communication.

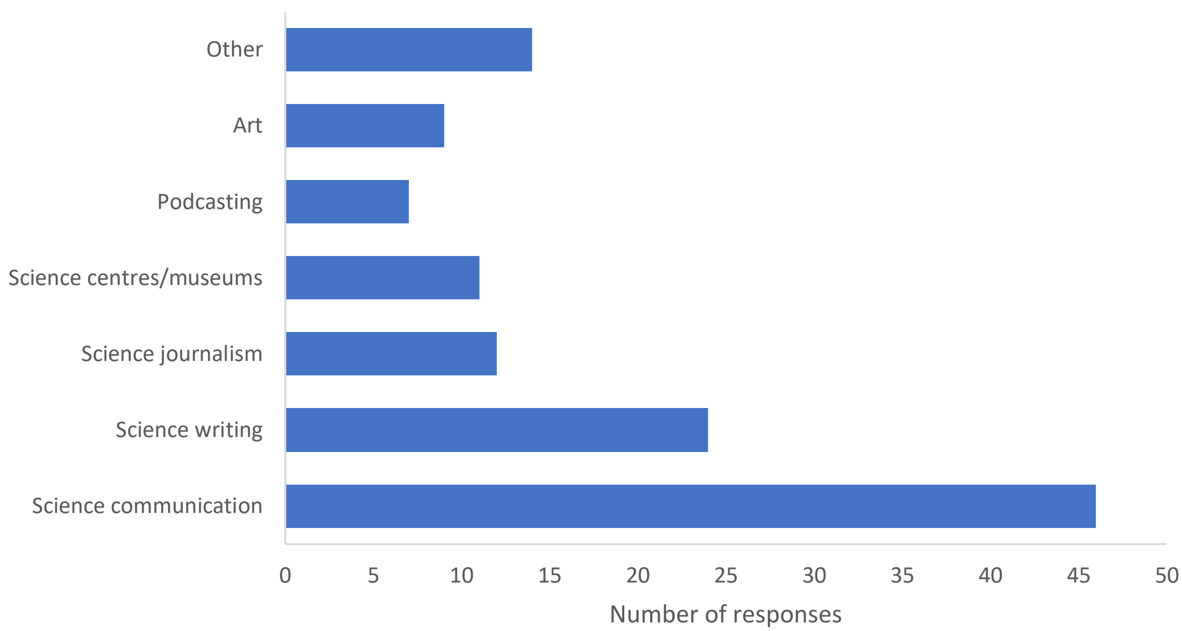

Figure 5. How science communicators in Canada categorise the nature of their work. Questionnaire respondents were able to select more than one category (number of respondents, n=54).

Almost all respondents indicated some level of higher education, with most (75%) having completed graduate level studies (Figure 6). Over two thirds of respondents (68%, n = 38) had a background in science, approximately an eighth of respondents (13%, n = 7) had a background in arts or social sciences, while another eighth had a mixed background with training in both science and arts or social sciences (13%, *n* = 7). Only 21% of respondents indicated that they received training in science communication prior to starting their work. Most indicated they "learned by doing" and/or didn't have a lot of opportunities for formal training early in their careers.

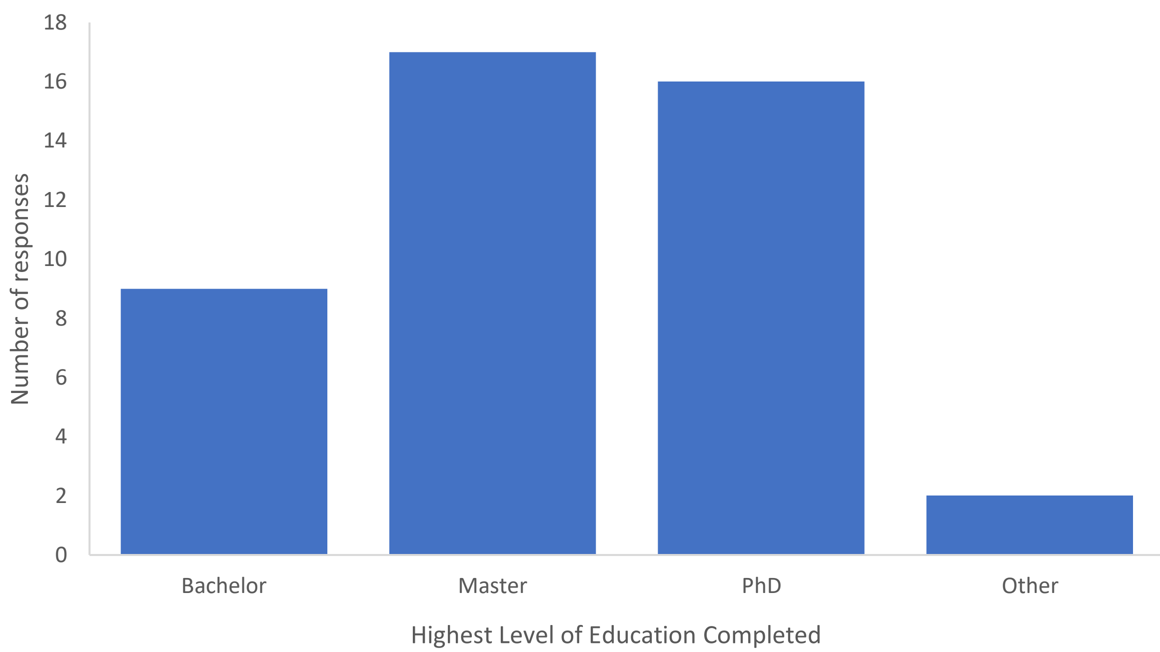

Figure 6. Highest level of education completed by questionnaire respondents. Level of education was voluntarily reported in an open-ended format, not all respondents chose to disclose this information (total number of responses, n = 44).

Q2 and Q3 aimed to compare the views of Canadian science communicators working in the field to understand whether different communicator groups were valued differently in the field. Respondents perceived journalists and writers to be the most active group when it comes to communicating science in Canada (Figure 7). Initial chi-squared (X^2 = 47.733, *df* = 5, *p-value* < 0.005) and subsequent pairwise chi-squared tests indicate that most respondents perceived journalists and writers to be more involved compared to science centres and museums (X^2 = 17.827, *df* = 1, *p-value* < 0.005), and government (X^2 =

26.738, *df* = 1, *p-value* < 0.005). Government alone was also perceived as less involved than scientists (X^2 = 10.122, *df* = 1, *p-value* < 0.05) (Figure 7). However, respondents indicated that all groups should be involved (Figure 8). Initial chi-squared (X^2 =113.62, *df* = 5, *p-value* < 0.005) and subsequent pairwise chi-squared tests (all *p-values* < 0.005) suggest that respondents believe all groups should be responsible for communicating science.

Q4 asked respondents to rate the importance of different groups engaging in science communication (Figure 9). The mean score of all groups was above the mid-point (3). Of all groups, respondents indicated that they perceive that it is less important for artists, and more important for science centres/museums, to be communicating science (Figure 9). Initial Kruskall-Wallis (*H* = 35.634, *df* = 5, *p*-value < 0.005) and subsequent pairwise Mann-Whitney *U* tests indicate that the importance of science centres/museums communicating science (M = 4.65) is higher than artists (*p*-value < 0.005), government (*p*-value < 0.01), and writers (*p*-value < 0.05). The importance of artists communicating science (M = 3.47) is also perceived as being lower than for scientists and journalists (*p*-values < 0.005).

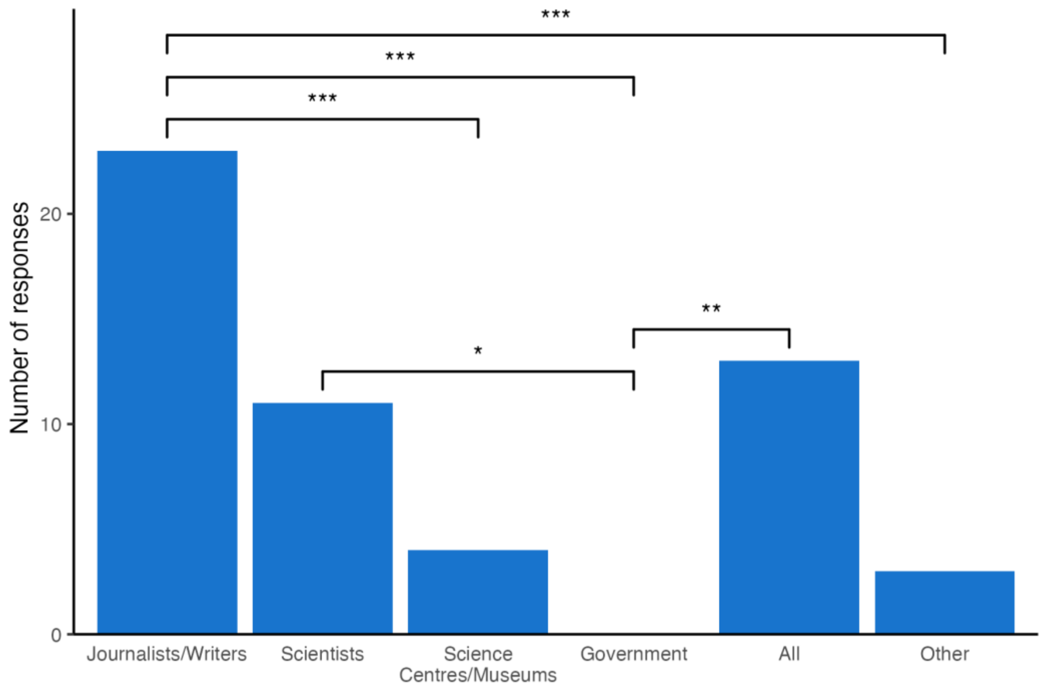

Figure 7. Various groups who science communicators in Canada think are predominantly communicating science in Canada (number of responses, n=54). Brackets indicate statistically significant differences in the pairwise chi-square comparisons, * p-value < 0.05, ** p-value < 0.01, *** p-value < 0.005.

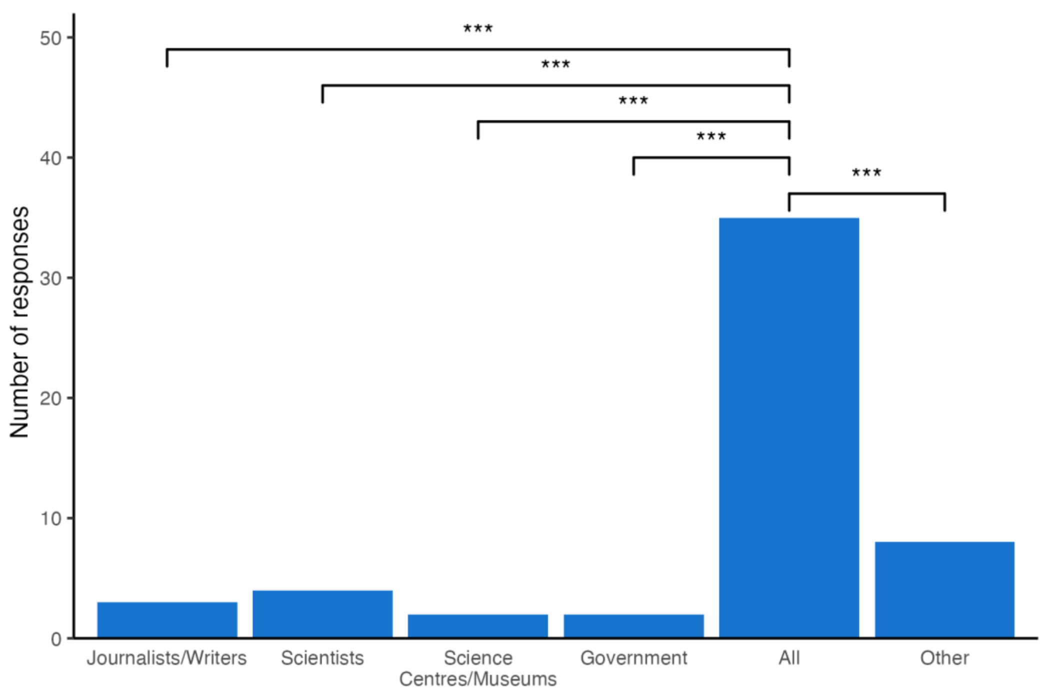

Figure 8. Various groups who science communicators in Canada think should predominantly be responsible for communicating science in Canada (number of responses, n=54). Brackets indicate statistically significant pairwise chi-square comparisons, *** p-value < 0.005.

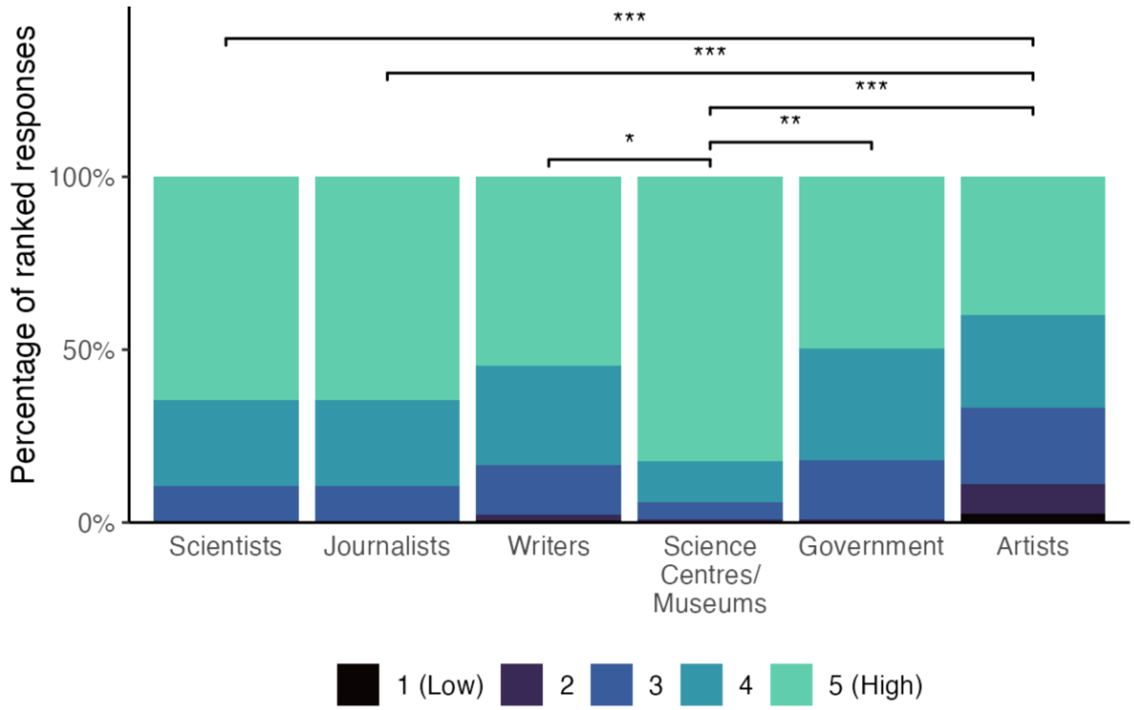

Figure 9. Percentage of rankings of how important science communicators think it is for scientists (number of responses, n=51), journalists (n=51), writers (n=51), science centres/museums (n=51), government (n=51), and artists (n=47) to actively communicate science on a scale of 1 (low importance) to 5 (high importance). Brackets indicate statistically significant pairwise Mann-Whitney U comparisons, * p-value <0.05, ** p-value < 0.01, *** p-value < 0.005

Q5 asked respondents to rate the importance of various purposes of science communication (Figure 10). On a scale from 1 (most important) to 4 (least important), respondents indicated consistent importance across all goals (all mean scores were at or above the midpoint of 2.5; Kruskall-Wallis H = 0.38534, df = 3, p-value > 0.05) (Figure 10).

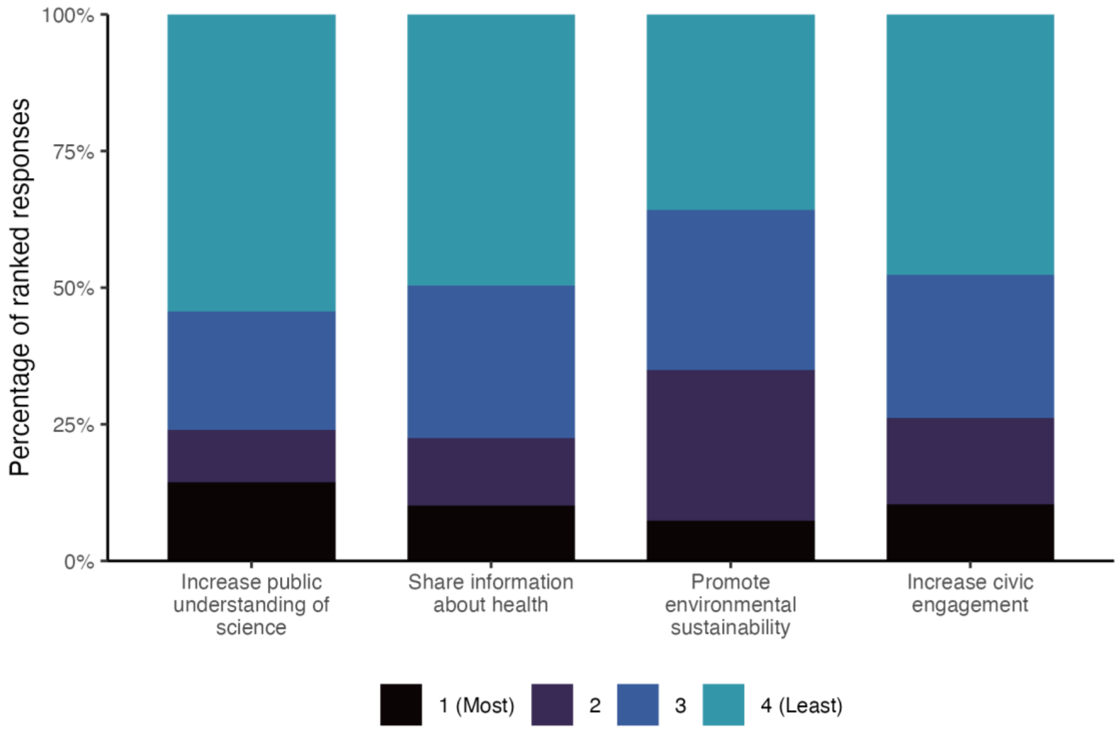

Figure 10. Percentage of rankings for the importance of science communication to increasing the public understanding of science (number of responses, n = 50), share information regarding personal and public health (n = 49), promote environmental sustainability (n = 49), increase civic engagement (n = 49).

3.3 Scientists & Science Communication

Most questionnaire respondents (85%) indicated that they perceive that it is important for scientists *in particular* to be trained in science communication. Respondents cited several benefits such as helping to build the science communication community, increasing public engagement with science, and (re)building trust in science and scientists (Table 1).

Just under half of the respondents (47%) felt that science was not being communicated effectively in Canada, citing various issues such as scientists undervaluing the field as well as a lack of funding, training, and public education in science (Table 2). While over half of the respondents (64%) indicated that science communication has improved in Canada, suggesting that the field has grown and developed over time and led to greater visibility, awareness, and interest, as well as more training opportunities and increased diversity (Table 3).

Table 1. Questionnaire results on Canadian science communicator opinions regarding the importance of training scientists in science communication. The question was: Do you think it is important for scientists in particular to be trained in science communication? Why or why not? Answers were sorted into general categories (yes, no, undecided), and then broken down by major theme and subtheme.

Yes / Undecided / No	Major themes	Subthemes	Example/Quote
Yes	Building the community	Important to create/ support trained sci comm professionals	it is important to create opportunities to support an industry of science communication professionals, who have the expertise, experience, and training specifically in communication and education, and not just training in science.
			... it ought to be mandatory for students in graduate-level programs to take a science communication course or two. Many scientists struggle to make their research not only accessible, but also compelling/entertaining
		Work better with science communication professionals	if they are working with science communicators they need to be able to communicate to them. Also, as communicators, we often facilitate videos or talks from scientists and if they already have training it is much better
		Increase perceived value of sci comm	current education systems do not train scientists for this and those who have these skills are undervalued
	Public Engagement	Valuable for scientists to speak directly to public	While it would be preferred to have professionals to the work, scientists cannot rely on others to increase public awareness of what we do. It is our responsibility to fill the gap
			It is important that scientists can communicate with the public, all levels of government, and the media. When information is shared directly then it is less likely to be distorted.
		Makes science more accessible	scientists should be trained in science communication to make their work more accessible. Lack of skills in science communication raises issues for the equitable dissemination of results, public interest, and for finding funding opportunities.
	Social Influence	Increase positive public engagement (i.e., visibility, inform public policy, fight misinformation)	Well-articulated stories about scientific discoveries and advances help demystify science, remind policymakers and the public of the importance of basic research and its impacts in our lives. It helps us also to fight against misinformation.
		Improve public perception of scientists	may also alleviate some levels of skepticism towards scientists, e.g., within health and climate science, as the public is provided with more accessible information and enhancements to their own science literacy.
Undecided	Collaboration	Not every scientist can/should communicate science	I think sharing their findings is important but I also think not every scientist can/should communicate science. I think they should collaborate with science communicators who focus on this specific part for their job
			... in an internet age scientists can bypass the media and talk to the public directly and should.
			only scientists with communication training, strategic thinking, and the best interests of their audiences should do public-facing comms, otherwise they risk doing harm to the public's trust in scientists
	Efficacy	Training helps make science more accessible	Academic language and conventions lend themselves strongly to confusion and misunderstanding when applied to non-academic audiences. Science communication training is critical to helping balance the need for specificity with the incredible importance of clarity, the latter of which is often sacrificed in the name of the former.
No	Research vs. Public Engagement	They're different skills	I don't think scientists need to be science communicators. Research, and public engagement are two very different skillsets. But I do believe that scientists who train in or are trained for science communication may better understand WHY the public needs to be better informed about science, how to do that, and what the ramifications of a science illiterate public are.
		Only those with training should communicate science	For most scientist, science communication is not important. It only becomes important when the scientist has to speak to the general public who are not familiar with science. Examples of scientists that would benefits from science communication training: Teachers, Educators, Professors, guest speakers, etc.

Table 2. Questionnaire results on Canadian science communicator opinions regarding the efficacy of science communication in Canada. The question was: Do you think science is being communicated effectively in Canada? Why or why not? Answers were sorted into general categories (positive, negative, neutral) depending on whether respondents indicated science is being communicated effectively in Canada, and then broken down by theme and subtheme.

Positive/ Neutral/ Negative	Major themes	Subthemes	Example/Quote
Positive	Improved over time	Quality	To a degree. We have a lot of excellent science communication here... I think Canadian science communicators have managed to do a lot with very little…
			...The quality of the content is good and there is something for all tastes... There still new discoveries made every week and older models are updated.
		Growing field	It's improving! I've noticed an increase in the number of scientists, science organizations and government agencies investing in their communications
			Sometimes. Depends on the topic and the timing. Much more "science" was communicated during the pandemic, and now re: climate change.
	Science widely available	Public health	Moderately effectively. I think public health science communication has improved or at least become more widespread during the pandemic…
		Various sources	Science is being communicated effectively in the sense it is widely available. The content is available through schools, libraries, television shows, podcast, museums, newspaper articles and more...
Neutral	Effectiveness varies	Combatting misinformation is an issue	I would say it's extremely variable. There are great examples of effective communication, but I think the prevalence of confusing, misleading or inaccurate science communication (mixed in with intentional misinformation) makes it understandably difficult for many people to recognize effective and trustworthy scicomm when they see it.
		Lack of understanding regarding the scientific process	...the biggest challenge to effective science communication in Canada is that we are missing the critical conversation that science is iterative. As we undertake new research, we gain new findings, which in turn changes the recommendations and policies that are made based on that science. Without that particular understanding of how science works, we will continue to be limited in our ability to communicate science effectively...
	Accessibility	Only available to those who seek it out	Canada has the capacity for effective science communication. But another significant challenge that it faces is building adaptive and resilient communication structures that ensure that messages are communicated quickly and accurately to the people who need them, when they need them. A lot of science communication can happen in an echo chamber, and I would like to see more attention to increasing the accessibility of science for everyone.
		Barriers to engagement & access	This is hard to say, I believe it is very field-specific. It depends on the socio-economic group you are looking at, and whether they are interested in or able to engage with English-speaking activities and products. I think public health comms around the pandemic and community health are lacking.
			Depends on where in Canada you mean. In the south, there's a lot of science communication via museums and activities/events like Science Odyssey. I work with northern communities who do not get the opportunities to go to museums or have science communication activities. They are left out. Often then also have poor-quality science education in addition to this, as teachers are hard to recruit and retain in the north. This has created a major science gap for northern youth.
			It is difficult to assess for me. I have the impression that it is more present in few English-speaking provinces, like Ontario, because young people or icons stand out on social networks. In French, there is a lack of known characters.

Negative	Sci Comm community issues	Lack of perceived value	...Lack of emphasis to scientists on the importance of public engagement (current focus and career advancement is dependent on highly specialized technical research publications, which target other experts in the field, and are almost impenetrable/inaccessible to the general public)
			Science communication to the broadest audiences has never been valued, recognized or rewarded by the scientific enterprise. It is not appreciated for things like tenure, promotion, awards within the scientific enterprise. It is seen as lesser, often belittled and rarely acknowledged as being meritorious....
		Lack of training	...lack of formal experience in communication by scientists
			...there are a lack of visual and expert communicators who understand the science being tasked with getting the message out
		Lack of funding	...lack of government/institutional funding and infrastructure to facilitate more engaged science communication
			...we need more [science communicators], well funded and well connected with each other
			...with the rising wave of misinformation and new methods of media consumption, there needs to be greater investment and support for this important work. The resources are far too limited.
	Public issues	Lack of education	Not so well and that is, in some large measure, because students aren't being adequately trained in statistics, probability, and the like. You can't understand most things that are scientific if you don't appreciate how often they aren't absolute.
			...The public does not understand that business as usual will doom us. Education through the media by scientists needs to mandated and communications must determine the deniers and vested interests that confuse the public
			...Engagement at school level is very basic...tooling the younger generation to better contextualise/ evaluate information needs to be reviewed/ reconfigured
			No. There is little to no emphasis placed on the scientific process and how science creates new knowledge. Until we do this, how can we expect non-scientists to understand /distinguish between what is good science an what is bad science, as well as accept why scientific findings are constantly changing.
		Children typically the target	...Science communication traditionally in Canada has been infantilized and much of the efforts of science centres and other proponents of science communication has been aimed at children. This contrasts with the way science is communicated in other countries - where adults are also considered prime target audiences.
			...Science museums are by and large catering exclusively to children and new parents and do not act as beacons of scientific knowledge for the adult (voting) population, which feels like a missed opportunity…
		Ineffective public messaging	There is a vast amount of information and misinformation, and at times, there doesn't seem to be clear, effective messaging…
			Looking at how the government has communicated about science during the pandemic, there was a lot of confusion as different agencies communicated contradictory information to the public. Having a more streamlined strategy would improve communications. Some of these agencies should be speaking to each other and not to the public.

Table 3. Questionnaire results on Canadian science communicator opinions regarding how science communication has changed over the course of their careers. The question was: How has science communication in Canada changed over the course of your career? Answers were sorted into general categories (better, worse, neutral), depending on whether respondents indicated improvement, and then broken down by theme and subtheme.

Better/ Neutral/ Worse	Major themes	Subthemes	Example/Quote
Better	Field has grown/developed	Increased communications	It seems like it has only really taken hold in Canada in the last few years and seems to be growing significantly.
			...Now you can read/view/hear about science all over the internet. If you want to know about something you can. But now the issue is: is it really true…
			...Today it is more understood and has become a professional field of work and study that moves way beyond the flash and bang of a stage performance to include information on daily decisions made by families. Science communication is in virtually every news cast and has become more common
		Popular among young scientists	Lots of younger scientists take it more seriously, and are good at it
			more scientists and young scientists involved
			More scientists, especially early career, are taking communications training…
		Increased diversity	...I do feel the SciComm voices have become more diversified
			...Lower barrier to entry to social media is a good thing
			…noticed an increase importance placed on equity, decolonization and inclusion...
			transition from "if we tell people the facts, we'll do what they say" to understanding that people are much more complicated, and therefore more nuanced and multifaceted communications approaches -- understanding the power of storytelling, art, etc.
			...I'm seeing more receptivity and interest in breaking away from conventional reports and harnessing illustration, graphic design, video, animation, infographics, and other methods that blend science with the arts to more effectively reach a broader array of audiences. I am also seeing greater awareness of the pervasiveness of colonial biases and attitudes throughout society and attempts (some small, some drastic) to decolonize science communication and include Indigenous collaborators rather than speaking "for them."
	Greater field value/visibility	Increased awareness	Awareness of its importance has certainly improved… Science communication has achieved some level of respectability and credibility as a career pathway although it has a long way to go in terms of being inclusive and diverse.
			...Increased visibility for science content is an encouraging progression...
			there's much more awareness about what "science communication" is and why it matters now than in the past. There's a lot of enthusiasm for it in academia, particularly among graduate students
			I have noticed that there are more science-themed movies, tv shows and non-fiction books available
			... [science communication] is more understood and has become a professional field of work and study that moves way beyond the flash and bang of a stage performance to include information on daily decisions made by families. Science communication is in virtually every news cast and has become more common.
	Increased desire to communicate science to public	More training opportunities	Biggest change is the growing existence of courses and training programs in science communication.
			There are more opportunities to follow a career in science communication. There are also more courses, training, certificate programs, and degrees in science communication which I am pleased to see.
			...Some universities offer science communication courses, or integrate science communication activities within course material (there are still very few programs dedicated to science communication in Canada) ...
			The university is taking careers in science communication seriously and offering workshops in science popularization, which used to be frowned upon.

		More interest	I have seen more academics become interested in it. I also see many science students who reach out and would like to do science communication as a job…
			...bigger push in general to communicate science to the general public. There are all sorts of groups like Science Slam and outreach organizations educating a lay and youth audiences…
			More of a focus and community, much more interest.
			... incredible to see the energy and effort behind science communication. There are so many fabulous individuals and groups who are doing important science communication work, often unpaid, but with more opportunities for contract work. I also believe that the tone has shifted in academia, with science communication efforts receiving more support... Many large organizations have staff dedicated to communications, and some research groups may even have a communications specialist involved or employed for part of a project...
Neutral	More communication is needed	Public Health	Began my career at the beginning of COVID-19, meaning I saw a huge need for science communication that was being nationally and internationally recognized. Many organizations are seeing the value and beginning to incorporate it into operations.
		More training	We need a lot more expertise in communication, human and social psychology, media content creation and other domains - to connect and integrate with scientists - to achieve improvements.
			growing demand for trained professionals who specialize in science communication, particularly from government agencies, hospital networks, and NGOs. There is an increased need for communicators who understand how to produce media for social distribution that is authentic in voice and accurate in content (trustworthy). There is a shift to employers seeking strategic science communicators with holistic skill sets, which is different than roles looking for scientists with media training or graphic design abilities.
	Landscape is changing	Social media a dominant channel	Social media became a key channel for science communication. This has accelerated the speed with which information is shared. It has created a variety of positive and negative outcomes from greater ability to reach large audiences and for scientists to communicate directly with the public, without gatekeepers, to changed objectives e.g., follower counts and sensational communications, or misinformation and disinformation campaigns.
			More and more is done through social media, people sharing articles and links with each other.
			More and More scientists are on social networks, especially twitter.
			The rise of social media, the drift away from beat reporters - including science reporters - to more generalists with little or no knowledge of science…
Worse	Persisting problems in Sci Comm	Divisions/Biases remain	... things have also deteriorated and gotten much more divisive and political
			...still not valued as much, even university teachers are seen as “second class” at times to research professors, and teaching and outreach really go hand-in-hand. I think there is a long standing bias against outreach as an important aspect of all science. This is shifting but very slowly. Usually science communication in academia is still an nice 'extra' thing you can do, and not something that is your main job.
		Lack of jobs	It feels like there's less full-time permanent jobs in science reporting than there was a decade ago.
			Unfortunately, the job landscape in science communication in Canada is very bleak at the moment. Outside of a few opportunities as science journalists and many jobs in PR, there is a dearth of jobs in the field.
		Misinformation is a problem	...negative interactions and ease of spread of misinformation have both led to regression and potentially a need for recalibration of how to use online platforms for Sci Comm
			on the defensive...a lot of time spent debunking fake science
			Science communication is really trending towards science education (as in, you should think what I think because it is correct.) Science communication primarily relies on people having basic understanding of what science is and isn't, so they can vet information. People are indeed finding and vetting their own information about vaccines, it's just not desirable from a gov'n/ scientist perspective... Science needs to feel relevant/ approachable from childhood on, which is where educators and science museums/ science centres come into play.

CHAPTER 4: DISCUSSION

4.1 Science Communication Training Programs Worldwide

Training opportunities around the world are diverse, with programs being offered through universities, as well as non-academic entities (e.g., charities, non-profits, societies, foundations, science centres, museums, businesses, and individuals). Moreover, programs vary in their educational setting (formal vs. informal) as well as length, and include degrees (both undergraduate and graduate), diplomas, certificates, minors, workshops, single courses, fellowships, intensives, short programs, and online courses, indicating an intent to reach a variety of participants.

Overall, most training opportunities are specifically intended for scientists, while programs specific to non-scientists are relatively rare among the existing programs. Globally the diversity of science communication training opportunities is high; however regional differences have emerged. North America, Europe, and Oceania offer more scientist-specific training, while programming specific to non-scientists is offered mostly in Africa. South American and Asian training opportunities have few specific requirements, with most of their programs being offered regardless of educational background of their potential students.

4.1.1 Science Communication Training for Non-Scientists

Of the few training opportunities offered specifically to non-scientists, most focus on science journalism, broadcasting, and writing. Since the 1900s science communication has predominantly been the work of science journalists (Fahy & Nisbet, 2011; Weingart & Guenther, 2016). Over time the role science journalists have played at the intersection of science and society has grown and changed. Initially they served as translators, distilling novel scientific discoveries so the public could better understand, then as advocates and promoters of science helping to raise the credibility and popularity of science in society, and finally as critics, observing and commentating on increasingly complex advancements in science and technology and science's relationship with industry and government (Fahy & Nisbet, 2011). Digitization, and with it the rise of the Internet and social media, has pushed science journalists out of traditional media (Brumfiel, 2009) and now they often work as freelancers or public relations specialists for scientific institutions (Brossard, 2013; Fahy & Nisbet, 2011).

However, this is mostly the case in western, developed, democratic countries. In underdeveloped regions like in much of Africa, where the Internet penetration rate is only around 25% (Adeniran, 2019), effective and accessible science communication must take place through other means like print/newspapers, television and radio, science cafés, and, more recently, on cell phones (Falade et al., 2020; Iacoella et al., 2022; Kaseje & Okeyo, 2020; Nyirenda et al., 2016; Mutheu and Wanjala, 2009). Therefore, a focus on the training of non-scientists in science communication makes sense in these regions.

Similarly, countries with strong government control or involvement in science communication such as China, Russia, Korea, and, until recently, Japan (Borissova & Malkov, 2020; Cho & Kim, 2012; Kim, 2020; Lin & Honglin, 2020; Watanabe, 2017; Watanabe & Kudo, 2020), have less targeted science communication programs, accepting students/trainees with a variety of educational backgrounds. In these areas, science communication emerged from, and/or was exerted upon by, government/state control of scientific information (Borissova & Malkov, 2020; Cho & Kim, 2012; Kim, 2020; Lin & Honglin, 2020; Watanabe & Kudo, 2020). In many ways the desire to train scientists to communicate was absent, with science communication falling on science journalists and the public relations professionals of universities and other research organizations (Borissova & Malkov, 2020; Lin & Honglin, 2020; Watanabe & Kudo, 2020). An emphasis on the training of science communications professionals regardless of background aligns with how science communication has evolved in the socio-political landscape of these countries.

4.1.2 Science Communication by Scientists

Scientists' engagement in science communication is not a new endeavor. Scientists have been engaging with the public in various ways since the beginning of science itself. From public lecture series and special science bulletins to magazine entries, books, radio and television appearances, and finally digital media, the field of science communication as a practice among scientists has grown and evolved over time with the changing of our interpersonal methods of communication. Though science communication as a designated, defined field is still in its infancy, it has been carried out for decades by scientists-science popularizers and communicators like Francis Bacon (in the 17th century), Michael Faraday (in the 19th century), Richard Feynman and Carl Sagan (in the 20th century), Stephen Hawking (in the 20th to early 21st century), Sir David Attenborough and David Suzuki (in the mid to late 20th to 21st century), as well as Neil deGrasse Tyson (in the late 20th to 21st century) and Brian Cox (in the 21st century).

Alongside the growth and popularization of science, scientific theories and technological advancements have become increasing complex. As a result, it has become increasingly important for scientists to be able to communicate and explain their findings to the public so that productive, informed discussions of scientific topics may occur. Furthermore, we've seen an overall push for scientists to be more active in public discourse around science (Besley, 2015; Brossard and Scheufele, 2013; Bucchi, 2017; Dudo & Besley, 2016; Fahy and Nisbet, 2011; Royal Society, 1985). Recent studies indicate that scientists have a strong desire to communicate with the public, however they often lack the skill or expertise to do so (Dudo & Besley, 2016; Dudo et al., 2021). It is no wonder that training opportunities to help scientists improve their engagement efforts have increased significantly over the last decade (Baram-Tsabari & Lewenstein, 2017; Mercer-Mapstone & Kuchel, 2015; Smith, 2020; Stylinski et al., 2018; Trench & Miller, 2012). The push to train scientists to communicate with the public is the result of the dynamic and ever-evolving landscapes of science, media, and society, as well as the increased interest and importance of science-related topics (such as the environment and public or personal health) to society.

Effective science communication is beneficial, and often necessary, to generate productive democratic discourse around science-based issues like healthcare and the environment (Negretti et al., 2022). Training programs directed at scientists make sense in relatively strong democratic regions like North America, Europe, and Oceania. Secondly, in democratic countries, government seems to take a more hands-off approach, which historically left science communication predominantly in the hands of journalists. Consequently, as the landscape of communication has changed from print and broadcast to online media, science journalism has dwindled (Fahy & Nisbet, 2011; Iyengar & Massey, 2018; Riedlinger et al., 2019). Fewer science stories being reported by traditional media has also had the effect of moving some discussion of science to online fora and social media (Allan, 2011; Brumfield, 2009; Fahy and Nisbet, 2011; Iyengar & Massey, 2018; Riedlinger et al., 2019). As a result, scientists no longer need to rely on journalists to communicate their research, however, many scientists lack the training to communicate effectively on their own (Dudo, 2015).

Furthermore, while the disconnect between science and society has persisted since the mid-1900s, it has grown in recent years due to the increased complexity of scientific and technological innovations making scientific concepts difficult to understand (Brownell et al., 2013; Dudo, 2015; Ho et al., 2008). This is especially true as innovations that may be conceived to address major global issues like climate change and alternative energy, as well as disease prevention and treatment often involve major ethical, moral, and legal considerations (Dean, 2009; Dudo, 2015; Leshner, 2003; Meredith, 2021). As a result, scientists have felt increased pressure to communicate science in public spaces. This, in combination with an increased desire to communicate, and a lower barrier of entry through the use of online platforms like personal websites, blogs, and social media has made it easier than ever of scientists actively participate in science communication (Allan, 2011; Iyengar & Massey, 2018; Riedlinger et al., 2019). As a result, many scientists are becoming increasingly interested in science communication and are looking for opportunities to improve their skills (Baram-Tsabari & Lewenstein, 2017; Dudo et al., 2020).

4.2 Who, What, When, Where, Why, How? A Survey of Canadian Professionals

Science communication in Canada is undertaken by a professionally diverse set of motivated individuals. A total of 54 Canadian science communicators including artists, government workers, science interpreters, media professionals, consultants, educators, researchers, bloggers, and other online content creators took part in our short questionnaire. Views of the Canadian science communication landscape varied between communicators, with nuanced, thoughtful responses regarding the state of the field, its efficacy, and how it may have grown or changed over time.

Canada is a relatively new player in the field of science communication, especially compared to older and/or larger countries like the United Kingdom and United States. While there are fewer programs offered here than elsewhere, the number and diversity of programs is growing. Canada is a culturally diverse, socialistic-democratic country which makes it well situated to produce a large variety of communications on many different scientific topics. The desire for a diverse landscape of science communication professionals is evident with strong support from communicators. As a result, we don't see the same evidence of division between communicators with backgrounds in science versus social science that have emerged in other regions like Europe (Davies et al., 2021; Gerber et al., 2020; Miller, 2008; Priest, 2010) and Australia (Metcalfe & Gascoigne, 2012; Metcalfe & Gascoigne, 2017).

4.2.1 Notes from the Field: Attitudes & Perspectives of Canadian Science Communicators

Most respondents (85%) considered themselves active science communicators, with the most dominant communication types being science writing, followed by science journalism and science centres or museums. This may have been expected, given the developmental history of the field in Canada (Riedlinger et al., 2020; Riedlinger et al., 2021), however, some additional inferences can be made. Firstly, this suggests science communication is a unified professional field. Furthermore, a handful of respondents did not select science communication as their main professional identifier. This may suggest some practitioners feel that they are not part of the general science communication community. Alternatively, they may feel that they occupy a specific niche or role within the overall field.

It is becoming increasingly common in North America, and Canada more specifically, as science journalists dwindle, for highly educated scientists to endeavour to communicate with the public, predominantly through online means (Riedlinger et al., 2019; Riedlinger et al., 2020; Riedlinger et al., 2021). The shift of most day-to-day news and communications to online, unmediated forums like Reddit and social media, such as Facebook, Instagram, TikTok, Twitter (now X), and YouTube, has led to rampant misinformation especially regarding science-related topics of health and the environment (Iyengar & Massey, 2018; Lazer et al., 2018; Scheufele & Krause, 2019;). Combating misinformation is one of the primary goals of many science communicators and it seems to be a factor driving scientists to communicate with the public (Iyengar & Massey, 2018; Gascoigne et al., 2020; Riedlinger et al., 2019; Riedlinger et al., 2020; Riedlinger et al., 2021).

While respondents indicated that specific communications training for scientists was important, most respondents indicated a lack of personal training prior to their own careers. Many indicated this was due to lack of training opportunities available to them early in their careers, citing “learning by doing” along with personal motivation and interest, leading to engagement in this type of work. This is likely to change over time given that training availability is quickly increasing, especially in formal settings like universities.

Among Canadian science communicators, journalists and writers were perceived to be the most active group in the field, while government was perceived to be least active. Interestingly, most respondents showed a strong desire for a diverse field of science communicators in Canada, indicating that all groups (i.e., journalists/ writers, scientists, science centres/museums, and government) should be involved in science communication. Furthermore, Canadian science communicators indicated that the most important group to be involved was science centres/museums. As one of very few spaces where people of all ages can interact with and experience science, science centres and museums are unique in their ability to reach a wide variety of people (Achiam & Sølberg, 2017; Owens et al., 2002). They also represent an opportunity for people to ask questions in a space that is designed to inspire wonder, raise questions, and facilitate exploration (Achiam & Sølberg, 2017; Carnall et al., 2013; Tlili et al., 2006). It appears that science communicators in Canada have a great appreciation and respect for science centres and museums, and that they are perceived to play an integral role in science communication. Many respondents indicated that government should play a critical role, especially regarding public acceptance of health science, as evidenced by the handling and dissemination of scientific information during the COVID-19 pandemic.

Canadian science communicators held differing views on the overarching goal of science communication. Indicating that the goals of increasing public understanding of science, sharing information about health, promoting environmental sustainability, and increasing civic engagement in science held equal importance. This suggests that communicators are either focusing on very specific areas of science communication such as health or environmental science, or that most communicate on a variety of topics and therefore do not consider any one to be more important than the other. Not everyone is communicating to achieve all these outcomes, some communicators are generalists, generating content on a wide range of scientific topics, while others focus on specific areas of science, such as medical communications. The number of "generalist" communicators may decrease over time as more, young, early-career scientists enter the field via online means like social media often focusing on specific topics where they feel they have some form of expertise (Riedlinger et al., 2019; Riedlinger et al., 2021).

Canadian science communicators who responded to the questionnaire indicated that, for better or worse, the field has grown and changed significantly over the course of their careers. They indicated that the field is shifting away from conventional means and adopting modern communication strategies. Specifically, practitioners are incorporating more illustrations, graphics, videos, and animations in an attempt to enhance their science communications. This suggests that science communicators are seeking out new skills or collaborating with people outside of science to improve their communications.

The prominence of science communication in Canada has grown in recent years, with greater interest, awareness, and visibility along with increased training leading to increased respect and credibility for practitioners among the public. This increased visibility and value may help the field attain greater respect specifically amongst scientists, academics, and the institutions in which they work. Furthermore, the employment landscape for future science communicators may improve as research institutions in Canada seek to develop their public relations strategies.

Some respondents to our questionnaire indicated that they held underlying feelings of apprehension and trepidation about the future of the field. Specific concerns included the availability of job opportunities, the prevalence of misinformation, and a perceived lack of understanding regarding the nature of science among members of the public. Our results are consistent with previous research showing that much of the science communication conducted in Canada occurs online, often for little or no pay, and often as a secondary job or hobby of the science communicators (Riedlinger et al., 2019). While online communication tools like social media have made it easier than ever to share science information, the overabundance of such information online can make it difficult to reach one's intended audience in a meaningful way. The need to compete for views, likes, shares, and followers may impact the accuracy, as well as the motivations behind, the content being produced online, which makes effectively assessing the quality and credibility of online sources increasingly difficult (Guess et al., 2020; Howell & Brossard, 2021; Kahne & Bowyer, 2017; Riedlinger et al., 2019). Furthermore, as with any online source, it can be difficult to identify the origins of the content, which may affect the communicator's credibility and the public's trust of their factual integrity. While there may be a desire for science communicators to use online personas to maintain some level of privacy, the resulting anonymity may also be used to hide conflicts of interest and ulterior motives, such as payments from sponsors and/or employers aiming to promote specific beliefs or attitudes towards certain scientific topics.

4.2.2 Canada vs the World: A Comparison of Approaches from Around the Globe

Science communicators engage in a variety of activities, with digital modes of communication having exploded in number over the last decade (Luzón & Pérez-Llantada, 2019). This is evident in Canada, as it is elsewhere in the world, where a variety of stakeholders regularly engage in science communication. However, Canadian science communicators, especially young, early career communicators, seem to have had some access to more formal science communication education, when compared to communicators in Europe (Davies et al., 2021; Nielsen, 2010), Africa (Gething, 2003; Kaseje & Okeyo, 2020), and Asia (Lin & Honglin; 2020; Navarro & McKinnon, 2020; Watanabe & Kudo, 2020).

Interestingly, in some European and Asian countries (such as England, France, Spain, Italy, Estonia, and China) the "origins" of science communication can often be traced back to scientists and science hobbyists (Bergeron, 2020; Lin & Honglin; 2020; Olesk, 2020; Pellegrini & Rubin, 2020; Revuelta et al., 2020). Advancements in printing and broadcast media as well as changes in socio-political structure shifted science communication to the spheres of media and government. In colonized countries such as Canada, the USA, the Philippines, and South Africa, some of the oldest forms of science communication, specifically Indigenous oral histories and traditional knowledge (Ambrosio, 2010; Joubert & Mkansi, 2020; Montemayor et al., 2020) have been significantly understudied. Furthermore, due to lasting impacts from colonization, the history of science communication in these, and other colonized countries, has been dominated by institutionalized processes such as print and other media as well as the establishment of governing bodies, learned societies, academies, associations, and museums (Bevan & Smith, 2020; Joubert & Mkansi, 2020; Riedlinger et al. 2019; Riedlinger et al. 2020; Riedlinger et al., 2021; Montemayor et al., 2020).

Equity, diversity, and inclusion in science communication is a new area of research, with recent studies assessing and discussing challenges in Australia, China, the Dutch-speaking Caribbean islands of Aruba, Bonaire, Curaçao, Saba, Sint Maarten, and Sint Eustatius (the ABCSSS Islands), Germany, India, Italy, Mexico, the Netherlands, New Zealand, Nigeria, South Africa, the United Kingdom, and the United States (Dawson, 2019; Finlay et al., 2021; Rasekoala, 2023). Canadian science communicators indicated that though there seems to be greater emphasis on diversity, equity, inclusion, and decolonization, diversification within the field of practice has been slow. Moving forward, it will be important to similarly explore, assess, discuss, and confront challenges of diversity, equity, and inclusion in Canadian science communication spheres. This includes partnering and engaging with diverse practitioners, audiences, and communities to learn about science communication practices that have gone unrecognized, breaking down barriers to access, participation, education, and professionalization as well as introducing and/or improving strategies of inclusion to better collaborate and communicate with diverse audiences and practitioners.

The perceived benefits of science communication appear to be similar in Canada as they are elsewhere, more specifically it can increase the perceived value of science and scientists, fight misinformation, inform public policy, and ultimately contribute to the public good by connecting people to research that may help them (Davies et al., 2019a;

Davies et al., 2021; Gething, 2003; Navarro & McKinnon, 2020; Nielsen, 2010; Riedlinger et al., 2019; Riedlinger et al., 2020; Riedlinger et al., 2021).

Barriers to science communication varied from one continent to the next, with issues including lack of infrastructure, lack of funding, and limited job opportunities, as well as fragmentation by geography, language, politics, discipline, and culture. In Canada the biggest areas of fragmentation seem to be geographical location, language, and culture (Davies et al., 2021; Gascoigne et al., 2010; Gerber et al., 2020; Hartz, 1997; Miller, 2008; Priest, 2010). Most communicators live and work in the south of the country, predominantly in Ontario and Quebec (Riedlinger et al., 2019). As a result, northern communities, especially those in the Canadian territories are less able to access science communication tailored to them and their needs. Quebec experiences linguistic and cultural barriers, not only to accessing but also promoting and sharing science communication, as the only French-dominant province. As a result, communicators indicated that, nationally, French science communicators are less well-known than their English counterparts. Immigrant populations are also more hindered in their access to Canadian science communications, as their English (and/or French) language skills may not be strong enough for them to be able to engage with activities and products designed for Western, English audiences and their cultural backgrounds.

4.3 Limitations

4.3.1 Limitations to the Review of Science Communication Programs

There are several limitations to this review of science communication programs. Firstly, programs were collected through web searches and reviewed by a single researcher in a multi-step iterative process. This search, while attempting to be comprehensive, was limited most significantly by language constraints. Due to the reviewer knowing only English, French, and basic Spanish, it is likely that a great number of programs were missed, specifically in Asia, Eastern Europe, and Africa. Furthermore, single courses were not counted from universities that offered degrees, diplomas, certificates, or short programs in science communication so as not to artificially inflate the role universities play in science communication training. Additionally, there seems to be great turnover in science communication training programs with many being offered sporadically, some were only offered once, while others were offered for several years before being cancelled. As a result, it is possible that some single courses were missed as they only existed for a short period of time and/or did not yet exist when the data was initially being compiled. The majority of programs were found using Google search and Google advance search however, some were found as the result of pre-existing lists which had been curated online, by science communicators and science communication enthusiasts.

4.3.2 Limitations to the Questionnaire of Canadian Science Communicators

The questionnaire provided to the science communication professionals in Canada, and the subsequent analysis of the gathered data had several limitations. Firstly, the number of practitioner responses was limited. Only about a quarter of individuals invited to complete the questionnaire responded. Moreover, the questions were not pre-tested for clarity or calibrated to ensure they were eliciting the desired information from respondents (for example, to limit the number of ways a question may be interpreted).

Additionally, limited demographic information was sought, which made it impossible to ascertain and ensure age, sexual/gender, or racial/ethnic diversity of the sample group. This also made it impossible to know whether a representative sample of Canadian science communicators had been achieved. While some respondents indicated that diversity was lacking in the science communication community, others indicated that diversity is increasing. This suggests that more research is required to determine whether the level of diversity in Canadian science communication matches the overall diversity of the country's population.

Secondly, as with the majority of science communication research, older, understudied forms of science communication were ignored. In Canada, as elsewhere, Indigenous people have rich, complex (predominantly oral) histories regarding traditional ecological knowledge, medicines and medicinal plants, and food including agriculture, hunting, and fishing (Berkes et al., 2000; Ohmagari & Berkes, 1997). These aspects of science communication, while admittedly difficult to study, are almost entirely missing from the histories of science communication presented in major research publications.

Lastly, though the focus of the research was to examine potential differences in attitudes and opinions of communicators with differing educational background, greater emphasis was placed on scientists as communicators. Though pertinent, given evidence of increased participation in the field by scientists, this may have had a negative effect on a significant portion of current non-scientist science communicators. If certain respondents felt as though questions were not pertinent to them, they could have skipped those questions, which could have skewed responses to the questionnaire. A similar problem could arise if respondents were giving "socially desirable responses" rather than ones that reflected their actual attitudes and perspectives (Leitz, 2010). Essentially, trying to answer in a way that may be favoured by society (Leitz, 2010), which could in this case be other practitioners or us as researchers.

4.4 Conclusions & Future Directions

Diversity among researchers, practitioners, and intended audiences of science communication is undeniable, whether on a global or local scale. This is reflected in the science communication training being offered as well. Professional science communication training programs are important as they serve to strengthen one's communication capabilities (Besley & Tanner, 2011; Salas et al., 2012), ultimately increasing communication efficacy. Today there are hundreds of training programs offered around the world to support and advance people's abilities in science communication.

While most programs seem to be offered in North America and Europe, a significant, and increasing number of programs are being offered elsewhere. While programs are offered in a variety of languages, cultural and ethnic diversity of participants is lacking in regions like North America (e.g., Dudo et al., 2021). Increasing trainee diversity will enhance the accessibility of science communication content, as people may be able to better tailor their messages for diverse audiences. Future studies should examine potential social, cultural, or economic barriers to training, especially in racialized and marginalized groups.

The field of science communication in Canada is equally diverse with a wide array of actors and stakeholders. As digital media grows, the field seems to be moving almost exclusively to online channels. This may exacerbate issues of trust towards science communicators, especially with the prevalence of masked or anonymous identities in online spaces. The intentions of the communications being produced may be called into question, as they may be suspected of trying to further intrinsic biases or self-serving goals. This suspicion may be heightened by attempts to monetize content through incentives related to increasing subscriber/follower counts and interactions with their content (e.g. through likes, comments, and shares) and profiting from sponsor or donor relationships. Online channels also present issues for engagement as there are still segments of the population that lack adequate access to the internet, and online media, while more accessible in some cases, often must be sought out by users. In this way, science communication may not be reaching as broad (or as general) an audience as desired, limited by the likelihood that individuals with a pre-existing interest in science are more likely to engage with science communication online.

Future research should investigate the accessibility of science communication in Canada, especially for diverse audiences including but not limited to, marginalized groups such as visible minorities (including new immigrants and Indigenous people), 2SLBGTQI+ individuals, and people who are deaf, hard-of-hearing, and/or blind. Accessibility of science communication in rural and remote areas including the Canadian territories should also be studied. Similarly, further research on older forms of science communication, specifically Indigenous science communication practices both pre- and post-colonisation should be studied in Canada as well as elsewhere. While it may be unrealistic or even inappropriate for all science communicators to speak for, or to attempt to represent, all cultures and perspectives, it is important for practitioners to consider how culture can affect both the delivery and reception of their science communications. Collaborating with cultural experts to tailor one's science communication can enhance the relatability of scientific information and help build trust and credibility within a community. Gaining a better understanding of the communities one is trying to engage and/or communicate with will only serve to improve the accessibility and efficacy of science communication practices.

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APPENDIX

Appendix A: Questionnaire for Science Communication Professionals

1. Which category/categories do you think applies to your work? Select all that apply.
    a. Science communication
    b. Science writing
    c. Science journalism
    d. Science Centres/Museums
    e. Podcasting
    f. Art
    g. Other, please specify ______________________________

2. Based on your observations as a science communication professional, who is ***predominantly involved*** in communicating science in Canada?
    a. Scientists/Academics
    b. Journalists/Writers
    c. Science Centres/Museums
    d. Government
    e. All of the above
    f. Other, please specify ______________________________

3. Based on your observations as a science communication professional, who ***should be predominantly responsible*** for communicating science in Canada?
    a. Scientists/Academics
    b. Journalists/Writers
    c. Science Centres/Museums
    d. Government
    e. All of the above
    f. Other, please specify ______________________________

4. Please rate how important you think it is for the following people to engage in science communication (1 = low importance, 5 = high importance).
    a. Scientists/Academics
    b. Journalists
    c. Writers
    d. Science Centres/Museums
    e. Government
    f. Artists
    g. Other, please specify ________________________

5. What do you think is the most important aspect of communicating science to the public?
    a. Increase public understanding of science
    b. Sharing important information about personal and public health
    c. Promoting environmental sustainability
    d. Increasing civic engagement
    e. Other, please specify ______________________________________

6. Do you think it is important for scientists ***in particular*** to be trained in science communication? Why or why not?

7. Do you think that science is being communicated effectively in Canada? Why or why not?

8. Please list all educational experience/credentials (i.e., degrees, diplomas, certificates, etc.) even if you don't feel it is relevant to your current career in science communication.

9. Please describe the academic and/or professional pathway to your career in science communication. Feel free to include any experience whether paid or volunteer.

10. How has science communication in Canada changed over the course of your career?

11. Is there anything else you would like to add about your experience communicating science in Canada?