INCLUSIVE SCIENCE COMMUNICATION IN THEORY AND PRACTICE

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frontiers Research Topics

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INCLUSIVE SCIENCE COMMUNICATION IN THEORY AND PRACTICE

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PERSPECTIVE
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Found in Translation: Collaborative Contemplations of Tibetan Buddhism and Western Science

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Development of an inclusive scientific community necessitates doing more than simply bringing science to diverse groups of people. Ideally, the sciences evolve through incorporation of diverse backgrounds, experiences, and worldviews. Efforts to promote inclusion of historically underrepresented racial, ethnic, cultural, religious, gender, and socioeconomic groups among science scholars are currently underway. Examination of these efforts yields valuable lessons to inform next steps in engaging diverse audiences with science. The Emory-Tibet Science Initiative may serve as one example of such efforts. The Dalai Lama invited Emory University to develop and teach a curriculum in Western science to Tibetan Buddhist monks and nuns. As the science curriculum has been taught and refined over the past decade, monastic scholars increasingly have taken ownership of the material. As Western scientific ideas and practices take hold in this setting, the experiences of monks and nuns offer unique insights into the process of translation, modes of communication, and long-term impacts of integrating diverse systems of knowledge. Given that the dominant language of science is English, Tibetan interpreters have been essential throughout the implementation of this project. Through the process of translating scientific terms, interpreters have considered differences in how words categorize, and therefore how people conceptualize, the world. Through comprehensive, culturally-responsive communication, scientific language is used as a tool to build and strengthen connections between monastics and their local and global communities. The intertwining of these complementary systems of knowledge iteratively informs translation, modes of communication, and broader impacts in the community.

Keywords: Tibetan Buddhism, audience-centered approach, strength-based approach, inclusive, science and religion dialogue, international science education, Dalai Lama, translation

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The Dalai Lama invited Emory University to develop and teach a curriculum in Western science to Tibetan Buddhist monastics (Lama, 2005). In 2008, faculty traveled to Dharamsala, India to initiate a 6-year pilot. Annually, faculty taught physics, biology, and neuroscience (Eisen, 2011). Since 2014, a revised curriculum has been taught in three monastic universities (Eisen and Konchok, 2018). As of June 2019, all 6 years of the curriculum were active. The project is an ideal platform for exploration of cross-cultural science communication (Jinpa, 2010; Heuman, 2014; Gray and Eisen, 2019). As scientific ideas and practices take hold in this setting, the experiences of scientists and monastics offer unique insights into the process of translation, modes of communication, and long-term impacts of integrating diverse systems of knowledge.

The dominant language of science is English; only a quarter of the monastics in the project understand at least half of the in-class English. Thus, Tibetan interpreters have been essential throughout the implementation of this project. Translating Western scientific ideas, concepts, and methods into a language and culture that has, until now, had minimal interaction with these principles is challenging. Even in a less complex setting, one might expect that some intended meanings would be lost or skewed during translation. While the Emory-Tibet Science Initiative (ETSI) translation team has found this to be true to some extent; much is also gained. The team has found in translation an expanded capacity to investigate differences in how words categorize, and therefore how people conceptualize, the world; to move beyond limits of word-to-word translation and into comprehensive, culturally-responsive communication; to motivate monastic students to use scientific language as a tool to build and strengthen connections with their local and global communities.

TIBETAN TRANSLATION TRADITION

In the eighth century, the Tibetan Emperor imported philosophy and practices from Nalanda and other Buddhist traditions in India (Huber, 2008). This not only brought knowledge of these different disciplines to Tibet, but also enriched the Tibetan language. Similarly, the Tibetan community is in the process of importing science into the Tibetan language; monastics are learning science and indigenous Tibetan scholars are writing treatises and integrating their own philosophical knowledge, reflection, and insights into the practice of science.

Eighth century Tibetan lo-tsawas (eyes of the world/translators) established translation guidelines with a list of examples accompanied by justifications for translations, detailed in the *Dra-jor bam-nyis* (Raine, 2010[1]). These general translation principles include: faithfully conveying content, maximizing resources in the target language, maintaining the spirit of the source; following syntactical rules of the target language, distinguishing between translating and editing, and aiming for a flowing rendition in the target language. These principles that shaped Tibetan translation of Buddhist texts over 1,000 years ago–ensuring integrity in meaning, language, and expressiveness–continue to guide science translation today.

These translation guidelines have been used for over a millennium, yet translation and creation of new terms remains challenging. The ETSI translation team has contributed over 5,000 scientific terms to the already rich Tibetan language in a collaborative process that combines traditional and twenty-first century approaches. The team identifies concepts that need to be clarified, considers Tibetan background knowledge and culture while selecting terms, and consults colleagues who have a variety of expertise.

[1]Toh 1523, Dege Tengyur, vol. co (sna-tshogs) page 131b-160B.

Concepts

The Nalanda tradition calls for creation of new words rather than defaulting to cognates. The addition of 5,000 scientific terms to the Tibetan language, and the evolving process used to create them, provides insights into the interplay between language, science, and Tibetan Buddhism. The ways society uses words to categorize the world—to divide and label our experiences of reality—varies by time, place, culture, and even academic discipline (Cruse, 1992). At first, simple translation seems as though it should suffice for words such as *fire* and *water* (**Table 1**). Other terms, such as *quark*, would be expected to require creation of a new Tibetan word. *Life* and *consciousness* call for careful explanation even in English, so these are destined to be translation challenges. It is untenable to create new terms for these concepts in Tibetan, as the current Tibetan terms are culturally and spiritually loaded.

Some terms such as fire and water have been fundamental to civilization for millennia. Their widespread use has pervaded their application in language colloquially, metaphorically, and scientifically (Taylor and Dewsbury, 2018). In saying there is a "fire in our heart," this does not referencing the narrow, scientific meaning of the rapid oxidation of material in an exothermic chemical process. The same is true for water; "water of life" does not refer to the molecular makeup of two hydrogen atoms and one oxygen atom. Scientific definitions provide specific meanings that constrain the terms in scientific dialogue for precise communication.

This issue is of particular confusion in Tibetan because terms like fire and water do not have well-established scientific meanings. In colloquial Tibetan, fire is a general term referring to that which produces heat and light. Therefore, one could say "the sun is a ball of fire" in Tibetan with correct meaning, although this phrase in the scientific sense would be incorrect, as the sun is a ball of gas undergoing nuclear fusion. Similarly, water in Buddhism may be used to describe anything that is wet, liquid, or flowing rather than referring to a specific chemical composition. Ultimately, scientific discoveries continuously produce and refine definitions to best reflect phenomena in the natural world.

In order for scientific Tibetan to have the level of precision of scientific English, new words must be introduced into the Tibetan lexicon. This provides a unique opportunity to coin words that may better reflect underlying scientific meanings than is present in current English. Ideally, such newly coined words will portray a sense of meaning for that term or concept from the word itself, without requiring specific background knowledge. Quark had no previous meaning itself in English (Mayer, 2018). The Tibetan translation is *quark-dool*; with *quark* having the pre-existing meaning of "innermost" and *dool* being the Tibetan word for "particle," thus suggesting the meaning of the full term (**Table 1**). This translation has the benefit of maintaining some sound of the English equivalent.

Precise definitions are even more important when considering complex concepts such as "life" (**Table 1**). Western introductory biology classes often begin with a definition of life based on lists of characteristics to classify something as living or non-living (Wilkin and Gray-Wilson, 2017). In Tibetan Buddhism, defining life is less clear. Life is translated as *tshe-srog*, which arguably

TABLE 1 | Example scientific terms and how these were translated into Tibetan concepts.

English term	Tibetan term	Translation explanation
Fire	མེ།	Distinguish between general heat and light and the scientific definition of combustion
Water	ཆུ།	Distinguish between anything that is liquid and water molecules composed of hydrogen and oxygen
Quark	ཕོག་རྡུལ།	Translated as "innermost particle"
Life	ཚེ་སྲོག	Distinguish between inclusion of consciousness in the definition of life and the scientific definition of life; Translated as life energy/life force
Life form	ཚེ་སྲོག་གི་རྣམ་པ།	Specifically referring to form(s) of life
Sentience	སེམས་ལྡན།	Translated as "possessing mind"
Cell body	ཕྲ་ཕུང་ལུས།	Distinguish between cell-bodies and cell-minds i.e., Do scientists consider cells to have a "mind"?
Body of a cell	ཕྲ་ཕུང་གི་ལུས།	Central part of a cell i.e., Not the dendrites of a nerve cell
Amygdala	ཁག་ཅིག་ཀླད་ཞོ།	Translated as "almond-shaped brain structure"
Organism	སྐྱེ་དངོས།	Translated as "growing/developing thing"
Mass	གདོས་ཚད།	Initially, a same Tibetan word (ལྗིད་ཚད་) was used for both mass and weight. The distinction between the two words was not clear. However, གདོས་ཚད་, which has much closer meaning, was later adopted as the translation of the word mass
Weight	ལྗིད་ཚད།	ལྗིད་ཚད་ is an equivalent term for weight. It is not a new term but it has acquired a finer definition because of the way weight is understood in science
Force, energy, power	ཤུགས། ནུས་པ། སྟོབས།	Although these three physics terms have distinct meaning, the three Tibetan terms had very similar meanings and were used interchangeably. Now these three terms have acquired distinct meanings and are used more strictly, especially amongst the monastic science students
Proton, neutron, electron	ཕོ་རྡུལ། བར་རྡུལ། གློག་རྡུལ།	The Tibetan terms for the three subatomic particles literally mean male (or positive) particle, neutral (or middle) particle and electrical particle. Using the words ཕོ་ (meaning male) and མོ་ (meaning female) for positive and negative is a relatively new phenomenon. Initially employed to convey the concepts of positive and negative numbers, the words acquired new usage as they were applied to these subatomic particles

relates to consciousness. This gets into problematic areas at the boundary of science and Buddhism, leading to questions such as: Are plants conscious? Are plants living? Are bacteria conscious? Are bacteria living? (Eisen and Konchok, 2018). One response for the translator is to differentiate living *beings* and living *thing*s; another, more daunting is to provide satisfactory answers in both Buddhism and science to the aforementioned questions.

Many scientific terms, especially those being generated at the forefront of research, have evolving definitions (McGee, 2004). The dynamic nature of such terms makes translation even more difficult. At the same time, this can inspire research questions. For example, translating names for functional regions of the brain facilitated debate of the evidence for such labels among neuroscientists. Cross-cultural linguistic dialogue may encourage increasingly precise ways of engaging science.

Audience-Centered Communication

Optimal communication interweaves knowledge of concepts *and* knowledge of the backgrounds and experiences of the receivers. It is important, therefore, to focus on how information is perceived by the audience, to understand the experience of delivering that information, to be truly present to the audience and deeply explore possible meanings before pinning down the one that best fits. Translators must move beyond maximizing technical precision at all times and instead ensure the intended audience understands concepts in-depth at every step.

One must have a thorough understanding of a topic in order to convey it to others; translating concepts adds an additional layer to that understanding. In a classroom setting, instructors may ask students to put lessons or concepts into their own words, rather than taking words directly from the instructor or the book. Educators can use principles of translation and audience-centric teaching to help guide students in processing information presented to them. This may involve providing space for literal translation from one language to another in multilingual classrooms or asking students to generate and share multiple interpretations of the same text or concept within one language. Variety in language captures nuances that are missed in other phrasings, so learning may be enhanced for multilingual students (Sieber, 2004). Conceptual descriptions in each language can complement one another; if one is unclear, the student may turn to the other language to clarify meaning.

Communal Translation

The importance of community in translation is emphasized when translating English science content into Tibetan as there is not a Tibetan spellcheck. To complicate matters further, Tibetan was spoken for centuries before being formally written

(Laufer, 1918). Subtle differences in spelling can result in vastly different meaning.

Translators often contact the author of a text for clarification or engage with other translators to consider options. The primary translator meticulously reviews feedback. Technical terms that appear for the first time in ETSI translation history are tabled for consideration at the next Translation Conference.

Ten scientific Tibetan translation conferences have convened since 2009 with the goal of creation and standardization of a new scientific lexicon. ETSI has used this lexicon in 20 textbooks, thousands of PowerPoints, and in video lectures developed specifically for the monastic audience (Emory-Tibet Science Initiative, 2019). The conferences draw on the expertise of monastics, lay scholars of Buddhist philosophy, Tibetan medical doctors, and Tibetans trained in western science. The process involves understanding the etymology of the source text and ensuring the evolving lexicon is simple, versatile, and consistent with existing Tibetan lexicons and grammatical rules. ETSI translators use a dialectical debate system borrowed from monastic learning to reach deeper clarity and understanding of definitions in context. When considering the relationship between a neuron and a brain cell—Are they the same thing, i.e., co-extensive/interchangeable? Are they mutually exclusive with no common locus between them? Does one include the other, while the other does not? Alternatively, do they have a four-cornered relation, where one finds a brain cell that is also a neuron and vice versa, while at the same time there are neurons that are not brain cells and vice versa? Through such dialogues one can come to an understanding that there are more than just neurons in the brain and that neurons outside of the brain have some unique properties (e.g., ability to regenerate when damaged) that are not clearly present in brain neurons. Here the goals are precision and accuracy in generating a definition that is neither too broad nor too narrow.

STRENGTH-BASED COMMUNICATION

The 6-year ETSI science curriculum makes heavy use of translated texts, as most internet sources containing scientific content for the public are in English. Reading comprehension is a challenge in monastic science classrooms. The students have a wide variety of educational backgrounds, and some students have not studied reading and writing in Tibetan well enough to comprehend the science materials that have been translated into Tibetan.

To address this challenge, science instructors adapted pre-existing monastic and Western pedagogical tools. For example, integration of science into traditional monastic debating. Each day's monastic Buddhism classes are followed by hours of evening debate where students alternately assume roles of challenger and defender (Tillemans, 1989) and draw on lessons from the day and their foundational knowledge to address the assigned topic while exploring their level of understanding.

In December 2015, Mind and Life Institute organized its 30th Mind and Life Dialogue at Sera Monastery. Monks from many monasteries gathered at Sera to listen to the conference. Taking advantage of this, a debate session was organized in which the ETSI monks were asked to debate on scientific topics such as visual perception and how it is formed, the dual nature of light and particles, and evolution. The group debate, held in Tibetan in the formal monastic style of debate, was presented to His Holiness the Dalai Lama and scientists. This debate, the first of its kind, generated much excitement and was possible because of programs such as ETSI.

Concrete examples, things one can see, feel, and experience, are beneficial for conveying ideas. This has been an especially important practice in communicating math concepts. As even the simplest mathematical equations are somewhat abstract, using examples from everyday life, such as how many rupees a cup of tea costs, is essential.

Presentation of science via multimedia formats in digestible chunks helps communicate information in ways that can be shared widely (Guo et al., 2014). Considering the interest of students in connecting their experiences, and what they have learned, with their networks, this is an excellent strategy to deliver lessons while tapping into their motivations for engaging with the content in the first place. Students have taken ownership of this strategy and initiated minute-long science talks that are shared in group messages and followed by debate. Some students have even written science-inspired poems (**Figure 1**).

Multiple modes of assessment reveal a more holistic understanding of student knowledge and application than can be detected by exams alone (Tal, 2005). Given the reading comprehension challenges in monastic classes, providing students with diverse opportunities to demonstrate learning—presentations, discussions, journals (Balgopal et al., 2017)—has proven even more important.

COMMUNITY CONNECTION

Effective science communication in education should extend beyond the boundaries of classroom walls. Teachers can challenge students to prepare for applying and extending their knowledge as global citizens though cross-cultural linguistic scientific dialogue (Ruano et al., 2014). Given that some western students have the conception that science is predominantly a solitary activity (Palmer, 1997), it is especially important to provide opportunities for students to realize the vast possibilities for human connection that science creates.

Local Learning/Global Growth

Monastics play an important role in the usage and spread of new terminology, especially newly coined Tibetan scientific words. When the monks and nuns take science classes in addition to their monastic studies, they use the Tibetan science terminology among their fellow monastics. 1496 monks from nine monasteries and 41 nuns from five nunneries have participated in ETSI summer intensive workshops. The ETSI curriculum is now included as part of the core monastic studies and is a required part of Gelug examinations—the examination for the Geshe Lharam degree, the highest monastic degree and equivalent to a western doctorate (Gray and Eisen, 2019).

Most of the large monasteries have been established near Tibetan settlements in exile to maintain strong connections between spiritual leaders in the Buddhist community and

གཅིག་འགྱུར།

གྲང་སིལ་གྱི་རླུང་བུ་འདི།
ངར་རེག་ནས་རྒྱུ་དུས།
ངས་སེམས་ཁོང་གི་བྱམས་བརྩེ་དྲན་བཞིན།
ཁྱེད་ལ་ལྷད་མེད་ཀྱི་སེམས་པ་གཏོང་ཡོད།

གནམ་འོག་གི་འཛིག་རྟེན་འདི་ན།
ཕྲ་ཕུང་གིས་གྲུབ་པའི་ཚེ་སྲོག་ཅིག
འདི་རང་ང་གཉིས་ཀྱི་འཚོ་རྟེན་དུ་ཡོད།

ནམ་མཁའ་གཅིག་གི་འོག་ལ།
འཚོ་རླུང་དང་ནག་རླུང་གི
དབུགས་གཏོང་ལེན་དང་།
ང་གཉིས་འཚོ་བཞིན་ཡོད།

གནམ་འོག་གི་འཛིག་རྟེན་འདི་ན།
ང་གཉིས་ནི།
ཁར་སྦོན་གྱིས་རྟེན་གཞི་བྱས་པའི་
ཚེ་སྲོག་སྡོང་པོའི་སྙིང་གི་
འཛུམ་གྱིས་བཞད་པའི་མེ་ཏོག་གཉིས་རེད།

ལྡུམ་རའི་ནང་སྣ་ཚོགས་པའི་མེ་ཏོག་བཞད་པ་བཞིན།
གོ་ལ་འདི་འདྲ་མིན་གྱི་སྐྱེ་ལྡན་གྱིས་ཁེངས་ཡོད་ཀྱང་།
ང་ཚོ་ནི་ཐུན་མོང་གི་མེས་པོ་གཅིག་ལས་མཆེད་པའི།
སྤྱི་སྐྱིད་ལྡན་པའི་ཁྱིམ་ཚང་གཅིག་གི་སྤུན་ཟླ་རེད།

ང་ཚོ་ནམ་འཆི་ལ་ངེས་པ་མེད་པས།
ཇི་སྲིད་འཚོ་བའི་བར་དུ།
རྨི་ལམ་འདྲ་བའི་མི་ཚེ་འདི་དོན་ལྡན་བྱེད་འོས།

རང་དབང་གི་གནམ་འོག་འདི་རུ།
ང་ཚོ་ཚང་མ།
གཅིག་འགྱུར་གྱིས་འཚོ་ན།
ང་ཚོ་ནམ་ཡང་བདེ་སྐྱིད་དང་འཚོ་ཐུབ།

མི་འཚོ་ནི་བདེ་སྐྱིད་ཡིན་པས།
མི་ཚེ་བདེ་སྐྱིད་དང་སྐྱེལ་དགོས།
འདི་རིང་བཞིན་སང་ཉིན་ཡང་།

Oneness

When this cold wind
Touches me and passes through
I recall my inner love and
Send you my warming heart waves.

Under this same sky
Today we have a life to live
a life made up of cells.

Under the same sky
we respirate
The same oxygen and CO_2

Under the same sky
We are blossoming flowers
Of a carbon-based life tree.

Like a diverse flower in a garden,
The earth is full of a different life.
But, we are a member of the happy family;
a descendant of a common ancestor.

The strength of life is unknown
We should make it meaningful
Hence we have it like a dream.

In this open sky,
We all rise to live.
To be oneness,
and we live happily together
Forever and ever.

Life is beautiful
Live it beautifully
As it is today.

FIGURE 1 | Poem authored by Stanzin Wangdan, one of the 2017–2019 Tenzin Gyatso Scholars who completed a 2-year science residency at Emory University.

lay members of the community. As monastics interact with local Tibetans during talks, teachings, and other academic conversations, they naturally begin to integrate science terminology that has been used in their coursework. This has sparked interest in science through a language the community can understand. Monastics have created social media groups, that include the lay Tibetan community, to discuss scientific concepts. Some of these include up to 500 members. This has also been accomplished through formalized science events hosted by monasteries and nunneries. In these ways, the use of new terminology reaches large numbers of people relatively quickly. This also serves to further the goal of fostering exchange between Tibetan Buddhism, language, culture, and history and the tradition of Western science (Eisen, 2011; Eisen and Konchok, 2018; Gray and Eisen, 2019). As there are more opportunities for engagement with the community outside of the monastery, Tibetan science language will be used in more ways that allow for it and the corresponding science to grow.

With their increasing engagement in science, monastics have begun to collaborate with ETSI scientists in original scientific research related to the greater Tibetan community. Neuroscience research investigating brain activity during monastic debate has been published and featured in news articles (Lakshmi, 2017; van Vugt et al., 2018). Western scientists have published their findings and discourse related to the initiative in professional journals, such as *Zebrafish* (Kimelman, 2018). In 2016, Gaden Shartse Monastic Science Center started an annual journal called Drops of Ancient and Modern Science, which contains articles on modern science and Buddhist science. Public health projects related to diabetes, depression, and water quality have been initiated in the monastic communities. These research projects are just one method of building meaningful connections with local and global communities that may open up new solutions and areas of inquiry.

A 100-YEAR PROJECT

This project serves as a model for broad cross-cultural science engagement. A range of bilingual, culturally relevant communication materials have been created throughout the lifetime of this initiative including textbooks, video lectures, and presentation slides. This work can be applied in other contexts through consideration and adaptation of the approach to science communication employed by ETSI. For example, the variety of educational materials generated are intended to reach a diverse group of learners including those in formal educational settings and those in the general public.

Ideally, science evolves through incorporation of diverse backgrounds, experiences, and worldviews that stimulate new directions, innovation, and creativity. ETSI fosters productive exchange between science and Tibetan Buddhist culture and knowledge. As this partnership takes root and blossoms, this will give rise to its own reflections and its own insights. This takes time. The Dalai Lama has called this a 100-year project.

ETSI looks to connect the multicultural nature of society and the ways we communicate science to advance a holistic understanding of the human condition. We have already begun to see how the intertwining of these complementary systems of knowledge creates positive feedback loops that continually inform translation, modes of communication, and broader impacts in the community.

AUTHOR CONTRIBUTIONS

KG, CW, and AE contributed conception and design of the article. KG wrote the first draft of the manuscript. DN, JP, TSa, TSo, KT, and DT wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Moving Toward Inclusion: Participant Responses to the Inclusive SciComm Symposium

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This study shares key findings from evaluation research for Inclusive SciComm: A Symposium on Advancing Inclusive Public Engagement with Science. The symposium, organized by the University of Rhode Island's Metcalf Institute for Marine & Environmental Reporting with support from partner organizations, took place on September 28 and 29, 2018 at the University of Rhode Island. Pre- and post-symposium surveys showed that after attending the symposium, participants reported higher levels of knowledge about and confidence in implementing inclusive approaches to science communication. Participants also exhibited three types of response orientations: emotion, knowledge, and action.

Keywords: science communication, inclusion, inclusive science communication, public engagement with science, science education

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INTRODUCTION

Social inclusion is an emerging area of importance in the field of science communication (see Canfield et al., this issue). The discipline of science communication itself is still growing and the term science communication has been defined in a variety of ways, with little clarity as to how it is differentiated from other associated terms such as public engagement with science, public understanding of science, and even outreach or broader impacts (Burns et al., 2003; Trench and Bucchi, 2010). We define science communication here as "the exchange of information and viewpoints about science to achieve a goal or objective such as fostering greater understanding of science and scientific methods or gaining greater insight into diverse public views and concerns about the science related to a contentious issue" (National Academies of Sciences Engineering and Medicine, 2010, p. 1, 2). We use this definition specifically because it emphasizes a bi-directional relationship that notes understanding and growth on both the part of scientists and the public. This definition of science communication aligns with how others define public engagement. The American Association for the Advancement of Science defines public engagement as "intentional, meaningful interactions that provide opportunities for mutual learning between scientists and members of the public" (American Association for the Advancement of Science, 2019, par 1). While we recognize that these two terms are often separated in the literature, they are also often times conflated, and we see both definitions aligning around goals of mutual learning and information sharing.

Inclusion is also different from participation; participation is primarily defined as trying to increase public input, whereas inclusion is concerned with "continuously creating a community involved in co-producing process, policies, and programs" for social issues (Quick and Feldman, 2011, p. 272). The need to prioritize participation and communication is largely recognized by funders, who often require evidence of impact and engagement as a condition for program funding (Burchell et al., 2009; Palmer and Schibeci, 2012; Fogg-Rogers et al., 2015), yet this symposium focused on socially inclusive science communication that goes beyond participation. Inclusive science communication is inherently a concept of co-production (Massarani and Merzagora, 2014), moving beyond the goal of simply democratizing knowledge. As Massarani and Merzagora (2014) note, "science communication can become a tool to foster social inclusion also beyond issues concerning science, and social inclusion can become a means to innovate science communication *in general*" (p. 2). While this need to move from dissemination toward co-production has been recognized within the field (Suldovsky, 2016), funding and measuring the impacts of engagement have remained elusive (Fogg-Rogers et al., 2015). There are considerable challenges to measuring impacts and change over time from a mutual learning and co-production orientation (Irwin, 2008). Furthermore, programs and practitioners often lack the basic resources of time or funding to perform evaluative research (Weitkamp, 2015). This paper shares evaluative research on a symposium designed for both researchers and practitioners who are interested in socially inclusive science communication as an orientation of co-production and mutual learning.

This study shares key findings from evaluation research for #InclusiveSciComm: A Symposium on Advancing Inclusive Public Engagement with Science. The symposium, organized by the University of Rhode Island's Metcalf Institute with support from partner organizations, took place on September 28 and 29, 2018 at the University of Rhode Island in Kingston, Rhode Island, USA. This research assessed how attendees at the symposium viewed the planned activities, what they saw as key barriers and opportunities for prioritizing inclusion in science communication/public engagement activities, and if the symposium experiences had any impact on how they view science communication and/or public engagement. The symposium addressed four themes, as designed by the conference planning committee, aimed at advancing the national (USA) conversation on inclusive public engagement: frameworks, challenges, media, and strategies. From higher education curricula to informal science learning to journalism, this unique symposium featured a range of researchers, practitioners, and educators who are exploring how science topics become part of public discourse, how social media and other disruptive technologies are shaping these conversations, and how inclusive approaches toward public engagement produce more compelling narratives and effective outcomes. The complete agenda of speakers, events, and sessions can be found online at https://inclusivescicomm.org/2018-symposium/agenda/.

As this was the first symposium of its kind, it was designed by a panel of practitioners and researchers with four exploratory objectives in mind:

- Identify needs and opportunities for more inclusive, intersectional, and asset-based approaches to science communication and public engagement.
- Highlight the work of science communication and public engagement practitioners and researchers (from academia, non-profits, public, and private sectors) whose work demonstrates effective inclusive and intersectional approaches for the fields.
- Discuss the structural problems that hinder inclusive approaches and how these problems can be addressed.
- Inspire new collaborations among attendees and provide practical information that attendees can implement in their work to prioritize inclusion.

The study was designed to evaluate the symposium, its impact on participant knowledge and efficacy, and ask exploratory questions about participant experiences with inclusive science communication. The study specifically aimed to address the following questions:

1) Did attending the symposium increase attendees' knowledge of and confidence in enacting inclusive approaches?
2) What do participants view as the biggest barriers and opportunities for inclusive engagement and science communication?
3) How did participants respond to the symposium experience?

METHODS

This study took place in Fall 2018. Data were collected in two online surveys, one pre-test and one post-test, both administered through Qualtrics. The two surveys asked both closed ended and opened ended questions about attendee perception and experience of the science symposium (complete surveys available as **Supplementary Material**). Surveys were chosen as the method for data collection because of funding and time constraints. For the upcoming 2019 symposium, researchers have added focus groups to account for the need to include more in-depth qualitative analysis.

One-hundred-fifty registered symposium attendees were invited to participate in this research. The symposium organizers provided an email list of all registered participants, which included the speakers and planning committee. Attendees received notification about the study from the lead organizer of the symposium, and then three initial recruitment emails were sent, each 2 days a part, during the week prior to the symposium. The post-test survey followed the same protocol, with three recruitment emails being sent in the 2 weeks following the symposium.

This pre-symposium survey was designed to take respondents ∼5–10 min to complete and assessed participant expectations for the symposium.

The post-symposium survey was designed to take respondents ∼10–15 min to complete and assessed participant experiences and reflections after symposium attendance.

The pre-test survey return rate was 53% ($N = 80$). The post-test survey return rate was 36% ($N = 54$). A total

TABLE 1 | Knowledge measures.

	Pre-test "Extremely"	Post-test "Extremely"	Pre-test "Very"	Post-test "Very"	Pre-test "Moderately"	Post-test" Moderately	Pre-test "Slightly"	Post-test "Slightly"	Pre-test "Not at all"	Post-test "Not at all"	Pre-test total	Post-test total
Identifying challenges	8.50%	8.50%	27.70%	46.80%	53%	40.40%	8.50%	4.00%	2%	0%	100%	100%
Identifying opportunities	2.20%	10.60%	4.30%	38.30%	47.80%	38.30%	37%	12.80%	8.70%	0.00%	100.00%	100.00%
Implementing strategies	0.00%	8.50%	10.90%	42.60%	30.40%	27.70%	34.80%	19.10%	23.90%	2.10%	100.00%	100.00%
Overcoming barriers	0%	2.1%	6.40%	38.30%	25.50%	40.40%	31.90%	12.80%	36.20%	6.40%	100.00%	100.00%
Identifying new ways to becoming engaged	2.2%	31.90%	23.90%	42.60%	43.50%	17.00%	15.20%	6.40%	15.20%	2%	100.00%	100.00%

of 45 participants completed both the pre-symposium and post-symposium surveys.

Several survey questions for were repeated in both the pre-test and post-test. Some additions were added to the post-symposium survey to gauge attendee perception of specific symposium sessions and events. For the majority of this study, researchers used all post-symposium survey responses. For the measurements of change between pre- and post-symposium responses, researchers only used matched response data from participants who completed both the pre- and post-tests ($N = 45$). Each results sub-section, below, indicates which specific data were used for specific analyses.

Descriptive Statistics of Survey Respondents

Demographics were collected only for the initial (pre-test) survey. Of the 80 participants who responded, 78% reported a female gender, 20% reported male, 1% identified non-binary/third gender, and 1% preferred not to identify.

Of the 80 respondents, most (97%) held higher education degrees. When asked to report their most advanced degree, 46% had doctoral degrees, 11% had partial credit toward a doctorate, 20% had master's degrees, 4% had partial credit toward a master's, and 16% had bachelor's degrees.

Participants represented diverse fields of work. The largest group of participants were in natural science research (24%), followed by the non-profit sector (14%), post-secondary education (13%), informal science education (9%), and social science research (9%). Other represented fields included art, K-12 education, education administration, funding, journalism, government regulatory agencies, government non-regulatory agencies, science communication training, science policy, and graduate studies.

A limitation of this study is that demographics and race/ethnicity were not included due to miscommunication among the conference planning and research team about whether this information was being collected during registration or through the survey instrument. The research team regrets this error and it has been corrected for the 2019 evaluation research, yet still believes the findings reported are useful for knowledge-building purposes in the growing area of inclusive science communication.

RESULTS

Changes in Participant Knowledge and Efficacy

RQ1 asked: *Did attending the symposium increase attendees' knowledge of and confidence in enacting inclusive approaches?*

The results reported in this section are based on participant data of the 45 survey respondents who completed both the pre- and post-test surveys. Surveys were matched based on a unique ID code assigned through Qualtrics. Results show both a significant positive effect in self-reported participant knowledge and efficacy after the symposium.

Pre- and post-event surveys asked attendees a variety of questions regarding their knowledge and confidence about inclusive science communication on a five-point Likert scale. Knowledge-based questions asked how knowledgeable individuals were at: identifying challenges related to inclusive science communication and public engagement with science (PES); identifying opportunities related to achieving inclusive science communication and PES; implementing strategies for creating more inclusive science communication and PES practices; implementing strategies for creating more inclusive science communication and PES research; implementing strategies for overcoming structural barriers that hinder inclusive approaches; and identifying new ways to become engaged in science communication and PES (see **Table 1** for knowledge-based frequencies). All knowledge-based questions were compiled into a composite and a mean score was then calculated. Next, to ensure reliability of the composite, a scale reliability test was run for pre-test and post-test knowledge-based questions. The Cronbach's alpha for the 6 knowledge-based items was 0.61 for the pre-test questions and 0.91 for the post-test questions. A Cronbach alpha of 0.61 is considered low but acceptable for exploratory communication research (Boyle and Schmierbach, 2015) and researchers expect that the pre-test alpha was low because of variation between some participants' experience with certain scale items measured upon entering the conference (i.e., some people came in with more knowledge of certain inclusion-related topics than others).

A repeated-measures analysis of variance (RM-ANOVA) was performed examining change over time in knowledge-based survey questions. There were two time points (Pre-test 1, Post-test 2). The analysis was performed using SPSS 24.0 for Mac.

The main effect of time on knowledge-based questions was significant, $F_{(1,46)} = 104.132$, $p \leq 0.001$, partial $\eta^2 = 0.69$. Therefore, the nature of change included a positive linear effect; Symposium participants reported feeling significantly more knowledgeable about inclusive science communication strategies after the symposium (see **Table 2** for knowledge-based mean data).

The efficacy-based questions asked individuals how confident they were regarding the same six actions asked for the knowledge-based questions. All confidence-based questions were compiled into a composite and a mean score was then calculated. Next, to ensure reliability of the composite, a scale reliability test was run for pre-test and post-test confidence-based questions. The Cronbach's alpha for the 6 confident-based items was 0.88 for the pre-test questions and 0.93 for the post-test questions (see **Table 3** for confidence-based frequencies).

A repeated-measures analysis of variance (RM-ANOVA) was performed examining change over time in confidence-based survey questions. There were two time points (Pre-test 1, Post-test 2). The analysis was performed using SPSS 24.0 for Mac.

The main effect of time on confidence-based questions was significant, $F_{(1,44)} = 70.129$, $p \leq 0.001$, partial $\eta^2 = 0.61$. The nature of change included a positive linear effect: Symposium participants reported feeling significantly more confident about inclusive science communication strategies after attending the symposium (see **Table 4** for confidence-based mean data).

Identified Barriers for Advancing Inclusive Science Communication

RQ2 asked: *What do participants view as the biggest barriers and opportunities for inclusive engagement and science communication?*

In the post-survey, participants were asked what they saw as key barriers for science communication and public engagement to become more inclusive. These questions were intentionally broad, allowing participants to share their own lived experiences. Participant responses were thematically coded using the method of constant comparison (Corbin and Strauss, 2008), which involves researchers looking for (1) prevalent themes from among all, or at least several, of the participant responses, and (2) discrepancies and differences among participant responses. Overall, responses were divided into two categories: barriers caused by presence and barriers caused by absence.

Barriers caused by presence indicate that some occurrence is keeping science communication and public engagement from being more inclusive. The most common respondent examples in this category were existing organizational structures in research and the academy, followed by inherent, unconscious, and implicit biases. Other responses included: white communicators not sharing leadership spaces with non-white communicators; laziness, stubbornness, or resistance toward inclusion efforts which result in fatigue for those doing inclusive science communication and public engagement; siloing of research and information; and geographic, linguistic, financial, cultural, and socioeconomic status factors.

Barriers caused by absence indicate that something is missing, which keeps science communication and public engagement from being more inclusive. The most common respondent examples in this category include lack of funding followed by lack of understanding, knowledge, training, or resources for doing inclusive science communication work. Other responses include: not assessing if inclusion efforts are actually inclusive; inadequate diversity among leadership in science communication efforts; limited opportunities or platforms; minimal networking, collaboration, or sharing of

TABLE 2 | Means for pre/post-test knowledge & gender.

Composite	Options	Mean	Standard deviation	N
Pre-test knowledge	Male	2.42	0.498	9
	Female	2.53	0.556	36
	Total	2.51	0.542	45
Post-test knowledge	Male	3.29	0.955	9
	Female	3.49	0.709	36
	Total	3.45	0.754	45

TABLE 4 | Means for pre/post-test confidence & gender.

Composite	Options	Mean	Standard deviation	N
Pre-test confidence	Male	2.43	0.499	9
	Female	2.48	0.837	36
	Total	2.47	0.776	45
Post-test confidence	Male	3.20	0.901	9
	Female	3.51	0.684	36
	Total	3.45	0.723	45

TABLE 3 | Confidence measures.

	Pre-test "Extremely"	Post-test "Extremely"	Pre-test "Very"	Post-test' "Very"	Pre-test "Moderately"	Post-test "Moderately"	Pre-test "Slightly"	Post-test "Slightly"	Pre-test "Not at all"	Post-test "Not at all"	Pre-test total	Post-test total
Identifying challenges	2.20%	13.30%	19.10%	44.40%	34.00%	33.30%	36.20%	8.90%	8.50%	0%	100.00%	100%
Identifying opportunities	2.20%	8.90%	10.60%	48.90%	36.20%	33.3%	40.40%	8.90%	10.60%	0.00%	100.00%	100%
Implementing strategies	0.00%	4.40%	13.30%	37.80%	31.10%	44.40%	31.10%	11.10%	24.50%	2.20%	100.00%	100%
Overcoming barriers	0%	0%	15.20%	48.90%	17.40%	33.30%	41.30%	15.60%	26.10%	2.20%	100.00%	100%
Identifying new ways to becoming engaged	2%	17.80%	25.50%	48.90%	34.00%	20.00%	27.70%	13.30%	10.60%	0%	100%	100%

information; and few opportunities for diverse, young scientists to be engaged in science.

When asked what they saw as key opportunities for making science communication and public engagement more inclusive, participant responses varied widely. Responses most heavily emphasized knowing and understanding diverse audiences and responding to those audiences by moving science out of the academy and into communities. Responses also indicated the importance of creating connections and building trust with the audience by engaging science communicators from marginalized groups. Other themes that appeared but with less prevalence across participant responses included making science education more inclusive, intentionally making space for and elevating diverse voices, changing restrictive institutional structures, measuring and assessing inclusive science communication approaches, creating a network of inclusive science communicators, and improving wider understanding of what inclusive science communication means and needs.

Response Orientations

RQ3 asked: *How did participants respond to the symposium experience?*

In the post-survey, participants explained how the symposium affected their perceptions of inclusive science communication and public engagement with science. Using the method of constant comparison (Corbin and Strauss, 2008), researchers examined responses to develop local concepts from the participants' experiences. Researchers found that participant responses aligned in three major themes: emotion-oriented, knowledge-oriented, and action-oriented. Some participants expressed one of these response orientations, while others expressed multiple orientations in their post-symposium reflections. Thus, it is difficult to say that a certain number of participants expressed one orientation more than another, but the prevalence with which certain types of concepts arose in responses resulted in the distillation of these three response orientations. For the purpose of this study, written statements were coded to one category based on the overarching or dominant sentiment of the statement. However, we acknowledge that crossover, especially with emotion/affect and knowledge, occurred. For example, the statement, "It pushed me to think differently, but I was also frustrated by some of the attendees who didn't seem to really understand how they are part of the problem," was coded as knowledge-based because the statement indicates that they thought differently or learned as a result of what was encountered at the event. At the same time, knowing that others lacked an understanding of their role in existing structures impacted the participant's emotional state and caused frustration.

Emotion-Oriented Response

Responses that articulated that the symposium made participants experience different affects during and after attending were coded as emotion-oriented responses. These responses were primarily positive, but some participants identified feeling overwhelmed or disheartened at the current state of inclusivity within science communication and PES. Below are examples of emotion-oriented responses:

> *"It made me feel very hopeful and more confident."*
> *"It's almost overwhelming to realize how far we have to go in some respects."*
> *"It was a powerful validation that what I have been doing is important and there is much to do."*
> *"The meeting was very powerful and motivating for me personally. Powerful in the sense that we had truly meaningful dialogue with one another [to] talk about the hard issues surrounding inclusion; some of these conversations were triggering of my personal adversities or those of other attendees. It was those experiences that actually provide a surge of motivation in me to focus on educating myself further and changing my personal practices."*
> *"The symposium didn't just help me develop the way I think about inclusive scicomm/PES but made me feel more secure in my role in the movement."*

These responses suggest that rich engagement, including keynote speakers and group discussions, had meaningful impacts on participants and influenced their feelings during and after symposium participation. This finding suggests that affect may play an important role in symposium participants' perceptions of inclusive science communication and public engagement with science.

Knowledge-Oriented Response

Participants who expressed a knowledge-oriented response explained that the symposium made them think differently or taught them something (Mack et al., 2012; Featherstone, 2014). This theme had the most responses. Below are examples of knowledge-oriented responses:

> *"I learned so much about deep challenges and potential solutions to these challenges."*
> *"I feel much more aware of the issues at-hand."*
> *"It pushed me to think differently, but I was also frustrated by some of the attendees who didn't seem to really understand how they are part of the problem."*
> *"Being welcomed at this symposium made it clear to me that being white doesn't preclude me from being a part of this conversation."*
> *"…there are many different ways to engage with the public that I had not previously considered."*
> *"Access and the barriers on that road of accessibility are so much more treacherous, winding, and uncharted, than I originally thought. I was uncomfortable for most of the symposium and felt out of place…this was an enlightening step toward recognizing what needs to happen if things are going to change in science communication and public engagement."*

Knowledge-oriented responses indicate that participants' experiences were informative in a variety of ways. These included, as illustrated in the examples above, better understandings of specific issues, general awareness, new ways of thinking, and better understanding of one's own experiences as related to inclusive science communication. Ultimately the knowledge-oriented responses indicate that participants left the symposium with new understandings about science communication and their relationship to it.

Action-Oriented Response

Participants who expressed an action-oriented response explained that the symposium gave them tools or motivation to act differently after leaving (Massarani and Merzagora, 2014; Streicher et al., 2014). Below are examples of action-oriented responses:

> *"It encouraged me to think more about specifically asking the needs of my students and working to provide tools that help them accomplish their goals, rather than setting too many concrete goals for a class myself."*
> *"…I both know and can identify more of the barriers to inclusive science communication, but I also feel like I have more tools and strategies to overcome those barriers."*
> *"…going forward I will use my connections/privilege to raise up the voices and experiences of minority scientists."*

This response orientation indicates that the symposium allowed participants to feel empowered to *do* inclusive science communication. These responses indicate the potential of such a symposium to cause participants to see a need to change their behaviors toward creating more inclusive science communication. Some participants expressed one of these response orientations, while others expressed multiple orientations and some expressed none (i.e., "None" or "It was fabulous") in their post-symposium reflections. Thus, it is difficult to say that a certain number of participants expressed one orientation more than another. But the prevalence of response orientations across all participant reflections shows that knowledge-oriented responses were most prevalent (14 instances), followed by emotion-oriented responses (nine instances) and action-based responses (six instances).

These three responses orientations—emotion, knowledge, and action—indicate the ways in which participants responded to their experience at this symposium. Each provides a distinct way in which respondents reported being affected by the symposium and their perceptions of inclusive science communication and public engagement with science. Responses suggest that this kind of symposium has the potential to provide transformative experiences for participants in multiple ways. In the case of this symposium, respondents described changes in their affect toward, understanding of, and ability to act on inclusive science communication and public engagement with science. Thus, it is important for inclusive science communication symposium organizers to think beyond merely informing attendees and to consider the transformational potential of engaging participants' emotional responses and empowering them with actionable tools. We recommend acknowledging, responding to, and further studying the dynamic and interconnected nature of information, affect, and action in doing inclusive science communication, as evidenced by our sample's responses.

After attending, participants shared the specific activities or networks they would like to develop or participate in to advance inclusive science communication/public engagement with science on a national scale. Answers varied, but creating or joining online networks for inclusive science communication was a popular answer. This included developing searchable databases around inclusion efforts for ideas and to see what does or does not work, hosting a network for best practices and creative solutions to local challenges, establishing an email listserv, and making available more webinars and digital discussions. Other responses addressed support for working and networking with large organizations. This included community organizations, such as YMCA, and larger science organizations. Some responses directly addressed educational efforts (Calabrese Barton and Tan, 2019), including developing guidelines and organizational resource banks for STEM institutions, developing a pedagogy of inclusion group/network, and broadening existing STEM outreach programs (e.g., Ask a Scientist and Skype a Scientist) by including more diverse scientists and schools. A few participants identified interest in support for working with news media and others identified support for storytelling events. One respondent noted a lack of attendees from Midwestern and Southern states at the symposium and suggested that national activities and networks cannot exist until all areas are represented and active. Another noted the emergent theme of an "urgent need for dialogue," and said that they would welcome more preparation about "facilitating difficult conversations about getting out of the way and lifting up."

STUDY LIMITATIONS

Limitations include practical considerations of administering an online survey, including lack of participant time, survey fatigue, and lack of tangible incentive. Limitations also include the exclusion of race/ethnicity from the survey's demographic questions due to an oversight by researchers, but this has been corrected for the ongoing 2019 study. An additional limitation is that participants were largely homogeneous, with the majority being females with advanced degrees, especially in natural science. Another limitation is the sample size, which decreased from the pre-test to the post-test survey. A final limitation is that of the method (survey) which does not allow for follow-up questioning or clarifications for qualitative responses. These limitations may have influenced results as the respondent pool was inherently reflective of the symposium being held at a university with a largely highly-educated audience. These limitations have been discussed at length in the interpretation of data and researchers do acknowledge that the lack of responses from certain diverse occupations, fields, and organizations.

CONCLUSION

Results from this study indicate that the symposium increased participant knowledge of and confidence in enacting inclusive approaches, reflecting the symposium's objectives to identify needs and opportunities for more inclusive science communication and PES, and to discuss structural problems and how these problems can be addressed. The qualitative data also make clear that this symposium had impacts on attendees. Attendee responses were emotion-oriented, knowledge-oriented, and/or action-oriented, indicating that the event achieved its intended objectives of highlighting varied approaches to science communication, discussing structural problems and solutions, providing practical information for implementation and inspiring new collaborations among attendees. Participants reflected on how they can apply what they heard and learned during the symposium, in various ways, in their own work, again reflecting the event's objectives of addressing structural problems and providing practical information that attendees can implement.

RQ2 asked what participants view as the biggest barriers and opportunities for inclusive engagement and science communication. Participant responses suggested that participants have experienced barriers in inclusive science communication caused by presence and caused by absence. These responses corroborate existing research literature. Regarding barriers caused by presence included existing organizational structures in research and the academy (Chilvers, 2012); siloing of research and information (Falk et al., 2011; Chilvers, 2012; National Science Foundation, 2018); inherent, unconscious, and implicit biases (Christidou, 2011; Taylor, 2014); white communicators not sharing leadership spaces with non-white communicators (Taylor, 2014, 2018); and laziness, stubbornness, or resistance toward inclusion efforts which result in fatigue for those doing inclusive science communication and public engagement (DiAngelo, 2012; Feinstein and Meshoulam, 2014; Bang et al., 2018).

The case is the same for barriers caused by absence: current literature indicates similar examples. These include lack of funding (Mack et al., 2012; Taylor, 2014); lack of understanding, knowledge, training, or resources for doing inclusive science communication work (Dawson, 2014; Feinstein and Meshoulam, 2014); not assessing if inclusion efforts are actually inclusive (Mack et al., 2012; Featherstone, 2014); inadequate diversity among leadership in science communication efforts (Feinstein and Meshoulam, 2014; Pearson and Schuldt, 2014; National Science Foundation, 2018); limited opportunities or platforms; minimal networking, collaboration, or sharing of information (Falk et al., 2011; Chilvers, 2012; Berditchevskaia et al., 2017); and few opportunities for diverse, young scientists to be engaged in science (Calabrese Barton and Tan, 2010, 2019).

Responses about opportunities were less cohesive than those about barriers, however the most common responses reflected understanding and connecting with diverse communities, and engaging members of diverse communities as science communicators. These responses indicate a need for further research on understanding the role of diverse voices in science communication as science communicators, community liaisons, and audiences.

Participants demonstrated a strong desire to continue a national conversation about how to increase inclusion in science communication and public engagement with science. Respondents offered various mechanisms for this, suggesting the creation of online networks, an online resource hub, or partnerships with existing institutions in education, research, or community (Davies et al., 2009; Feinstein and Meshoulam, 2014; Hobbs et al., 2019). These findings highlight the need to expand opportunities for online and in-person discussions about how to prioritize and achieve inclusive approaches to science communication (see Canfield et al., this issue; Falk et al., 2011). These networks and events could help participants work through identified barriers and opportunities to inclusive engagement and, importantly, build new collaborations, especially between researchers and practitioners. Participants identified structural barriers or deficiencies as some of the most difficult to address, such as lack of funding for this type of work (Dawson, 2012; Mack et al., 2012). Participants identified innovative strategies for moving science communication out of the academy and into more culturally-contextualized settings, offering ideas of storytelling events and partnering with already-established community groups.

Finally, this study highlights the need for more coordinated efforts for inclusive science communication engagement that spans geography, audience, and scale. While participants identified various areas for development, it was clear that there was a desire for more information-sharing and collaboration across contexts to help practitioners, researchers, and other interested groups learn from each other's successes and failures (Falk et al., 2011; Featherstone, 2014; Treffry-Goatley, 2014).

FUTURE WORK AND USE OF RESULTS

The goal of this evaluation research was to identify what participants wanted from Inclusive SciComm: A Symposium on Advancing Inclusive Public Engagement with Science, what their experiences were at the symposium, and their broader reflections on inclusive science communication after attending the symposium. This study is immediately useful for informing the design of future convenings with similar objectives, helping organizers understand how to be more responsive to participants' needs, expectations, and experiences. Inclusive science communication, defined in its broadest sense, is an area ripe for further study. Convenings like the InclusiveSciComm Symposium can help identify research gaps that, once addressed, could truly expand inclusive practice. This research provides insights for inclusive science communication researchers and practitioners based on the experiences of participants by examining their perceived knowledge and confidence after attending, clarifying their perspectives on barriers and opportunities for inclusive science communication and engagement, and understanding their responses to the symposium experience.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available as they are protected by IRB.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Oregon Research Compliance Services. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HS led the development and implementation of the research design, oversaw analysis, interpreting, and writing results. SM assisted with the development and implementation of the survey, as well as the writing of the results. KC assisted in all levels of data interpretation and writing. RG performed qualitative coding, analysis, and writing the findings of the open-ended survey data. MM performed the statistical analysis on pre- and post-event knowledge and confidence. KM assisted with the development and implementation of the survey.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/article/10.3389/fcomm.2019.00077/full#supplementary-material.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Corrigendum: Moving Toward Inclusion: Participant Responses to the Inclusive SciComm Symposium

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In the original article, there was a mistake in **Tables 1** and **3** as published. The authors reported cumulative percentages instead of valid percentages. The corrected tables appear below.

The authors apologize for this error and state that this does not change the scientific conclusions of the article in any way. The original article has been updated

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TABLE 1 | Knowledge measures.

	Pre-test "Extremely"	Post-test "Extremely"	Pre-test "Very"	Post-test "Very"	Pre-test "Moderately"	Post-test" Moderately	Pre-test "Slightly"	Post-test "Slightly"	Pre-test "Not at all"	Post-test "Not at all"	Pre-test total	Post-test total
Identifying challenges	8.50%	8.50%	27.70%	46.80%	53%	40.40%	8.50%	4.00%	2%	0%	100%	100%
Identifying opportunities	2.20%	10.60%	4.30%	38.30%	47.80%	38.30%	37%	12.80%	8.70%	0.00%	100.00%	100.00%
Implementing strategies	0.00%	8.50%	10.90%	42.60%	30.40%	27.70%	34.80%	19.10%	23.90%	2.10%	100.00%	100.00%
Overcoming barriers	0%	2.1%	6.40%	38.30%	25.50%	40.40%	31.90%	12.80%	36.20%	6.40%	100.00%	100.00%
Identifying new ways to becoming engaged	2.2%	31.90%	23.90%	42.60%	43.50%	17.00%	15.20%	6.40%	15.20%	2%	100.00%	100.00%

TABLE 3 | Confidence measures.

	Pre-test "Extremely"	Post-test "Extremely"	Pre-test "Very"	Post-test' "Very"	Pre-test "Moderately"	Post-test "Moderately	Pre-test "Slightly"	Post-test "Slightly"	Pre-test "Not at all"	Post-test "Not at all"	Pre-test total	Post-test total
Identifying challenges	2.20%	13.30%	19.10%	44.40%	34.00%	33.30%	36.20%	8.90%	8.50%	0%	100.00%	100%
Identifying opportunities	2.20%	8.90%	10.60%	48.90%	36.20%	33.3%	40.40%	8.90%	10.60%	0.00%	100.00%	100%
Implementing strategies	0.00%	4.40%	13.30%	37.80%	31.10%	44.40%	31.10%	11.10%	24.50%	2.20%	100.00%	100%
Overcoming barriers	0%	0%	15.20%	48.90%	17.40%	33.30%	41.30%	15.60%	26.10%	2.20%	100.00%	100%
Identifying new ways to becoming engaged	2%	17.80%	25.50%	48.90%	34.00%	20.00%	27.70%	13.30%	10.60%	0%	100%	100%

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Science Communication Demands a Critical Approach That Centers Inclusion, Equity, and Intersectionality

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We live in an era of abundant scientific information, yet access to information and to opportunities for substantive public engagement with the processes and outcomes of science are still inequitably distributed. Even with increasing interest in science communication and public engagement with science, historically marginalized and minoritized individuals and communities are largely overlooked and undervalued in these efforts. To address this gap, this paper aims to define inclusive science communication and clarify and amplify the field. We present inclusive science communication as one path forward to redress the systemic problems of inequitable access to and engagement with STEMM (science, technology, engineering, mathematics, and medicine). We describe the first national Inclusive Science Communication (InclusiveSciComm) Symposium held in the U.S. Based on the experience of organizing the symposium, we discuss recommendations for other convenings to help build a community of practice for inclusive science communication. In both research and practice, we advocate for more experimentation to help make inclusive science communication the future of science communication writ large, in order to engage diverse publics in their multiple ways of knowing and expand a sense of belonging in STEMM.

Keywords: science communication, inclusion, public engagement, critical dialogue, equity, inclusive science communication, informal science learning, journalism

INTRODUCTION

We live in an era of abundant scientific information, yet access to information and to opportunities for substantive public engagement with the processes and outcomes of science are still inequitably distributed. Even as interest in science communication[1] has grown (Chilvers, 2012; Dudo and Besley, 2016), marginalized individuals and communities remain largely undervalued in these efforts (Dawson, 2014b; Feinstein and Meshoulam, 2014; Streicher et al., 2014). This paper aims to advance the field of inclusive science communication (ISC) with a definition and rationale, examples, priorities for integrating research and practice across relevant disciplines, and a symposium-based model for building an ISC community of practice.

We envision a fundamental shift in science communication whereby inclusion, equity, and intersectionality ground all research and practice. Eventually, we hope the term "inclusive science communication" will be redundant. For now, however, the "inclusive" descriptor is a valuable framing device to clarify objectives and speed this transition. To this end, we define ISC as an intentional and reflexive practice and research approach that:

- Recognizes historical oppressions, discrimination, and inequities and centers the voices, knowledge, and experiences of marginalized individuals and communities in STEMM dialogue.
- Acknowledges that each person's individual characteristics (e.g., gender, race, physical ability) overlap with one another (defined as "intersectionality" by Crenshaw, 1989) and that these intersectional identities affect their status in the world (Shimmin et al., 2017).
- Further acknowledges that explicit and implicit biases (historical, cultural, experiential) of science communication practitioners and scholars influence the design and implementation of their work (Reich et al., 2010; Dawson, 2014c).
- Rejects the oversimplifications of the deficit model (Trench, 2008; Simis et al., 2016), in which science communicators treat public audiences as lacking relevant knowledge or experience.
- Incorporates asset-based methods that respect and value the ideas, experiences, questions, and criticisms that diverse publics bring to conversations about STEMM (Banks et al., 2007).
- Aims to cultivate belonging and engagement of audience and collaborator perspectives (Wynne, 1992; Cheryan et al., 2013; Haywood and Besley, 2014; Leggett-Robinson et al., 2018).
- Offers a multi-scaled approach to shift organizational cultures and structures and redress the systemic problems of inequitable access to and engagement with STEMM (Anila, 2017; Bevan et al., 2018).
- Is relevant across formal and informal learning and engagement settings.

In summary, we urge a paradigmatic shift in science communication toward an overarching objective of expanding a sense of belonging in STEMM and approaches that embrace varied forms of expertise and ways of knowing.

Why Do We Need Inclusive Science Communication?

As a result of science communicators' cultural and epistemological tunnel vision, their efforts tend to benefit specific (e.g., affluent, college-educated, non-disabled) audiences (Ash and Lombana, 2013; Dawson, 2014c; Medin and Bang, 2014; Taylor, 2018). ISC aims to address the shortcomings in how researchers and communicators define and engage public audiences in STEMM topics, particularly tackling the deficit approach to science communication (Nisbet and Scheufele, 2009; Smallman, 2016). As Dawson (2019, p. 170) stated, "to continue with business as usual is to be complicit in practices that uphold and exacerbate racism, class discrimination, sexism, and other forms of oppression". In renouncing the status quo, we argue against science communication that singularly portrays science in the Western mold: that is, as objective and universal (Cobern and Loving, 2001; Medin and Bang, 2014; Bang et al., 2018) or as "governed by a rigid scientific method that produces incontestable facts" (Cunningham and Helms, 1998, p. 485). Because science communication is inherently contextual (Chilvers, 2012; Streicher et al., 2014; Bang et al., 2018), it is well-suited to counter assumptions of the Western model. ISC offers a critical approach that interrogates history, politics, and society, examining how people's multiple identities interact to affect their engagement with STEMM fields and issues of societal relevance (Feinstein and Meshoulam, 2014; Massarani and Merzagora, 2014; Schuldt and Pearson, 2016; Bevan et al., 2018; Calabrese Barton and Tan, 2019).

ISC can leverage society's intellectual assets (knowledge, experience, ways of knowing) to address the many wicked problems of our time (Rittel and Webber, 1973). These problems require STEMM-based solutions as well as community engagement and support (Wynne, 1992; Cohen et al., 2012; Perié et al., 2014; Mansyur et al., 2016). Such a massive effort requires a range of communication objectives, from sparking curiosity to building trust that drives behavioral change, and methods, from culturally-relevant exhibit design to community-engaged research (Reich et al., 2010; Dawson, 2012b; Haywood and Besley, 2014; Perié et al., 2014; Dudo and Besley, 2016; Berditchevskaia et al., 2017). This understanding of ISC leverages multiple science communication models (Lewenstein, 2003), including contextual (e.g., culturally-responsive design, per Calabrese Barton and Tan, 2010), lay expertise (e.g., multiple ways of knowing, per Delgado Bernal, 2002), and public participation (e.g., co-creation and collaborative design, per Shirk et al., 2012). Inclusive approaches can yield broad benefits including improved science learning (Johnson et al., 2014; Lemus et al., 2014), an increased sense of science identity (Carlone and Johnson, 2007; Ong et al., 2011) and science capital (Archer et al., 2015; Dewitt et al., 2016) for underrepresented communities, and greater empathy among technical experts (Casapulla et al., 2018).

[1]We define "science communication" in the broadest sense, encompassing any information exchange designed to engage targeted audiences in conversations or activities related to STEMM topics.

ISC is a multi-scaled path toward systemic change (a paradigmatic shift, per Watson et al., 2008) that can redress inequities not only in science communication, but in STEMM education and practice. ISC practice, training, and research requires intentional—but not tokenized—involvement of underrepresented people in influential leadership positions (Pearson and Schuldt, 2014; Taylor, 2014). For example, the American Association for the Advancement of Science's If/Then Ambassadors program aims to highlight successful women in STEMM fields, showing girls different career pathways and how STEMM affects their lives (American Association for the Advancement of Science, 2019). Such representation provides "visual cues of belonging" (Pearson and Schuldt, 2014) needed to break down persistent stereotypes in the Western academic system (e.g., scientists as white males and environmentalists as white) and build trust in science communicators (Campbell et al., 2008; Davies et al., 2009; Mack et al., 2012; Cheryan et al., 2013; Taylor, 2014). While we view diverse representation and leadership as a critical early step toward systemic change, we note that it represents only one aspect of the shift needed to center inclusion (Hurtado et al., 2017).

EXISTING RESEARCH ON INCLUSIVE SCIENCE COMMUNICATION

Education scholars have studied inclusion for several decades (Cunningham and Helms, 1998; Aikenhead, 2001; Diangelo and Sensoy, 2010; Reich et al., 2010; Dewsbury, 2019), but research explicitly addressing ISC and its value is relatively new. A series of comments in the *Journal of Science Communication* discussed "socially inclusive science communication[2]," including an argument that "placing equity at the heart of science communication is crucial for developing more inclusive science communication practices," (Dawson, 2014b, p. 1). To our knowledge, this is the only peer-reviewed reference that uses ISC as we present it here.

Informal science learning (ISL) and science communication have similarities in practice and research but are based on different theories and rarely used in concert (Bevan et al., 2018; Dawson, 2019). In recognition of this overlap, we include research on inclusive approaches to ISL, particularly since this is the silo in which most ISC-relevant research is located (Dawson, 2019).

Reich et al. (2010, p. 10) described inclusive ISL as encompassing "physical, cognitive, and social dimensions", but efforts at inclusion often focus on access as the primary impediment to STEMM engagement (Rahm and Ash, 2008). Such oversimplifications fail to address assumptions about who belongs in STEMM spaces, forcing marginalized populations to participate in a space they have historically been excluded from, implicitly, explicitly, and/or intentionally (Dawson, 2014c, 2019; Massarani and Merzagora, 2014; Bevan et al., 2018). Framing access as the impediment assumes certain publics are uninterested in science or are not participating due to a failure to recognize the value of such engagement (Dawson, 2014b). This deficit mindset discounts the multiple ways of experiencing and practicing science, placing blame on marginalized groups rather than designer or institutional failures to create an inclusive space (Dawson, 2014b; Medin and Bang, 2014; Perié et al., 2014). When efforts at broadening participation fail to consider intersectional identities and the history that produced them, they are more likely to recreate the systems that marginalize people in the first place (Dawson, 2019; Torres-Gerald, 2019).

[2]In Europe, "socially inclusive science communication" has been used to refer to inclusion of minoritized social identities, distinct from "inclusive communication," which generally references accessibility of communications for people with disabilities (Shiose et al., 2010; Scottish Government, 2011). This distinction has not taken root in the U.S.

ISL also offers evidence for the value of inclusive public engagement from museum settings (Dawson, 2012a,b, 2014a,b,c, 2019; Feinstein and Meshoulam, 2014), gaming and design-based learning in afterschool primary and secondary school settings (Kafai et al., 2016; Hobbs et al., 2019), and community-engaged research (Haywood and Besley, 2014; Petersen et al., 2016; Soleri et al., 2016). Bevan et al. (2018) compiled many examples of effective ISC projects, emphasizing the importance of reflection, adaptation, and institutional change.

The existing research provides a foundation for ISC, albeit one that requires more blocks and cement. As we build on this foundation, related fields will benefit from an open floor plan with fewer walls. To this end, ISC should explore themes from ISL and formal education to learn from context-specific practice and research, and to develop common frameworks (National Research Council, 2009). Although significant research gaps remain in ISL, especially regarding methods for systematizing inclusion within institutions and organizations (Reich et al., 2010), a transdisciplinary approach to ISC will help dismantle research and practice silos and achieve the systemic change we seek (Fischhoff, 2013).

A MODEL FOR BUILDING COMMUNITY TO ADVANCE INCLUSIVE SCIENCE COMMUNICATION

A growing number of practitioners are experimenting with inclusive approaches that have not yet reached the peer-reviewed literature. ISC practice ranges from public engagement approaches such as Dr. Danielle N. Lee's use of hip hop themes and lyrics to launch conversations about animal behavior (Johnson, 2019) to journalists and science writers intentionally featuring diverse sources in their reporting (Yong, 2018). Asset-based practices—those that value the knowledge and experiences of participants, vs. viewing differences as shortcomings—offer rich ideas for expanding and codifying ISC, but only if they are shared and normalized (Jensen and Holliman, 2015).

Some of these practitioners have found community online, especially via Twitter. Online communities can support learning and identity formation (Hall, 2009; Reed, 2013), but they do not foster the substantive interdisciplinary conversations needed to advance ISC as a cohesive intellectual framework. Conferences can generate awareness, ideas, collaborations, and dialogue (Hatcher et al., 2006; Oester et al., 2017), yet, there are few in-person opportunities for ISC researchers or practitioners to network.

One previous conference, the 2014 International Public Communication of Science and Technology conference (PCST), brought together science communication researchers and practitioners around the central theme of "science communication for social inclusion[3] and political engagement" (Featherstone, 2014; Treffry-Goatley, 2014). The PCST conference demonstrated a key tension in ISC; many ISC practitioners are not publishing their work but researchers look to the published literature to inform their research questions and seek funding. There remains a significant shortage of research/practice collaborations that could ameliorate these challenges (Featherstone, 2014).

To address these gaps, the University of Rhode Island's (URI) Metcalf Institute organized the United States' first national conference about ISC: #InclusiveSciComm: A Symposium on Advancing Inclusive Public Engagement with Science. The co-authors of this paper include the inaugural planning committee for the InclusiveSciComm Symposium.

InclusiveSciComm Symposium organizers created the 2018 program to:

- Identify needs and opportunities for inclusive, intersectional, and asset-based science communication approaches;
- Highlight practitioners and researchers whose work can serve as cross-sectoral models;
- Discuss structural problems that hinder inclusive approaches and how these problems can be addressed; and
- Inspire new collaborations among attendees and provide practical information that attendees could implement in their work to prioritize inclusion.

Registrants included 150 science communication practitioners, trainers, educators and researchers at various career stages. The agenda was designed to foster conversations and develop networks that transcend disciplinary expertise and sectoral employment, offer examples of ISC approaches applied in diverse settings, and help participants center inclusion in their own work, with a concluding discussion on the next steps for advancing ISC (see Smith et al., 2020, for a detailed analysis of pre/post symposium survey data). Anecdotal responses on Twitter and conversations with organizers revealed diverse outcomes including new collaborations, changes in program design, and especially among graduate students, greater interest in ISC careers.

We acknowledge the limitations of drawing broad conclusions from a single event. As described above, this emerging field of study demands much more attention and rigorous assessment. We share our experience of trying to foster an ISC community of practice via the symposium as a model for supporting learning and change-making across science communication modalities and settings. We provide these recommendations to help others advance the field by launching intentional and rigorous ISC conversations in their respective communities.

Plan for a Range of Experiences and Perspectives

This began with the planning committee, which sought diverse perspectives, and encouraged open communication about how to model inclusion. Organizers carefully selected a diverse range of speakers from varied disciplines whose work centered inclusion from the beginning of their science communication efforts (e.g., the Broad Science podcast, the American Geophysical Union's Thriving Earth Exchange, Two Photon Art). Symposium attendees had wide-ranging experience related to advancing diversity, equity, and inclusion (DEI). This mixture enriched the symposium, helping those who were less experienced in discussing DEI to identify gaps in inclusive practice and specific actions to address them, without frustrating the more experienced attendees.

Given the diverse perspectives needed to inform ISC, participants and speakers should represent a wide range of sectors, disciplines, geographies, and marginalized identities. For example, while ISC related to people with disabilities was addressed in several symposium panels, participants noted that they would like this to be a greater focus in future events, along with sexuality, gender, nationality, and age.

Embrace Varied Approaches to Inclusive Science Communication

This was a fundamental tenet of the InclusiveSciComm Symposium, and survey comments indicate that many attendees had not previously appreciated the wide variety of methods for ISC research and practice. One participant noted, "this conference helped me realize that there are far more people playing different roles who care deeply about inclusive scicomm than just practitioners who are trained in science." This heightened awareness of how ISC can be integrated across disciplines and sectors is a valuable outcome of in-person meetings.

Dialogue and Practice Are Essential

While symposium participants left with new knowledge, perspectives, and tools, there was a clear desire for more opportunities to practice the application of their new insights. Future ISC meetings and trainings should address practitioners' lack of language, skills, and confidence for facilitating difficult conversations across difference. Discussions about potentially uncomfortable topics such as privilege, power, or marginalization are essential for inclusive practice and pedagogy (Miller et al., 2004). To advance ISC, practitioners and researchers need more opportunities to practice this "critical dialogue" (Laman et al., 2012).

Discuss Opportunities for Systemic and Structural Change at Different Scales

Symposium attendees sought ways to address the structural problems that hinder ISC, from inconsistent institutional support

[3]Science communication for social inclusion addresses the role of science communication in society. Socially inclusive science communication refers to an approach to science communication. We do not favor one priority over the other. Rather, we believe ISC should concern itself with both approach and the societal role of science communication.

for science communication activities to underrepresentation of marginalized identities in science journalism and community-engaged research. Systemic change takes place at different scales. It could focus on influence or agency in relationships (Calabrese Barton and Tan, 2010; Anila, 2017), such that community collaborators are truly engaged in science communication efforts and their knowledge assets are recognized and valued (Yosso, 2005; Philip and Azevedo, 2017). Alternately, systemic change could happen at the institutional scale, e.g., a newsroom makes hiring or editorial decisions based on inclusive priorities (Arana, 2018; Columbia Journalism Review, 2018) or a university changes the promotion and tenure review process to value science communication (Jacobson et al., 2004; Scheufele, 2013).

DISCUSSION: FUTURE DIRECTIONS

ISC is a rich area for study. Based on literature and our symposium experience, we propose several key issues that require integrated research and practice, and, especially, interdisciplinary discussion (Trench and Bucchi, 2010). Case studies of intentionally inclusive public engagement with science (PES) and ISL efforts will clarify how program objectives and settings might influence outcomes. Longitudinal studies of programs and institutions could identify effective strategies to address the systemic failures that have excluded marginalized peoples from STEMM and, instead, promote "life-long, life-wide, and life-deep" STEMM learning (Banks et al., 2007). Few studies have explored how cultural processes (Manzini, 2003) and epistemological orientations (Medin and Bang, 2014; Philip and Azevedo, 2017) inform effective science communication. Finally, practitioner and researcher uncertainty about how to approach critical dialogue has important implications for the ways individuals and communities relate to and perceive science (National Research Council, 2009; Dawson, 2014a,b), public participation in STEMM research (Haywood and Besley, 2014), and the degree to which public discourse about contentious scientific topics is fully representative and valued (Wynne, 1992; Biegelbauer and Hansen, 2011). Meetings such as the InclusiveSciComm Symposium offer a venue for clarifying the priorities for ISC and connecting siloed disciplines and sectors to advance the field.

CONCLUSION

Science communication practitioners and scholars need to consider how identities operate not only interpersonally, but also systemically (Choo and Ferree, 2010; Falcón, 2016). ISC requires intentional design based on a goal of including the diverse experiences and identities participants bring to their learning environments. Science communication can and must become a field that supports our pluralistic societies. Without actively reframing our approach, researchers, and practitioners are perpetuating inequities by default (Dawson, 2019). We advocate for ISC as a critical approach that embodies an intentional investment in supporting and recognizing inclusion, equity, and intersectionality from ideation to implementation and evaluation. More transdisciplinary, cross-sectoral convenings like the InclusiveSciComm Symposium are needed to build an ISC community of practice. We hope this growing community will seed changes in how science communication is envisioned, practiced, and perceived.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Oregon Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KC was the lead author. SMe provided substantive edits throughout the process. AM, SMa, ANM, MF-M, BD, and CT contributed important ideas and edits for the final version. All authors contributed as thought partners in conceiving the paper.

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Activating Neighborliness Frames: Drawing on Culturally-Relevant Discourses of Community to Build a Stronger and More Diverse Environmental Movement

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In this article, I draw on my experience as an environmental social scientist and narrative nonfiction writer conducting research in working class conservative agricultural communities that frequently challenge or reject science communication. Based on my own trial-and-error path as a public intellectual committed to advancing sustainable agriculture, I present a method that I've developed to promote broader and more diverse public dialogue about environmental problem solving. Acknowledging that people interpret the world through socially-reinforced cultural cognition and pre-existing cognitive frames—and also that humans are social animals who thrive in groups I propose that frames can be the science communicator's friend. I have yet to find a community that does not have some connection to ancestral or local knowledge about community interdependence and the importance of being a good neighbor. Indeed, I often find that these "neighborliness" frames are at the very core of people's cultural cognition. Such neighborliness frames, in turn, provide a strong foundation for environmental consciousness. Thus, by being curious about a community's unique history with and knowledge about neighborliness, science communicators can help to build up frames necessary for environmental actions, while also helping cultivate broader understandings of the "neighborhood" within which communities' values and worldviews demand action.

Keywords: environmental communication, cultural cognition, frames, environmental movements, social change, rural politics

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INTRODUCTION

"You're working where?" my classmate asked, incredulous. In response to a question about my dissertation, I had just divulged that I was collaborating with a group of farmers in rural Montana on a project about transition to sustainable agriculture. "Uh, how's that going?" my classmate stammered, when I affirmed that this was indeed my plan.

Rural Montana, I've found, isn't where most people expect to encounter bold action on environmental issues. And despite the fact that I'm a proud Montanan, I've struggled a bit with how to have environmental conversations in certain corners of my home state. This is, after all, a state that picked Donald Trump over Hillary Clinton and George Bush over Al Gore, seemingly choosing climate denial and climate inaction over environmental progress.

So as I prepared to ask farmers about soil health and crop rotation strategies for my dissertation research, a deeper question was nagging at me: in a rural area where climate change is going to have serious consequences for agriculture and public health, how can collective action be mobilized in the context of a libertarian conservative political climate in which "big government," climate science, and climate scientists are not widely trusted? At the crux of this looming question was a very immediate practical matter: how should I talk about environmental issues with people who might not self-identify as environmentalists?

THE DILEMMA OF CULTURAL COGNITION

Meanwhile, in the pages of science communication journals, a motley group of linguists, psychologists, political scientists, and concerned climate modelers were debating a similar question: why was the public failing to respond to climate change? For decades, the conventional wisdom was that people weren't taking action on climate change because they were poorly informed about it. On the basis of this belief, massive information and educational campaigns were launched to ensure that all Americans were exposed to basic climate science. Yet massive climate action did not result, and well into the 2000s, polls reported that large numbers of people–both in the US and around the world–either did not believe climate change was real or did not believe that it was linked to human activities (Groffman et al., 2010). So what went wrong?

Just as I was heading off for my dissertation fieldwork, Yale psychologist Dan Kahan was putting the finishing touches on a book chapter that would sum up his findings about this very question (Kahan, 2013). Kahan conducted dozens of studies about science communication designed to fix people's "deficit" of information on climate change, to understand how people responded to and acted on this new information. His conclusion? Kahan found that scientific literacy and concern about climate risk weren't very well correlated– in some cases people had a lot of science *knowledge* but this didn't translate into *concern*–or, presumably, action. To Kahan, these findings suggested that the information deficit theory of climate inaction was not a sound basis for designing effective science communications. In its place, Kahan proposed a different model: cultural cognition.

As deeply social beings, Kahan's theory held, people judge new scientific information according to worldviews they share with their friends and neighbors. These cultural norms powerfully influence who people trust and how they judge or incorporate new information into their existing mental models of the world. If new information threatens the shared identity of the group or an individual's belonging within it, it's likely to be discredited or rejected.

How is it possible for two people to draw such radically different conclusions from the same information? Just as Kahan was developing the cultural cognition model, linguist George Lakoff was helping to shed light on this question by applying his longstanding work on cognitive frames to the dilemma facing the environmental movement (Lakoff, 2010). Our brains, Lakoff argued, need structures for organizing the vast amounts of information they are tasked with absorbing. These structures, which function as templates into which information can be slotted, are what linguists call frames. They help us do things like interpret information in context, connect cause and effect, and recognize relationships. They also greatly impact the conclusions we draw from new information. For example, a "direct causation" frame could yield very different conclusions than a "systemic causation" frame with multiple relationships and feedback loops, leading one person to assume a cold snap is evidence that global temperatures are not rising while another person might see it as a sign of further 'climate chaos." A "personal responsibility" frame might lead one person to blame a farmer for applying fossil-fuel based fertilizer while a "social responsibility" frame might lead another person to blame the agricultural industrial complex.

For many science communicators, these insights from Groffman, Kahan, and Lakoff felt deeply discouraging. Didn't facts matter? Couldn't people be persuaded with data?

For another group of scholars, however, the conversation about cultural cognition felt promising and familiar. Beginning in the 1980s, feminist philosophers of knowledge like Donna Haraway and Sandra Harding had been making the case that people filter information through social experience. As made clear by the term Harding chose to describe this process, "strong objectivity," feminist philosophers of science saw great possibility in acknowledging and drawing on socially mediated knowledge (Harding, 1995). We might in fact get a more accurate picture of the world through these "situated" forms of knowledge, these scholars argued, so long as we put them in dialogue with one another and didn't allow one group's version to dominate the conversation (Haraway, 1988).

Buoyed by this feminist analysis, which I was fortunate to have encountered in graduate seminars, I headed off to the northern great plains with great curiosity about how situated knowledges might inform a robust response to environmental challenges facing farmers in rural Montana.

NEIGHBORLINESS FRAMES

Three important themes returned again and again in my interviews with Montana farmers, two of which didn't appear to have anything to do with the environment.

One theme that came up frequently was the cultural practice of mutual aid, which had often made a major impression on farmers in their early years. People recounted childhood experiences helping out at barnraisings and sharing equipment with other farmers nearby, and they taught me a new verb that encompassed these practices and others: "neighboring."

A second theme that emerged from my interviews was early exposure to cooperatives, which helped farmers get better prices for their grain by marketing their harvests collectively. The group that promoted most of the early cooperatives, the Farmers Union, hosted camps that many of my interviewees had attended as kids, further deepening their understanding of cooperative principles and relationships with other families participating in the Farmers Union.

The third theme, which begin to move into more familiar environmental territory, was an observation that many farmers made about the relationships among elements of their farming systems. As farmers transitioned to organic farming systems reliant on ecological relationships, they were struck by the way in which lentils left behind residual nitrogen in the soil for next year's grain crop, and the way rhizobia bacteria set up shop in lentil roots and converted nitrogen into a form available to plants. They begin to notice a pattern that characterized *both* these ecological communities on their farm *and* the human communities they belonged to: interdependence. When I asked one farmer about the greatest lesson he'd learned about sustainable farming his response was "that you can't do it alone" (Carlisle, 2015).

As I continued hearing similar stories from farmers (of all political stripes) who were transitioning to sustainable agriculture, I began to think of these stories, in Lakoff's parlance, as the building blocks of neighborliness frames. Through a series of experiences that emphasized or revealed interdependence, farmers had learned to see the world as a neighborhood, in which residents relied on one another and flourished through cooperation. Childhood values told them that being a good neighbor was important: in both moral terms and practical ones (when you get a flat tire in the middle of nowhere, you better hope you've built up some goodwill with the folks close by). They were thus primed to recognize this "neighboring" behavior in their cropping systems, and their experiences with ecological symbiosis further reinforced their "neighborhood" model of human relationships.

This robust circulation of neighborliness frames appeared to be happening among Montana ranchers as well. Just a few years earlier, sociologist Jill Belsky and forestry professor Laurie Yung, both of the University of Montana, uncovered a "community approach to private property," among ostensibly libertarian ranchers on the Rocky Mountain Front. When new amenity buyers arrived in the neighborhood and restricted hunting and trailing of cattle through their property, these ranchers began articulating what Yung and Belsky termed "community claims to public goods on private lands," including the obligation to manage weeds and a culture of "helping activities," in addition to social norms of hunting and trailing access (Yung and Belsky, 2007).

Looking beyond Montana, I began to see examples of neighborliness frames everywhere, from the ahupua'a system in Hawaii (Vaughan et al., 2017) to the "peoplesheds" of the U.S. Corn Belt (Atwell et al., 2009). Might such neighborliness frames be a critical piece of our biocultural evolution as humans? Might we then hypothesize that most people carry some form of ancestral knowledge concerning the importance of community?

If so, we may have a way forward for environmental communication. Rather than trying to *overcome* cultural cognition with more "facts," we can *amplify* neighborliness frames that function as culturally embedded models of ecological connection.

NEIGHBORLINESS FRAMES AT WORK

In rural Montana, I found, such amplification of neighborliness frames had powered significant environmental action. The rise of organic farming, which now covers over 437,000 acres in the state (second only to California) (Lavey, 2018), begin in the 1980s with a scrappy rural NGO called the Alternative Energy Resources Organization (AERO). AERO explicitly drew on mutual aid customs and "neighboring" norms both to get its work done and to describe the function and benefits of ecological farming systems. They adopted organizing practices honed through Farmer's Union meetings, and celebrated the neighborliness of farm communities at a time when rural morale was low (Carlisle, 2015).

The centerpiece of AERO's organizing efforts was a network of Farm Improvement Clubs modeled on the corn and beef improvement clubs sponsored by agricultural extension offices in the 1940s. AERO staffer Nancy Matheson had a hunch that these 1940s era neighbor-to-neighbor clubs focused on "improvement" for the regional agricultural community (a cultural cognition approach to science communication) may have done more to spread the industrial model of agriculture than showy postwar demonstrations at agricultural colleges (a knowledge deficit approach to science communication). If farmer-to-farmer efforts focused on community improvement had been successful in spreading the science and technology of industrial agriculture, she reasoned, perhaps this same method of communication and organizing could be successful in spreading the science and technology of sustainable agriculture.

Matheson, who had grown up in a Farmers Union family in rural north central Montana, infused the Farm Improvement Club program with the tone and flavor of Farmers Union meetings. The application for club funding invited teams of farmers to come together to work on a common challenge, in the spirit of mutual aid. Many former club members I interviewed told me that they were even more committed to "not letting my fellow farmers down" than they were to the specific farming challenge that brought them into the club in the first place. At the end of each year, AERO convened all the clubs to share their results, bringing together the geographically disparate network of participating farmers into a community that felt like a neighborhood.

Though not formally trained in science communication, Matheson understood that the biggest barrier to changing a mental model could be the risk of being out of step with your "tribe" or even losing friends. Indeed, many early organic farmers did lose friends when they stopped using chemicals on their farm: one farmer described his wife's devastation when they were no longer invited to the neighborhood Christmas party. At the center of "cultural cognition," Matheson intuitively recognized, is a culture. Thus, the Farm Improvement Club program worked to build a robust culture and community that offered farmers a sense of continuity and connection with longstanding norms and values, so that they could confidently incorporate new agricultural practices into this social framework.

At the same time, AERO used neighborliness frames to build more expansive mental models of the "neighborhood," to include partnership with urban eaters of farmers' crops and larger-scale ecological citizenship within a common watershed and even a common atmosphere. In this way, climate change entered the discussion not as new and threatening information, but as the extension of a familiar conversation.

During its decade-long tenure over the course of the 1990s, AERO's Farm Improvement Club Program grew to 120 clubs, with over 500 participating producers. The model was so successful that USDA funded AERO to train its extension agents and soil conservationists—not just in Montana, but across four other states as well (Carlisle, 2015).

DISCUSSION

In my own research and writing–from my dissertation forward–I've tried to learn from AERO's example. Before proposing sustainable agricultural practices or climate mitigation and adaptation as new ideas, I've tried to start by asking some fundamental questions. How do people here understand their connection to each other and the natural world? What sense of obligation do they feel to one another, and perhaps to the land? I've uncovered some surprising answers to these questions, as ostensibly recalcitrant tough guys turn out to be incredibly tender caretakers of their cattle and fiscal conservatives shell out serious money to restore watersheds that have been part of their family history for generations. Such commitments form the foundation of the "new ideas," "shared norms," "participation processes," and "common vision of place" that scholars cite as the keystone of successful collaborations that have overcome seemingly intractable difficulties and differences by forging new alliances and shared governance (Weber, 2009; Sprain et al., 2016). Ironically, perhaps, it is often by digging a bit deeper into communities' complex political and social histories that possibilities for novel political configurations emerge. This may not get us all the way to successful collective action on climate, but such hopeful examples from agricultural communities suggest a good start. By being curious about a community's unique history with and knowledge about neighborliness, science communicators can help to build up frames necessary for environmental actions, while also helping cultivate broader understandings of the "neighborhood" within which communities' values and worldviews demand action.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Check for updates

Situating the Scientist: Creating Inclusive Science Communication Through Equity Framing and Environmental Justice

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This article draws on environmental justice (EJ) scholarship to develop a novel concept of equity framing that can be used to achieve more inclusive science communication. We argue that centering equity in our communications framing can provide an essential point of access for marginalized communities to engage with scientific communication, and also an important opportunity for scientific researchers and writers to become more accountable to disadvantaged communities. Viewing science communication through an equity lens asks communicators to not only frame science in ways that are salient to particular audiences, but it also asks communicators to attend to particular discriminatory historical practices that have targeted marginalized communities, and continue to do so through current scientific discourse. EJ strategies for equity framing include asking science communicators to (1) become aware of their own positionality and partial perspectives, (2) name sources of inequity that arise from uneven power relations, and (3) find intersections with initiatives that are rooted in the experiences of disadvantaged communities. To ground our approach to equity framing, we also present our experiences teaching Stanford University's first comprehensive class on environmental justice as a case study. Key outcomes included: adding missing perspectives to scientific knowledge production by inviting representatives from diverse and marginalized communities to teach us; increasing the social relevance of scientific findings by asking our students to center the concerns and insights of marginalized communities in their communication; and encouraging collective action to address equity concerns and achieve a healthier society for all.

Keywords: environmental justice, scientific discourse, positionality, equity framing, EJ pedagogy

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INTRODUCTION

In this article, we map out a process for more inclusive science communication grounded in the practices of environmental justice (EJ), with a specific focus on communication of the environmental sciences. We ground our analysis in the history of the EJ movement as it emerged as a transformative paradigm that has centered the fight for equity in environmentalism through a variety of discursive strategies (Bullard, 1993, 1996, 2000; Taylor, 1997, 2000; Pellow, 2016).

We argue that science communication, as a field of inquiry and practice, must undergo a similar paradigm shift—namely through an increased attentiveness to equity framing as an essential tool ensuring that equity issues can be understood as a critical part of, and not separate from, science communication. To facilitate this shift, we develop a novel concept of equity framing, based on EJ practices.

Equity framing, meaning framing that centers equity, is concerned with the quality of fairness and inclusion that people receive (Rumley, 2014) and rejects a homogeneous approach to the distribution of justice (Bryner, 2002). By acknowledging preexisting inequalities among social groups, equity framing emphasizes that scientific knowledge is not divorced from the cultural, social and political histories in which it is embedded. In this way, equity framing provides an essential point of access for disadvantaged communities to engage with science communication, and also an important opportunity for researchers and science writers to increase their accountability to disadvantaged communities. When we say science communicators we mean all of these different people: writers, journalists, and teachers, science instructors, and scientists themselves.

Scientific knowledge is not developed through individual facts, but through the achievement of consensus about what counts as facts (Penrose and Katz, 2010). Research suggests that such consensus is built and communicated through discursive framing—with science communicators highlighting particular aspects of a scientific question or findings that are salient to particular audiences (Taylor, 2000; Druckman and Lupia, 2017). Discursive framing refers to the interpretive storylines that set a specific train of thought in motion, by communicating why an issue might be a problem, who or what might be responsible for it, and what should be done about it (Nisbet, 2009). Frames in communication affect audience opinion by not only informing them about an issue, but also creating the potential to reorient their thinking (Lakoff, 2004; Chong and Druckman, 2007).

The importance of framing in science communication may be challenged by advocates for positivist or "objective" science, which builds off the assumption that science can ultimately achieve a single, knowable truth. Debates over the objectivity of science are beyond the scope of this article. However, we discuss science communication from the standpoint that there is no such thing as unframed information. In doing so, we draw attention to the way in which science communication is typically framed, and consider structural elements around who is controlling the dominant communication framing. We also consider the potential for socially engaged science communicators to adopt alternative framings that center equity concerns, and practical tools for doing so.

Science has always been shaped by the values of the dominant culture in which scientists participate and live (Taylor, 2000; Penrose and Katz, 2010). So too has the mainstream framing of science been shaped by the dominant, homogenous voices—scientists and journalists who are predominantly white, educated, and male (Puritty et al., 2017; Grieco, 2018). In contrast, framing that has emerged from the environmental justice movement comes directly from communities of color and other marginalized groups, and thereby reflects their lived experiences. Because environmental justice is the first sector of the environmental movement to frame human-nature relations through the lens of race, class and gender (Taylor, 2016), the EJ movement encourages increased awareness of historical and current inequities in society. Given their direct experiences with discrimination based on social position, e.g., race and class, frontline environmental justice leaders have consistently focused on social equity concerns around environmental issues. As a result, equity framing rooted in EJ traditions involves recognizing how racial minorities and other marginalized groups bear the brunt of the discriminatory environmental policies and practices.

Viewing science communication through an equity lens asks communicators to better understand the ways in which their framing is connected to particular historical practices that have targeted and harmed marginalized communities, and continue to do so, in part through current scientific discourse. To achieve a more inclusive science, science communicators need to understand this broader sociopolitical context, which has been well-documented by environmental justice scholars. Equity framing can help science communicators engage with difficult histories of racialized violence and abuse, and benefit from environmental justice concepts that have "transformed the way mainstream environmentalists think about the environment and also the way many people of color think about it" (Taylor, 2000, p. 17). This is because environmental justice framing requires us to consider the embodied experiences of frontline communities living the realities of racial discrimination and environmental harms—making interconnected social and environmental inequities visible in a new way.

In the following sections, we unpack an equity framing approach that is rooted in EJ scholarship, which can be adopted by science communicators. We center EJ voices and ideas, and apply them in ways that will be useful for science communicators seeking to build a more inclusive approach. We begin by discussing what is at stake if science communicators do not pursue equity framing. We then highlight specific equity framing strategies that emerge from foundational EJ scholarship. Because we do not assume that science communicators have been previously exposed to equity framing, we illustrate our process of teaching equity framing practices through an introductory college course on environmental justice, where we engaged with our students as current and future science communicators.

THE NEED FOR EQUITY FRAMING: HISTORICAL CONTEXT

To document the need for equity framing, we look to the historical record. The environmental justice literature makes visible the ways that marginalized populations, often made up of people of color or economically marginalized communities, have been treated as inferior and less valuable to society than others. According to Pellow (2016, p. 4), a critical environmental justice (CEJ) intervention shows the ways these communities are marked for erasure and early death, and counters this violence with the contention that "threatened bodies, populations and spaces" must be attended to, and that addressing this problem is in fact "*indispensible* to building" environmentally just futures for all.

Science communication strategies that forward an environmental justice intervention are sorely needed. We see what is at stake, for example, when we examine the impacts of Paul Ehrlich's best-seller *The Population Bomb*. Ehrlich's text makes the scientific argument that population growth was the cause of the "dying planet" and urges immediate action to save human civilization (Ehrlich, 1968). While we do not take issue with the science behind his study—increasing populations do result in more resources used—his framing of the population "problem" as an issue of human numbers, has had significant negative repercussions (Mann, 2018). Based on the problem framing of "numbers" of people and imminent world collapse, Ehrlich's text emphasizes the need for population control measures that included sterilization, a policy approach that has been applied predominantly to non-white populations in the developing world.

Ehrlich's framing has been and continues to be taken up by others, including mainstream environmental organizations like the Sierra Club (Barringer, 2004), to incite a wave of population alarm, with the blame for global ecological disaster often being placed on the reproductive capacities of the world's poor (Gosine, 2010). In the years immediately following Ehrlich's book, people of color were made the target of unethical, state-sponsored population reduction programs and policies that subjected them to experimental procedures and involuntary sterilization programs. This included Native American women across the US and Chicano women in Los Angeles being forcibly sterilized throughout the late 1960s and 70s (Lawrence, 2000; Taylor, 2000). Growing population alarm also contributed to millions of state-sponsored forced sterilizations in India, and large numbers of coerced abortions in China (including selective abortions based on gender) following the adoption of China's "one-child" policy (Mann, 2018).

Environmental journalist David Roberts takes these associations into account when he notes that he never discusses "overpopulation" in his writing. "When political movements or leaders adopt population control as a central concern… let's just say it never goes well. In practice, where you find concern over "population," you very often find racism, xenophobia, or eugenics lurking in the wings. It's almost always, ahem, *particular* populations that need reducing" (Roberts, 2018). Instead, he argues that when reporting on overpopulation, science communicators might focus on framing that centers family planning research, or on education initiatives for girls, which research suggests are two of the most powerful mitigators that encourage a decrease in human populations and reduce carbon emissions. This example illustrates how science communicators can become self-aware and active agents, attending to the impact of their framing on marginalized communities and their well-being in relation to dominant society. This, we suggest, is one element of equity framing.

EJ SCHOLARSHIP: STRATEGIES FOR MORE INCLUSIVE SCIENCE COMMUNICATION

Equity framing that is based on environmental justice practices seeks to make discrimination and disproportionately harmful impacts on communities of color and other marginalized groups more visible, and also lifts up community agency and leadership that is occurring in response to such impacts. Centering community leadership is particularly important for disrupting narratives that consistently portray marginalized communities as the victims, lacking the authority and knowledge to develop their own solutions. When making choices about framing, science communicators can also be informed by the leadership of marginalized communities. This intervention can bring about multiple benefits, which include helping communicators avoid racially targeted applications of scientific findings. In this way, environmental justice helps us to challenge dominant framings of the world, and to disrupt harmful scientific narratives that perpetuate racial discrimination.

In the following section, we introduce practical interventions from foundational environmental justice scholarship that science communicators can adopt for building a more inclusive framework that brings a wider spectrum of society into our efforts to understand and address significant environmental challenges. These EJ strategies ask science communicators to (1) become aware of their own positionality and partial perspectives, (2) name sources of inequity that arise from uneven power relations, and (3) find intersections with initiatives that are rooted in the experiences of disadvantaged communities.

First, environmental justice scholars emphasize *centering the voices of persons of color* in environmental problem solving, along with representatives of other marginalized communities—a goal which aligns with building more inclusive science communication strategies. Environmental justice scholars explain the need for direct representation by people of color and other disadvantaged groups in communications and decision-making through the concept of positionality, which describes how an individual's perspective is shaped by their social position, including class, gender and sexuality, racial identity, and other determinants of social privilege. As an important point of clarification, becoming more aware of one's positionality is not about developing a more pluralistic, multicultural perspective. Rather, it is related to a more difficult task of acknowledging and deconstructing the dominant narratives and personal privileges embodied in our race, class, gender, etc. that shape the ways in which we understand the world.

Discussing positionality in the environmental justice context, Pulido and Peña (1998) consider how people experience environmental problems differently based on their social position. In their analysis of United Farmworkers Organizing Committee (UFWOC) pesticide campaigns from the 1960s in California, for example, Pulido and Peña (1998, p. 38) have documented how farmworker positions differed from mainstream environmentalist groups. Mainstream groups were primarily working for wildlife and consumer protection from pesticide residues—issues that were largely removed from social justice concerns. In contrast, farmworkers were concerned about direct human contact with pesticides sprayed in agricultural fields and the resulting health impacts, including reproductive harms. In taking a more radical framing to pesticide issues than mainstream environmentalists, framing that included making the occupational hazards of pesticide use visible, farmworkers were "informed by their working class and subordinated position within a racialized division of labor" (Pulido and Peña, 1998, p. 38).

Importantly, occupational hazards of pesticide use were not included in policy solutions put forward by mainstream environmental groups. It was only widespread consumer boycotts that made their concerns visible to agricultural producers and the public, which finally enabled United Farmworkers labor organizers to gain a voice in decision-making. Pulido and Peña (1998) environmental justice analysis underscores the role of positionality in environmental communication, as well as policy formation. The EJ perspective makes visible the vital role that the UFWOC and farmworkers themselves played in creating policy change to address key social justice issues related to pesticide use, and the inability of mainstream actors to fully represent farmworkers experiences and concerns. This was a difficult challenge for UFWOC, which can be understood as follows:

> "mainstream and subaltern actors hold different positions within the socioeconomic structure that, in turn, frame their struggles differently.... Mainstream activists are involved in negotiating policy. They may stand in solidarity with the affected community, but for subaltern actors it is their land and their bodies that are at risk" (Pulido and Peña, 1998, p. 34).

Second, environmental justice scholarship demonstrates how shifting away from a dominant worldview requires *seeing and naming sources of inequity* in our society, a task that may not come easily for people in all social positions. Through the work of the UFWOC, the broader public began to see how social justice issues were intertwined with mainstream environmental concerns over pesticide use—a shift that occurred when farmworkers demonstrated the embodied, racialized, and uneven distribution of environmental harms resulting from pesticide exposures in the fields. As Pulido and Peña (1998, p. 38) point out, those in more privileged positions may be "incapable of oppositional politics that would allow them to make the connections between agribusiness, the state, environmental degradation, and highly-exploited workers." This is, in part, due to the positionality of mainstream organizations and their leaders, whose social and economic capital (e.g., funding sources, board members, individual social positions) may be more closely tied to dominant structures enabling farmworker exploitation.

As EJ scholars show, it is precisely such attention to the politics, ethics, and structural inequities surrounding our science that will enable a more inclusive understanding of environmental problems. And by expanding our worldview, we can better evaluate multiple policy interventions that consider social equity issues alongside environmental protections. In the pesticides case, for example, the different lived experiences of mainstream environmental organizations and farmworker union organizers contributed to divergent policy goals that separated these two groups. For mainstream environmentalists, the decisions to ban the pesticide DDT was a major win, given constituent concerns around devastating impacts to birds and wildlife from this long lasting pesticide, as well as health concerns regarding persistent pesticide residues in consumer products. After the DDT ban, however, United Farmworkers continued fighting against specific forms of organophosphates, used as a DDT replacement. These organophosphates were acutely toxic, and therefore, more dangerous for workers who were being exposed to these poisons immediately following pesticide application, primarily through contact with foliage. In summary, EJ practices require us to be critically aware of our positionality: what it allows us to see and what it prevents us from seeing, and how this affects our understanding of environmental policy impacts on marginalized communities.

Third, environmental justice scholars emphasize moving beyond dominant environmental narratives by *locating strategic intersections with social justice movements*, thereby bringing a greater political consciousness to environmental issues. Through her historical analysis of environmental movements, EJ scholar Dorceta Taylor illustrates what it means to use an environmental justice frame to restructure dominant narratives. Taylor (2000) discusses the importance of understanding that EJ movements did not create new discourses or identities from scratch. Instead, the movement adopted highly salient aspects of successful social movements led by communities of color, especially the Civil Rights movement. Early EJ leaders in the 1970s and early 1980s specifically drew from (a) preexisting frames on racism and civil rights, and (b) the identities of labor activists, students, community organizers, academics, and policymakers engaging in current social justice movements.

By engaging with these movements led primarily by communities of color, EJ practices pushed far beyond the typical understanding of the environmental movement and its origin points, which have historically emphasized the perspectives of middle-class white men (e.g., John Muir, Gifford Pinchot) and a romantic view of untouched wilderness. As Taylor (2000, p. 524) explains, the romantic wilderness narrative "does not account for the way in which race, class, gender, labor market experiences, and politics influence environmental activism. It leaves the reader to assume that everyone had similar environmental experiences and responses to environmental occurrences." By using an environmental justice frame, however, Taylor (2000) debunks the dominant narrative and *expands* what it means to be an "environmentalist," thereby including marginalized communities that have experienced various forms of environmental discrimination:

> "environmental justice activists do not draw on Romantic/Transcendental images to motivate their supporters. Instead, they evoke images of racism, appropriation of land, and the destruction of communities and cultures. The environmental justice images have their roots in the social justice struggles emanating from the period of conquest and slavery; more

recently, the images draw on potent symbols of the civil rights movement and the struggles of other people of color in the 1960s and 1970s" (Taylor, 2000, p. 514).

In order to deconstruct the environmental movement's dominant narratives, Taylor's research and writing brings to light "the 19th-century experience of people of color (forced relocations, living on reservations, appropriation of land, slavery, and sharecropping, among other things)" (Taylor, 2000, p. 514). Despite the historic whiteness of the environmental movement and its many silences on issues of racial discrimination, the possibility for "equity framing" becomes possible by exploring the intersections between mainstream society and social justice movements that are actively responding to social inequities. It is through such intersections that both mainstream and EJ groups may open up more inclusive science communication and policy spaces that begin to address the needs of less privileged communities in a meaningful way.

To this point, the EJ interventions above intersect with arguments made by feminist scholars, who argue that community standpoints provide a more critical worldview, which encourages the visibility of communities whose concerns are too often erased (Haraway, 1988; Harding, 2004, 2008; Sangtin Writers Collective Nagar, 2006). By becoming more aware of the standpoints of marginalized communities and their lived experiences, as well as developing a critical awareness of our own positionality (e.g., our own race class and gender), we begin to see where our blinders are and to better understand our own "partial perspective." Thus, we hope to "become more answerable for what we learn how to see" (Haraway, 1988, p. 583). Following Haraway's work on situated knowledge (1998), we refer to this intervention as "situating the science." It is by situating ourselves as science communicators that we may better recognize that all knowledge comes from a speaking *position* that is affected by social location—the privileges or lack thereof, which arise, for example, from our race, class, or gender identification.

While we draw on foundational EJ texts in this section, we also see these interventions being discussed in current environmental justice research. This evolving field includes EJ scholarship exploring emerging social movements, e.g., climate justice, food justice, energy justice, Indigenous sovereignty movements, etc. (Mohai et al., 2009; Agyeman et al., 2016). It involves critical EJ analyses of globalization and supply chains (Pellow, 2007), as well as EJ solutions calling for "just transitions" to a green economy that address the needs of marginalized communities (Agyeman, 2013). And it also encompasses EJ insights regarding unequal access to environmental privileges, e.g., parks, green space, community services, etc. that have been shaped by longstanding racial and economic segregation (Pulido, 2000; Park and Pellow, 2011; Snyder et al., 2014; Corbin, 2018).

TEACHING INCLUSIVE SCIENCE COMMUNICATION: A CASE STUDY

In this section we draw on our experiences teaching the first Introduction to Environmental Justice survey course at Stanford University to illustrate one example of how equity framing rooted in environmental justice practices can be taught and applied to science communicators (**Figure 1**). The main question driving this article—how can we build more inclusive science communication— also provided the grounding for our pedagogy. Our class engaged deeply in questions of inclusivity: How do I write in a way that makes the problems disadvantaged communities face and their solutions more visible? How do I do this in a way that does not render the knowledge and leadership of disadvantaged communities invisible? How do I ground my scientific research in larger social and political contexts that make our knowledge more complete? How has my own positionality affected my research questions, research design, and communication choices? And how do I effectively communicate with my intended audience(s) about equity issues, as an important part of the story?

To demonstrate our approach, we highlight four elements of our pedagogy drawing from EJ practices and equity framing: (1) Situating ourselves as a model for our students;

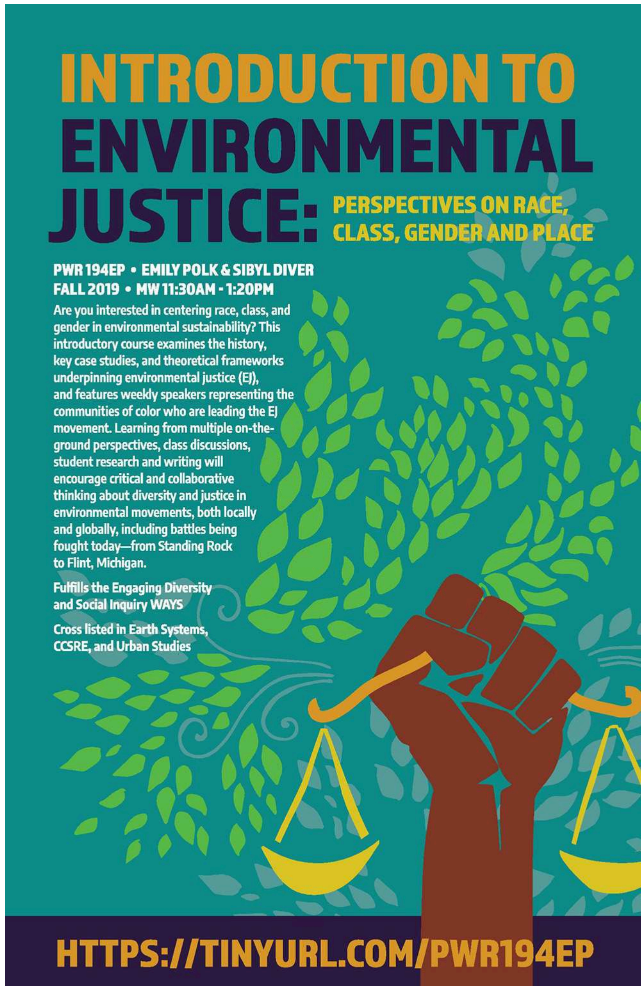

FIGURE 1 | Intro to Environmental Justice course poster, designed by Stephanie Muscat, Sibyl Diver, and Emily Polk. Used with permission.

(2)Intentionally setting an inclusive tone and situating ourselves in EJ conversations; (3) Developing a diverse curriculum that centers committees of color, and other marginalized groups; (4) Emphasizing teaching from frontline EJ communities who use narrative storytelling and other tools for reimagining a more equitable world as a reclamation of community agency; and (5) Asking students to practice equity framing rooted in EJ practices in their own science communication, which we facilitated though an independent student research assignment. These classroom experiences trained our students to see equity issues through an EJ lens, and also to imagine how they could best situate themselves, given their own social positions, in their own communication. We see these two skills as core components of "equity framing."

While we recognize Stanford as an elite institution with greater capacity to support direct community engagement in the classroom, we suggest that our approach can be adopted across a range of higher education institutions. It is important to note that our class community included 20 students from diverse race, class and gender backgrounds, many of whom were from or connected to frontline communities experiencing disproportionate environmental harms. Financial support for this course originated from a variety of cross-campus interdisciplinary collaborations—departments and programs that had long heard the student demand for more courses focused on environmental justice and wanted to be involved. When bringing frontline community leaders to our classroom, we opened up these sessions to the entire campus as an EJ speaker series, in order to afford greater access to their knowledge and experiences, and to build greater legitimacy and support for our work. While meeting community leaders in person was highly impactful, we also supplemented curriculum materials with videos and direct testimonies from frontline communities, as an additional low-cost strategy that can be employed by a wide range of educational institutions.

The foundation of our course was the community we created within our classroom. To model best practices for equity framing, we began by *situating ourselves* as course instructors. Polk is an environmental communication scholar at Stanford who studies the mobilization of community led social movements that arise as a response to climate change. Her interest in environmental justice began as a human rights journalist working for years with marginalized communities in Nepal, on the Thai/Burma border, and in a Liberian refugee camp in Ghana. She currently lives in the East Bay region near San Francisco where her community is directly impacted by a myriad of environmental justice issues. Diver is an environmental social scientist at Stanford. She is originally from a small coastal town in Delaware, with Irish and English heritage. She does community-engaged scholarship on Indigenous water governance in the Pacific Northwest. This includes a long-term research partnership with the Karuk Tribe, which is working to protect and restore cultural resources on aboriginal territory that is currently recognized as National Forest. She began working on these issues as a Russian translator, facilitating international exchanges for Indigenous community leaders on land rights and Indigenous resource management. Together the two instructors have more than 40 years of combined experience working with community-based organizations working on environmental and human rights issues.

To *set an inclusive tone* that enabled critical, yet mutually supportive discussions, we invited Dr. Roxy Manning, a licensed clinical psychologist and (Nonviolent Communication) NVC Certified Trainer as our first speaker. Dr. Manning spoke to our class about her personal experiences as an Afro-Caribbean immigrant who had recently lost her young son, along with her professional experience leading trainings around the world. Continually returning to the importance of cultivating empathy for ourselves and for others, her workshop gave our class language to communicate the emotional challenges that arise from immersing oneself in environmental justice work, and tools for authentically engaging with our own social positions.

Dr. Manning's training underscored the need for personal reflection on our situated position in society, especially when attempting a more inclusive approach to science communication. As Dr. Roxy explained, "When working in communities, we need to be aware of our own privilege." If not, she added that you are in danger of (1) taking control, and (2) preferentially holding your own perspective as legitimate. As Dr. Manning pointed out, "we don't know what we don't know." Manning described her own reflexive process, recognizing the limitations of her knowledge in communications with others. When entering a new situation, she reminds herself, "I need to get quiet, and I need to get curious." To support Mannings teachings about how we can respectfully discuss complex issues of race, class, and privilege, we combined Dr. Manning's teaching with a critical discussion on situated knowledge.

This approach emphasized entering conversations with humility. Honing our ability to listen to individuals from a different social position than ourselves can have profound implications for learning and communicating. At the same time, Dr. Manning clarified how cultivating humility does not mean abdicating the privileges that may arise from one's social positioning. Rather, she encouraged individuals to become self-aware of their privilege and leverage it appropriately. As Manning told us, "we need allies." In a classroom at Stanford, this line of conversation inevitably directs us to the question, what do we do with our own personal privilege, when entering into social justice spaces? We also encouraged students to appreciate their ability to *know* based on their individual social positions and embodied experiences."

The third element of our pedagogy involved *developing a diverse curriculum* that offered students a foundation in the history of environmental justice, through historical accounts coming directly from the EJ organizers, theorists, and scholars of color. We paid keen attention to centering voices from communities of color and other marginalized groups. By challenging dominant mainstream framing in environmental science that does not include scholarship by persons of color, this approach provided a more complete knowledge of the uneven power relations and discriminatory practices driving environmental justice problems, and an entry point for students from more privileged backgrounds into challenging social justice issues. It also enabled students of color and other marginalized students, some of whom were from the communities we were reading about, to see their own selves reflected back to them—an important consideration for science communicators who seek to build trust with a broader audience.

A fourth component was *emphasizing the teachings of frontline communities*, which we accomplished through interactive workshops with frontline environmental justice leaders. We invited EJ leaders to guest teach on a range of issues, including climate justice, food justice, queer ecologies, Afrofuturism, Indigenous knowledge, toxic waste exposures, among other topics. By having frontline EJ leaders as our teachers we disrupted traditional notions of expert knowledge production in environmental science. Students learned best practices for building more inclusive science communication through listening to these community voices, their unique stories, and their particular strategies, especially community-led resilience in the face environmental disparities. For example, Karuk tribal member and traditional dip net fisherman Ron Reed from the Karuk Tribe explained dam construction on the livelihoods, health, and culture of tribal members. Haleh Zandi of Planting Justice described her work supporting recently incarcerated individuals with work and healing as part of an intentional and diverse urban agriculture community. And Chryl Corbin, a scholar activist working with Oakland City Parks, spoke about how she uses Afrofuturism-inspired tactics to encourage city employees to reimagine themselves as green JEDI (justice, equity, diversity, and inclusion) warriors, working together with African American community members.

It was through the storytelling of EJ leaders that students gained tools for "seeing" EJ problems for the first time, as well as imagining innovative solutions through an EJ lens. For example, following one lecture where we viewed architectural mock-ups of Oakland City "green" development, one student shared her experience realizing that she failed to notice that there were no black people included in the pictures of the professional "revision" of Oakland waterfront areas that were historically the center of black culture. But instead of leaving students with a hopeless problem, speakers encouraged us to draw on art, science, fiction, and other sources of inspiration to reenvision and communicate the possibilities for a more equitable society.

Learning how to communicate in ways that sustain and support these solutions included finding pathways for meaningful allyship between marginalized communities and individuals coming from more privileged social positions. Paloma Hernandez, a Stanford graduate and EJ campaigner working in South LA, where she grew up in the Latinx community, shared some "working guidelines" for EJ allies that emphasized the importance of listening to communities. These including the following:

- "When we see a "disadvantaged community," we too often see only what it doesn't have and not what it does. Community power exists wherever you go, sometimes where you least expect it.
- Don't presume to have the answers. You might have research concluding one thing, which is great. But if a community org believes another thing, you need to really put on your listening ears to understand why. Reality is nuanced. Our lives are complex.
- Sometimes there will be spaces you will want to enter, and you might have the very best intentions, and you will still not be wanted. You might have to just let it go."

As a final teaching strategy, we asked our students to *practice equity framing through developing their own research project* that offered a unique contribution to our environmental justice conversations and environmental communication. This was a carefully scaffolded assignment, which provided students with sense of agency in the writing and research process. It also enabled students to support one another and build community together through ongoing peer review. The research assignment gave students the opportunity to write about any issue that they wanted, with diverse topics ranging from policy analyses of low-income weatherization programs to case studies of food justice organizations to intersections between religion and responses to climate change. Their geographic locations were also diverse, covering fracking in Pennsylvania, water justice in Michigan, housing rights in North Carolina, and public health in Hawaii, to name a few. We note the diversity in topic and geography to suggest the possibilities for communicating environmental research using an equity frame.

To encourage a more inclusive approach to science communication, we required our students to use a range of sources that included community voices, and to consider who counted as an authority on their topic and why. This challenged traditional academic notions of expertise and creating space for our students to mobilize different kinds of authority, particularly the voices of impacted communities. We also asked students to identify their intended audience, and which genre of media would be most effective in reaching that audience. By intentionally analyzing the audience and genre, students needed to find the appropriate language to effectively engage with their intended audience, engage with the sociopolitical context of their research, and consider real world applications for scientific findings. These rhetorical considerations aid in what Lupia (2013) calls "source credibility." Recent research shows it is the communicators who emphasize common interests with their audience and relevant expertise who are most effective at establishing themselves as a credible, or trustworthy source. Building trust is fundamental to inclusive science communication and cannot be developed without an attention to the needs of an audience and the researcher's own positionality.

We also asked students to negotiate their positionality through the research process. Note that a positionality statement was not necessarily part of the final written product, and we do not support navel gazing in research or writing. However, we wanted students to practice situating their own identity (race, gender, class) as part of their thinking, research, and communication practices. We also wanted them to understand how their social position relative to an EJ issue could help them build credibility in their communication. We asked each student to work in small groups and discuss the following questions: What is your own positionality as a researcher? How do your various identities intersect with the questions you have asked? What experiences inspired you to ask the questions you do? How might they influence the way you interpret and select your sources? What affordances are you offered by your positionality? What particular vantage point do you have that is unique from others?

By asking students to consider the ways their own experiences and identities intersect with their research questions, we intentionally prepared them to conduct a more nuanced and contextual analysis, working toward a more just and inclusive communication process. Their learning through this process is illustrated by some of our students' reflections about the class, included here.

> *Science is often depicted as apolitical and empirical, beyond the influence of culture and politics... Scientific knowledge should be situated knowledge. I learned about how science can often take "a view from nowhere" which obscures the positionality of the researcher. This discussions made me think critically about how the narratives presented in some of my biology classes often conveyed knowledge in an ahistorical and apolitical way that hides the connections between the history of biology and the history of colonial and racial injustices.*
> *Week after week the speakers shocked, surprised, challenged, imagined with us. Young black and brown folks came into our little [Wallenberg] spaces and showed us how to rewrite narratives. They came with a range of emotions and tactics from militance and liberation to curiosity and queering (a verb is a doing word). We talked about the evolution of EJ and the intersectionality in movements and stories. Are we fighting or are we empathizing? Both. Both and. Both and also therefore.*
> *Not only have we thought and learned and expanded our frame of what it means to be an environmentalist, learning (in my case) about nuance and struggles that don't directly affect us or have been erased, we have also learned, nay been pushed, to contemplate how to generate, and how our research projects and voices might add to the movement or literature on EJ to further things moving forward.*
> *You've opened my eyes to problems I'd heard about but didn't really comprehend, and histories I'd never knew. You make me think about organizing in a totally new way. Honestly, if I'm aware enough I'll probably spend the rest of my life digesting this class.*

In sharing these highlights, we do not wish to suggest that the learning process was easy. Building the skills for more inclusive science communication through EJ practices required intentionality, an investment in time and energy, and willingness to learn from one another. In this way, our classroom environment was not unlike the process of scientific discovery in itself—an iterative process built on curiosity, collaboration and commiseration; learning from mistakes; listening to each other, and supporting one another in the development of a project that could contribute something larger than our individual selves.

THE TRANSFORMATIVE POTENTIAL OF EQUITY FRAMING

In conclusion, we argue that equity framing can be transformative for science communication because it leads to a greater ability to communicate in a more inclusive manner. Equity framing makes visible the inextricable connections between science and society in ways that serve a broader segment of society, including groups that are disadvantaged by their social position (e.g., race, class, gender, etc.) As a case in point, we can look to the impact of environmental justice on the broader environmental movement,

> "The environmental justice discourse has also transformed the way mainstream environmentalists think about the environment and also the way many people of color think about and relate to the environment. Because of environmental justice, it is no longer considered appropriate for mainstream environmentalists to define and analyze environmental issues without considering the social justice implications of the problem" (Taylor, 2000, p. 523).

Thus, we suggest that incorporating EJ practices and equity framing into science communication does more than support inclusive communication for marginalized communities. Rather, it benefits all people, in the following ways. First, by including the concerns and insights of marginalized communities as part of science communication, we can increase the **social relevance** of scientific findings and **build greater trust** in knowledge production occurring within the academy, specialized laboratories, or other isolated spaces of inquiry. Second, by communicating scientific problems in a way that connects with more diverse and marginalized communities, we invite these communities to participate in scientific knowledge production, and thereby add important experiences and perspectives to a career field that has historically been dominated by white males. This intervention breaks down hierarchies to encourage a **more complete understanding** of the world. Third, by addressing equity concerns in our science communication, and in our science, we may better contribute to building a **healthier society** for all.

This article also leads to a number of important questions about next steps for building more inclusive science communication. How can science communicators play a part in preventing the silences and erasures of the knowledge and experiences of marginalized communities on the frontlines of our most significant environmental crises? EJ teaches us that it is the representatives of disadvantaged communities who need to become science communicators, in order to more effectively speak for themselves and their lived experiences. How can we each support this process as scholars, as scientists, as journalists, and as change makers?

Building on our experiences teaching environmental justice to future science communicators, we suggest that science communicators can learn to speak from an allied position, perhaps by intentionally reflecting on their own positionality and finding authentic points of intersection with the needs and priorities of disadvantaged communities. But in doing so, how do science communicators better involve leadership from disadvantaged communities in their writing and research processes, without introducing additional burdens?

We acknowledge that these are big and timely questions given the magnitude of social and environmental crises facing our communities. We also acknowledge that science communicators—journalists and teachers and scientists—bear a tremendous responsibility with framing scientific knowledge, including environmental science, in ways that are critically attuned to equity. We turn our attention to equity framing as one solution because such a framing addresses the visceral experiences of frontline communities often left out of dominant narratives; and helps us to consider our own positionality in the research and communication process, perhaps enabling a form of science communication that contributes to more impactful collective action. As demonstrated through our classroom teaching, this is a challenging task, which requires creating greater intellectual and emotional space for science communicators to engage with social and environmental justice concerns. Through our application of equity framing techniques, we seek to achieve more inclusive science communication, as well as a more just and sustainable world.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

AUTHOR CONTRIBUTIONS

The ideas in this manuscript emerged during many conversations across several years between EP and SD as they developed Stanford's first comprehensive Introduction to Environmental Justice course.

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frontiers in Communication

OPINION
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CómoSciWri: Resources to Help Science Writers Engage Bicultural and Bilingual Audiences in the United States

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A HISTORY OF OVERLOOKED PERSPECTIVES

As translators of technical knowledge and research discoveries, science writers have opportunities to affect the discourse of human society. Accordingly, science writers in the United States—including journalists and public information officers (PIOs)—have an obligation to communicate science to the nation's increasingly bicultural and bilingual population.

Such considerations and approaches toward science writing are not a novel need in the United States. As in other U.S. media niches, science writers and science communicators in the majority culture have long overlooked Native American and African American perspectives. A majority culture is the one with power and privilege in a society or other groupings, such as professions and institutions. It manifests as a dominant culture that sets the expectations and valuations of what is acceptable as norms. This has implications in science and research, as when a majority culture sets the terms for what is valued without the consideration of other cultural identities (Alegria et al., 2010).

Science writing in the U.S.—from journalistic stories to institutional content—have largely relied on references, examples, and narratives that resonate best with white American audiences. People of color represented just 22.6% of the workforce in U.S. newsrooms in a recent survey [American Society of News Editors (ASNE), 2018]. This bias has consequences (Kueffer and Larson, 2014). When editors and writers overlook the perspectives and narratives of oppressed peoples and minority cultures, they miss reporting on fallacies or prejudices within the scientific endeavor itself. The history of science and the media in the U.S. are littered with examples of "Columbusing" that devalue, erase, or co-opt the perspective of colonized, Indigenous, or formerly enslaved peoples (e.g., discoveries resulting from medical experimentation on African American bodies; failing to credit traditional ecological and agricultural knowledge held by tribes and slaves; overlooking the disproportionate exposure of migrant workers to pesticides; Salinas, 2014; Judkis, 2017). Equally culpable are examples of "Hispandering"—when a writer crosses the fine line from acknowledging to patronizing an ethnic group through the writer's choice of narrative and language (e.g., using a Cultural Deficit Model that devalues or erases the cultural assets and resources of a demographic group while emphasizing its deficiencies and failings, often in stereotype; Salkind, 2008).

CONVENING "COMMUNICATING CIENCIA"

Science writers in the U.S. can right these wrongs by improving their craft and recalibrating their storytelling lens, and acknowledging the historicity and perspectives of science beyond that of the majority culture. In an effort to educate more U.S. science writers on diversity, equity, and inclusion (DEI) considerations for their craft, we convened a pair of workshops in 2016 and 2018 at the annual meeting of the National Association of Science Writers (NASW), a major U.S. professional society of science journalists, PIOs, and other communicators, with more than 2,000 members, of which 88% identify as white [National Association of Science Writers (NASW), 2018].

As we set out to compile best practices for inclusive and culturally-sensitive reporting, we decided to use the U.S. Latinx and Hispanic experience as a focusing lens, given that "Hispanic origin" has been one of the fastest growing census demographics in the U.S. in recent decades, second only to Asian Americans (Flores et al., 2019). In particular, we gleaned lessons from public outreach and informal science education practitioners, who have had to be relatively early adopters of DEI frameworks by nature of their direct contact with cultural and demographic shifts in public audiences.

Here, we summarize the recommendations compiled at our two NASW workshops. Titled "Communicating Ciencia" (Twitter hashtag: #CómoSciWri; Website: http://www.communicatingciencia.org), we presented practical tips woven from journalism, public information, and public outreach, then led participants through interactive exercises (**Figure 1**) to cement their understanding. While they focus on the U.S. Latinx experience, these best practices are broadly transferable to science writing for identities and communities rooted around any U.S. cultural demographic. The strategies suggested here can also be applied by scientists and other professionals who write for a general audience.

ACKNOWLEDGE THE LANGUAGE OF DIVERSITY

Science writers must first grasp the terminology of U.S. Hispanic and Latino identities. In the U.S., *Latino* refers to cultures stemming from colonialism-created Latin America—encompassing both Spanish and Portuguese influences and languages—whereas *Hispanic* refers specifically to cultures stemming from Spanish colonialism. And though collectively influenced by Spanish imperialism, Spanish-speaking cultures are not homogenous, and writers must take care to recognize cultural and historical nuances across communities and identities (e.g., Cubans vs. Puerto Ricans vs. Peruvians). For example, the identity *Chicano/Chicana* (alternatively spelled *Xicano/Xicana*) is a term used by some Mexican-Americans and Latinos, particularly those with Indigenous heritage. More recently, these descriptors have taken on gender-neutral forms, such as *Chicanx* or *Latinx* (Gutiérrez and Almaguer, 2016; Simón, 2018).

Equally important is the proper inclusion of diacritical marks and alphabet letters when writing words and names of Spanish or Portuguese descent—the omission of which may change the meaning of entire words (e.g., *ano* vs. *año* in Spanish). Another example is personal names, which should reflect the writing conventions of that culture (e.g., for Spanish names, including both paternal and maternal surnames in subsequent mentions of a person referenced in a story).

Other such distinctions in language and identity terminology exist for other U.S. cultures, be they Japanese American traditions or Native Hawaiian traditions (Peryer, 2019). It is the responsibility of science writers to acknowledge these spellings and details in their work.

EMBRACE THE AWKWARDNESS

Indeed, communities are not faceless crowds. Like their readers, the communities that science writers cover are not homogenous. The so-called "general public" is filled with diverse, real faces, each with unique intersections of personal identities and cultural understandings. Science writers must take care not to make assumptions about a community or culture. No matter how constrained the medium (e.g., a 30 s radio piece) or how broad the scope (e.g., national attitudes toward gene therapy), science writers should keep cultural nuances in mind when researching potential stories, and when listening and speaking to their sources.

Science writers will likely find themselves in trouble if they simply "parachute" into a community they are unfamiliar with. One way to avoid these pitfalls is to find a "fixer"—someone familiar with a community's members, history, and voices, and who is trusted by members of that community. This might entail identifying a trusted community member or asking for a recommendation for a community liaison from a colleague that has worked with that group in the past. Collaborating with knowledgeable sources allows a writer to fully uncover and grasp how an issue pervades and impacts a community, and these ambassadors may also unlock access to more reticent interviewees.

Accordingly, as outsiders to a community, science writers must simply embrace the awkwardness inherent in these situations. By expressing humility and asking respectful questions, science writers can parlay their lack of knowledge into a genuine curiosity to learn—defusing hesitation among community members and possibly encouraging them to reveal important insights they were previously unwilling to share.

ACTIVATE CONNECTIONS

One way science writers can gain further familiarity with a community is to partner with a museum or informal science center serving the geographic region of interest. Learn from these professionals who have been trained in outreach and education, and who by default are tasked with translating science to a diversity of visitor audiences.

Outreach staff can share their best practices for inclusivity and bridging cultural contexts. They can also act as fixers, given their role in engaging leaders, educators, and parents within a specific

#CómoSciWri Workshop Activity Example — Editing a Story

Read the following passage and analyze for inclusivity and cultural competency, as well as for readership engagement with regards to our regional demographics.

> When Central Valley College environmental researcher Stephen Strange arrived in Stanislaus County, he saw a community in need. Trash littered local streams where immigrant children swam. Illegal trash burns and dumping dotted this rural landscape of predominantly farm laborers from Mexico, Guatemala, and El Salvador. But Strange found a ray of hope when he met Angelica Colon, a Hispanic graduate student who rose above her humble roots and walked into his lab one day.
>
> Colon grew up in Stanislaus County, and became interested in studying plastics pollution after volunteering with a local environmental nonprofit while in high school. In the course of her internship translating health outreach messages for non-English speakers, she realized that plastic waste had infiltrated all aspects of life in her community: microplastics could be found in the makeup she used and in the fish she ate, while chemicals leached from the water bottles and frying pans her family used.

Questions to Consider:

- Are there elements in this copy that are patronizing or condescending?
- Are there elements that make the topic relatable to our readership?
- How might this narrative be improved?
- How might this reporting in general be improved?
- What other instructions would you send back to the reporter who wrote this?

FIGURE 1 | A learning activity conducted during the ScienceWriters2018 workshop "Communicating Ciencia" which asked participants to edit a sample passage for inclusion and cultural sensitivity.

community. And like science writers, outreach professionals have a need to break down industry vocabulary and jargon. Communicating in simple ways is key in any language—science writers and informal science educators or interpreters have much to share with one another in this regard.

However, outreach professionals often take additional steps to activate connections between their audience and a scientific topic. Beyond identifying their visitors' personal, cultural, and geographical contexts, outreach professionals also endeavor to determine their audience's preferred modes of idea sharing (e.g., social media, word of mouth, community convenings) beyond a museum's brick-and-mortar walls. Science writers can certainly emulate this strategy when approaching a community or culture as outsiders, both in finding and engaging prospective interviewees and sources, and in where to disseminate and share their stories once published.

CREATE A COMFORT ZONE FOR LEARNING

Outreach professionals also are adept at creating a "comfort zone" for their visitors to learn and understand a concept. For one, outreach professionals realize that science may be a visitor's third language. Scientific jargon already seems like a foreign language to most native English speakers. If a visitor already has English as their second language, then they may face additional difficulties in unraveling yet another set of specialized vocabulary (Lemke, 1990).

This does not simply mean finding a corollary technical term in Spanish or Portuguese; the preferred solution is to give science a place in the visitor's or reader's world. Even if they are not a science enthusiast or scholar, visitors, and readers are informed citizens who make life decisions (e.g., healthcare, family, home maintenance) daily. By explaining scientific concepts within the framework of everyday activities, outreach professionals and science writers alike can create context that lets the visitor or reader discover the relevance of science to their lives, and say, "Science has a place in my world."

Another way to identify and set this framework is to start with kids. Within any culture, children are focused on learning the fundamental contexts, norms, and pop references of that community. In making the science relatable to children within a target audience, science writers can often reveal trends and angles that also extend to adults.

RESIST INDIVIDUALISM

In fact, youth can drive changes to those very contexts, norms, and pop references. Hispanic and Latinx youth are increasingly pushing beyond singular labels to express their complex identities, reclaiming and remixing elements of their cultural heritage (e.g., Colombian), U.S. context (e.g., East Los Angeles), and individual intersection (e.g., queer) through music, language, social media memes, and other creative expression. These trends of "hybridity" and "transculturation" underscore the importance of avoiding broad assumptions about what is "Hispanic" when writing about a community (Rodríguez-Valls, 2016).

These trends also are incredible opportunities for science writers. Immigrant communities—from descendants of African American slaves to Syrian refugees today—inevitably contribute more new elements to the majority culture than they take from it. Tracking these cultural changes can certainly help science writers be more inclusive in their craft, and may also help them anticipate broader cultural shifts in U.S. cultural contexts.

To identify, interpret, and embrace these shifts, science writers are once again counseled to resist individualism in their practice. We encourage science writers to find bicultural colleagues to collaborate with—learning and writing together, and ultimately sharing bylines. The process will push a writer's potential and broaden their experience, and in turn improve the reach and depth of the published story or project. These collaborations should also extend to graphic communicators with bicultural and bilingual experience. Photos, infographics, and other visuals are helpful when communicating to audiences with a range of language fluency levels, and graphics and images are equally susceptible to cultural insensitivities and biases if assumptions are made.

TAKE A CULTURAL LENS TO SCIENCE

In closing, we encourage writers to take a cultural lens to science as a whole. This means defining culture not just within an ethnic or racial context, but also examining the culture of science as a profession and practice. For example, examining who is doing the science, and how a scientist's cultural experiences might shape their approach, can add value to how a topic or discovery is reported and entice additional readers and audiences. Likewise, recognizing the culture and language of science itself—the limitations and structure of academia, its jargon, scholarly prestige, and its foundation in Anglo-American world-views—can help science writers better realize the assumptions embedded in the traditional Western view of the scientific endeavor, and better avoid assumptions or tropes that encourage prejudices and turn away potential readers (Herbers, 2007).

Demographic trends in the U.S. are bringing Hispanic and Latinx voices at the forefront, with African American and Native American voices still seeking due coverage. Science writers must embrace these ongoing shifts in diversity, and do the work to understand the contexts and nuances that make each culture and subculture unique.

From embracing hybridity and transculturalism to activating community connections and applying a cultural lens to science, the approaches outlined above can help journalists and PIOs better communicate science in the United States. By identifying, acknowledging, and distinguishing language, historical, and social nuances across cultural and ethnic identities, science writers can engage more readers and amplify their reach. Simply put, they will write better stories, represent overlooked voices, and report more holistically on the research enterprise—and better fulfill their duty as society's science translators.

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BL and BO organized the ScienceWriters2016 and ScienceWriters2018 workshops. BL led manuscript effort and wrote initial drafts. BO led editing, formatting, and peer-review response. All other authors contributed equally to this manuscript.

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SUPPLEMENTARY MATERIAL

Session slides and session handouts from the 2016 and 2018 Communicating Ciencia workshops are available as PDFs at http://communicatingciencia.org.

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Science Communication in Multiple Languages Is Critical to Its Effectiveness

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INTRODUCTION

In 1967, English was recognized as the language of international science (Gordin, 2015) and it continues to dominate global scientific activities to this day. Around 80% of all journals indexed in SCOPUS are published in English (van Weijen, 2012). The linguistic domination of English is also observed in scientific journalism worldwide, which heavily depends on English-only sources (Nguyen and Tran, 2019). While the use of a single international language of science facilitates the dissemination of knowledge across national and cultural boundaries, the English language often acts as a gatekeeper to scientific discourse (Tardy, 2004).

The hegemony of English in science promotes and enforces the imposition of one particular cultural point-of-view over others (Alves and Pozzebon, 2013). By ignoring other languages, traditional mass media (e.g., newspapers, magazines), social media, and scientific journals ignore the cultures and perspectives of non-English speaking communities (Gibbs, 1995; Canagarajah, 1996, 2002; Kachru, 1997). A recent Google search (February, 2020) of the term "science" in 11 languages with the largest numbers of native speakers exemplifies the disproportionate dominance of English (**Figure 1**). It is clear that English is overrepresented in these search results, even after normalizing for the total number of native speakers per language (**Figure 1**). One explanation could be that the term "science" may not be as engaging and meaningful as other science-related terms in other languages. An alternative explanation could be that scientific communication in a language correlates with scientific activity in the corresponding countries. Such is the case in the field of bioinformatics, where the nations with the highest impact (h-index) are those that are the most active in academic publishing (Chasapi et al., 2020). Nonetheless, English search results are still ∼8 times more popular even when compared to languages spoken in countries with a strong history of scientific production like Germany and Russia (**Figure 1**).

Facing the biggest existential threats to humanity requires understanding and support of science at a global scale, as exemplified by a multitude of climate-related natural disasters (Garcia Escobar and Rabanales, 2020; Stone, 2020) and the recent COVID-19 outbreak (Zarocostas, 2020). This opinion piece discusses some consequences of the (almost exclusive) use of English in the current global scientific landscape, and provides recommendations to expand both formal and informal science communication beyond the English language.

Consequences of the Use of English as the International Language of Science

While having a "universal language of science" has allowed scientists to communicate ideas freely and gain access to global scientific literature, the primary use of a single language has created barriers for those who are non-native English speakers. For example, writing manuscripts and grants, preparing and presenting oral presentations, and general communication in English is much

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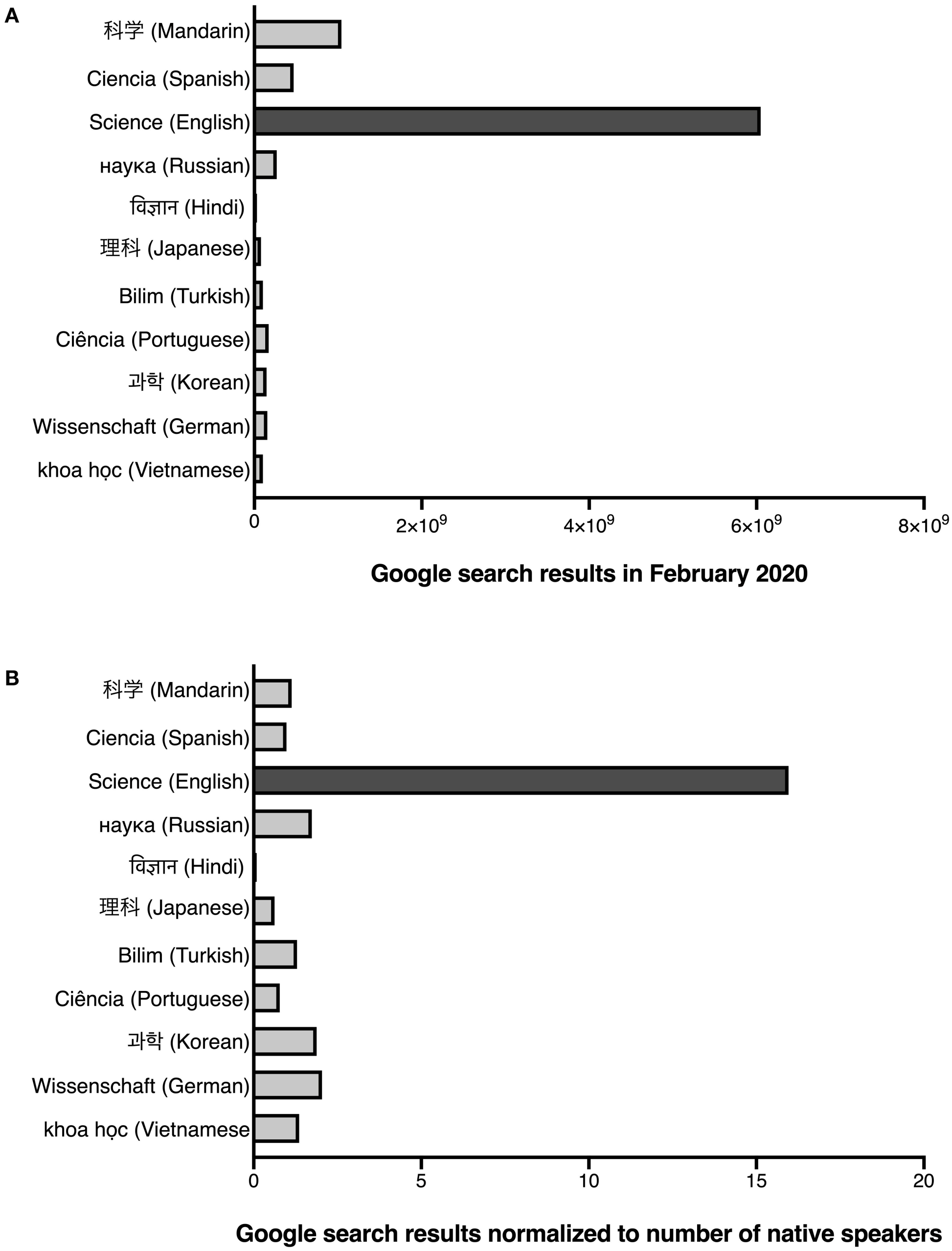

FIGURE 1 | Google search results highlight the hegemony of English in science communication. **(A)** Google search results of the term "science" in multiple languages. Google searches were conducted on February 12, 2020 using 11 of the most widely spoken languages by number of native speakers (Eberhard et al., 2019). Languages are organized from highest to lowest number of native speakers top to bottom. **(B)** Google search results of the term "science" in multiple languages normalized by the total number of native speakers per language.

more challenging for scientists with English as a Foreign Language (EFL) (Ramirez-Castaneda, 2020). EFL speakers report that the quality of English in their manuscripts under review, not the scientific content, is the primary target for criticism, limiting access to a fair chance at publication (Drubin and Kellogg, 2012). This English-only phenomenon creates challenges and gaps in the transfer of knowledge between communities (Amano et al., 2016).

Scientific discourse carried out in the native language of a target audience yields greater participation, motivation and optimism, and leads to stronger connections to concepts in the native culture (Manzini, 2000). Yet, most scientists today feel pressure to publish their papers in influential or globally-recognized English journals that are regarded as yielding more citations (Di Bitetti and Ferreras, 2017) and having a higher impact than any in their mother tongue (Bortolus, 2012).

On the SCImago Journal Rank, which ranks scientific journals on the citations their articles receive, the top 50 journals are published in English. Due to the hegemony of English-language science, the desire to publish in respected English journals has prompted journals that previously published in local languages (e.g., *Animal Biodiversity and Conservation* in Spain, *Natureza & Conservação* in Brazil) to severely decrease or even cease publishing in their local language(s) to increase reach within the global scientific community.

There are ingrained systemic biases within larger institutional bodies (e.g., tenure requirements at universities or publication expectations at granting agencies) pushing scientists to publish work primarily in English (Bortolus, 2012). Similar biases and financial pressures in newsrooms worldwide contribute to the dominance of English in scientific journalism. However, as a consequence, scientific knowledge originating from non-English speaking countries (or pertaining to these regions) is not available in the local language(s). This means that for an individual, or entity, not knowing English limits their access to scientific information (Amano et al., 2016). Learning a new language is not always feasible; many communities do not have access to the educational tools and financial resources needed to learn a new language. In Colombia, high English-proficiency among scientists positively correlates with high-socioeconomic status (Ramirez-Castaneda, 2020). In addition, the time spent learning that language could be used instead for other purposes (e.g., conducting scientific research). Thus, the predominant use of English in science contributes to the widening of social and scientific inequities worldwide.

Recommendations to Increase Multilingualism in Science Communication

We, the authors of this Opinion, have spent the entirety of our professional careers in English-speaking settings away from our birthplaces and family. Frustrated by the lack of resources available in Spanish, our native tongue, each of us embarked on a path to create content in our native tongue and broaden access to scientific information. The recommendations in this piece were crafted based on our personal experiences, the cumulative experiences of like-minded colleagues, and evidence-based best practices backed by concrete examples of and studies in scientific communication. We propose some approaches to (1) expand access to scientific knowledge in languages other than English, (2) train STEM professionals and communicators to engage with local and global audiences through culturally-relevant strategies, and (3) encourage grassroots efforts to democratize science communication and create inclusive communities.

Expand access to scientific knowledge in traditional publishing and mass media

- *For scientific journals: Translate research abstracts and articles to make them available in other languages.*

  The latest scientific findings are often unavailable to a large portion of the scientific community and the general public who are EFL speakers. This is particularly concerning in cases where this information is not accessible to the same communities and individuals that could benefit the most from the research. The onus should fall on scientific journals to begin to offer translations of at least the most widely read publications in their archive. Some journals like Emerging Themes in Epidemiology (Fung, 2008) are currently providing abstracts translated into other languages. To achieve this, publishers could enlist translating services from organizations like the American Translators Association or the International Association of Professional Translators and Interpreters. Other approaches have been described previously by Meneghini and Packer (2007). Additionally, the development of technology (e.g., by Google Translate) specifically designed for high-quality simultaneous translation of scientific writing would allow English-only speakers to share the burden of multilingual communication (Alves and Pozzebon, 2013). These practices, in conjunction with Open Access policies, will begin to even the scientific playing field.

- *For media in English-speaking societies: Highlight scientists working in settings where English is not the native language.*

  The bias to publish in English is not only limited to academic journals but is also prevalent in global mass media (e.g., newspapers, television, radio, blogs). An unintended consequence is the lack of coverage of scientists working in areas where other languages are spoken, primarily in low and middle-income countries. News outlets should consider diversifying the types of scientists that are highlighted to ensure more backgrounds are represented and, wherever possible, providing translations of published stories in the relevant native language. The Forbes online science division, for example, has recently made an effort (primarily led by journalist Andrew Wight), to increase the coverage of science stories across countries in Asia, Africa, and Latin America (Wight, 2020).

- *For media in societies where English is not the native language: Increase local science coverage.*

  Scientists who are not fluent in English struggle to gain recognition for their work, sometimes including in their own countries. Moreover, newspapers and traditional mass media in non-English speaking parts of the world often do not employ science journalists and instead rely on press releases from the Associated Press and other international news sources that do not cover local scientific discoveries (Nguyen and Tran, 2019). As a result, local findings go unreported and support for local science wanes. Greater support for and training in scientific journalism worldwide is needed to advance these local efforts. People trust leaders whose values and worldviews align with their own (Fiske and Dupree, 2014). Thus, enlisting local professionals who can better relate to the intended audiences is crucial. Networks like Agência Bori in Brazil that connect scientists to journalists could help facilitate these types of connections (Estarque, 2020).

- *Create culturally relevant content.*

  Truly inclusive scientific communication requires audience engagement through approaches that recognize the voices and experiences of the target community (Canfield et al., 2020). Simple translations of existing content are insufficient to capture attention and present complex information in an understandable manner. Instead, scientists and content creators in both traditional and social media should employ culturally-relevant expressions, metaphors (Taylor and Dewsbury, 2018), experiences (Djonko-Moore et al., 2018), and storytelling approaches (Dahlstrom, 2014; Hunter-Doniger et al., 2018). For example, a soccer (fútbol) analogy might be more appropriate in many parts of the world than an American football metaphor. News outlets and budding science communicators can look to journalist Sibusiso Biyela's work in South Africa as an example of the successful integration of creative storytelling in native contexts (Kwon, 2019).

Training STEM professionals and communicators

- *Train scientists and communicators to engage with and relate to diverse audiences.*

  Independent of the language of choice, the success of any initiative seeking to communicate science depends on the ability of the scientist/communicator to engage with the audience. This can be achieved through a variety of methods including (but not limited to) storytelling (Green et al., 2018), art as a communication tool (Lesen et al., 2016), and citizen science (Phillips et al., 2019). All of these approaches can and should be adapted to incorporate the local languages, practices, and cultural norms relevant to the target audience; however, STEM students and professionals are rarely trained on these strategies. To fully integrate STEM into strategies for societal progress, it is imperative for academic institutions and national science agencies worldwide to implement multicultural science communication training programs at all career levels. Organizations and initiatives like the Massive Science Consortium, Reclaiming STEM, the Biota Project (Cheng et al., 2018), the "Communicating Ciencia" workshop (Landis et al., 2020), and the Inclusive SciComm symposium (Canfield et al., 2020) are already implementing inclusive training strategies that could be adapted to other languages and cultures.

- *Encourage and support STEM students and professionals to seek opportunities to talk about their work in their native tongue.*

  Numerous STEM professionals leave home to work and train in a location where English is the primary language. Even when pursuing a career in their home countries, systemic pressures encourage these scientists to prioritize English-only opportunities (Tardy, 2004). Therefore, the ability to discuss, present, and write about science in their native tongue(s) can be severely compromised. This is especially true for scientists from indigenous communities, whose worldviews often get erased as a result from scientific discourse (Ammon, 2011). Attending conferences and events to disseminate one's work is highly valued by universities and institutions; however, these international events rarely (if ever) feature languages outside of English. Additionally, local events to present one's research to lay audiences in languages other than English is often not supported by both supervisors and institutions even though multilingual fluency is fundamental for science on a global scale. Trainees and faculty should be encouraged to pursue and participate in events and activities that allow them the opportunity to share their work in their native language(s).

  Some organizations and universities have taken it upon themselves to share fundamental scientific knowledge with communities that have difficulty accessing formal education and scientific information in their own language(s). For example, Clubes de Ciencia is a non-profit organization that offers STEM workshops for high-school and college students throughout Spain and Latin America (Ferreira et al., 2019). Similarly, the Imagine Project at the Federal University of Santa Catarina in Brazil promotes scientific inclusion and cultural exchange by translating scientific videos into indigenous languages (with subtitles) that are shared with remote communities (Ramos and Empinotti, 2017). These types of efforts are crucial to encourage the decolonization of science, expand access to scientific knowledge, and even participate in the active protection of endangered languages.

Encouraging grassroots efforts

- *Take advantage of the ubiquity and accessibility of social media platforms to reach a wider diversity of audiences.*

  Social media platforms have become ubiquitous and powerful tools for the dissemination of information. Over the past 10 years, social media use has grown from 7 to 65% of adults worldwide (Perrin-Cocon et al., 2013). As a consequence, the landscape in which science communication takes place is changing. Researchers are no longer discussing their findings exclusively via publications in scientific journals or high-profile magazine articles. They are also engaging with other scientists and various audiences through social media outlets like Twitter and Instagram. These platforms are available to scientists globally at low or no financial cost and, as a result, STEM professionals and communicators are increasingly interested in using social media for public engagement (Pew Research Center, 2015). If these networks were used in conjunction with strategies to support efforts in languages other than English, they could effectively lower the barriers of access to knowledge worldwide. Science YouTube channels like Ciencia Café Pa Sumercé (Colombia), Hayчпok (Russia), Kainaat (Pakistan), and Manual do Mondo (Brazil) are currently producing engaging and culturally relevant content within their respective countries. Recent research has demonstrated the effectiveness of engaging with audiences on social media platforms, like Instagram, to counteract negative perceptions of scientists (Brown Jarreau et al., 2019).

- *Create communities where scientific communicators in different languages can interact with one another.*

  The practice of science communication is no longer limited to celebrity scientists like Bill Nye the Science Guy or Neil deGrasse Tyson; it is now available to anyone with access to social media outlets. Science communicators are important in keeping science in the public eye. However, this is often seen as an unimportant efforts when compared to publishing articles and attending conferences, and therefore engaging in these efforts can be isolating. Increasingly, researchers are turning to social media to form supportive communities, where content creators/communicators can collaborate.

Social media and other digital platforms could help facilitate collaboration. For example, the "STEM Squad" community on Facebook, centered on the advancement and inclusion of women in STEM careers, has become an important resource by increasing the representation of marginalized scientists in the public lens, financially supporting innovative projects for outreach and inclusion, and creating a space for multilingual conversations. Similarly, the "Joe's Big Idea" Slack community offers a private space for scientific communicators to share resources and opportunities, ask questions, and engage with others interested in communicating in other languages. Unified hashtags (like #WissComm [#SciComm] and #ComunicaCiencia [#CommunicateScience] used by German- and Spanish-speakers, respectively) can help pool engagement efforts in the chosen language. For in-person support, organized events to celebrate science like Science Festivals (Bultitude et al., 2011) can allow researchers to meet face-to-face and share their science with the greater public in their native language(s).

CONCLUSIONS

There is a language bias in the current global scientific landscape that leaves non-English speakers at a disadvantage and prevents them from actively participating in the scientific process both as scientists and citizens. Science's language bias extends beyond words printed in elite English-only journals. It manifests in how science is reported in mass and social media outlets, in the researchers represented in the media, and often in the lack of contact between communities and their local scientists. Exposure to diverse role models has profound effects on aspiring young scientists, as exemplified by the "Scully effect" reported by the Geena Davis Institute on Gender in Media. In this study, 63% of surveyed women in STEM specifically cited Dana Scully's character in *The X-Files* as increasing their belief in the importance of STEM (Geena Davis Institute of Gender in Media, 2018). Beyond representation, access to scientific knowledge is also a matter of equity and fairness.

The National Science Education Standards defines science literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Academy of Sciences, 1996). Previous work has demonstrated that democratic societies that are scientifically literate make equitable choices regarding science-related policy issues (European Commission, 1995; Rudolph and Horibe, 2016). Thus, effective communication of science and science literacy are socioeconomically imperative for all societies. Considering basic science is primarily funded by government funds in many countries (OECD, 2015), access to and understanding of science is also a right for tax-paying citizens around the world.

There are multiple steps—many outlined in this manuscript—journal publishers, media outlets, academic institutions, and government agencies should take to improve how science is communicated around the world. The burden of these efforts should not fall exclusively on the shoulders of EFL speakers. As long as English remains the gatekeeper to scientific discourse, people of other cultural backgrounds will continue to find it increasingly difficult to participate in the scientific process and benefit from its outcomes. We hope this piece sparks new discussions within the ongoing conversation around developing effective strategies for multilingual and inclusive outreach efforts to communicate scientific content formally and informally. The future of the scientific enterprise worldwide depends on it.

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Linking Scholarship and Practice: Narrative and Identity in Science

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In recent years, science communicators have enthusiastically embraced storytelling as a means of dramatizing the process of science and humanizing the scientists who conduct it. Compared to evidence-based argumentation, narratives do tend to be more engaging, more comprehensible, more believable, and more persuasive to non-specialist audiences. However, the gaps between research and practice in this field are considerable, in part because both comprise many distinct areas of expertise. Here, we draw on our experience as a professional storytelling organization and seek to narrow some of these gaps by linking the scholarship to our practice, and to encourage engagement with scholars about future directions in the field. This perspective article intends to synthesize theory and practice to address two major questions: What is the impact of stories on audiences? What is the impact of stories on their tellers? We consider both questions in the knowledge that science and science communication are only beginning to address the historic and ongoing underrepresentation of stories from many racial, ethnic, cultural, religious, gender, and socioeconomic groups. We focus on how stories influence social stereotypes about scientists, as well as identity and belonging within science, and conclude with the link between narrative identity and mental health and well-being.

Keywords: storytelling, narrative, identity, narrative transportation, persuasion, mental health

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INTRODUCTION

Modern science relies on a tradition of formal training and public scholarship that pairs meticulous study with vigorous debate. This rational and self-correcting enterprise has led to audacious and profound achievements—rockets and computers, antibiotics and organ transplants—ideas and innovations that have expanded and enhanced the human experience in marvelous ways. Or so the story goes.

Inside and outside of academia, many people idealize science as an objective, dispassionate, and above all, logical process (e.g., Howe, 2009). Yet any description of science represents a powerful set of rhetorical choices. Who is held up as heroic or groundbreaking? How are historical events described? What events and which people are minimized or altogether ignored, and why?

Decades of work by social scientists, philosophers, and historians of science offer "compelling evidence that science is in fact a richly rhetorical enterprise that reflects the complex, ambiguous, and probabilistic world that scientists and the rest of us actually inhabit" (Charney, 1993). In other words, scientific discourse has explicitly persuasive goals, and we should not mistake a rhetorical strategy of impersonal, dispassionate language as sufficient evidence of an author's objectivity.

The social reality of all human beings is shaped by powerful and intersecting cultural dimensions, such as race, class, gender, ability, religion, nationality, and more. Claims of "rational" or "objective" truth often serve to reinforce existing power structures, or more pointedly, to "smuggle the privileged choice of the privileged to depersonify their claims and then pass them off as the universal authority and the universal good" (Bell, 1995).

Science is never undertaken in a vacuum. The questions scientists ask, which scientists ask those questions, the methods they employ, and their ultimate conclusions take place within a broader cultural, political, and social context. Interrogating the principles and assumptions of science leads us to profound questions about the nature of reality (ontology) and how we acquire knowledge (epistemology). To ignore the ontological and epistemological dimensions of science is to compromise the validity of research designs and muddle the interpretation of results (Moon and Blackman, 2014). To divorce the products of research from the environment in which they are generated is to only tell half the story.

This perspective article is focused on telling a fuller story of science through first-person narratives. We present our own efforts as practitioners, describe the challenges we experience, and discuss the academic research that inspires and supports our work. We hope this contributes to a more "coherent science communication research enterprise" (National Academies of Sciences Engineering Medicine, 2017) by supporting a richer exchange of ideas between theory and practice.

FIRST-PERSON SCIENCE STORYTELLING

The Story Collider is a non-profit organization that produces live shows and a weekly podcast dedicated to true, personal stories about science. Since 2010, we have produced more than 300 of these storytelling shows, and each features five people telling a 10-min story. All stories are recorded, and a subset are published in the weekly Story Collider podcast.

Story Collider storytellers range from pre-eminent senior scientists to comedians who last studied science in high school. They are patients, parents, writers, researchers, and more—a large and diverse group whose only uniting factor is that they want to talk about how science has touched their life. Self-identified demographic data for storytellers has been collected since 2018. Of 569 respondents to date, 42% are people of color, and 67% are women or non-binary. The concept is not to "give them a voice," but rather, to pass the microphone and offer a stage, particularly to perspectives that Western academic science has historically ignored, diminished, erased, and actively silenced (Smith, 2017; Dung et al., 2019). Each storyteller works with two Story Collider producers for 4–6 weeks before the show to refine their story. Stories vary enormously in topic, tone, how narrowly they focus on science, and how widely they range into the full spectrum of human experience. Some are hilarious, others are heartbreaking. Our producers encourage storytellers to examine and, when appropriate, challenge claims about the nature of science, the norms of scientific institutions, the behaviors of scientists, and perhaps most importantly, their own past and possible future selves.

DEFINITIONS AND UTILITY OF STORIES

Storytelling can be unscientific, or worse, anti-scientific. The word itself evokes childhood and fairytales. Its connotations of whimsy, fantasy, and play can feel like the antithesis of "serious science." Yet story comprehension and recall are cognitive developmental milestones (Dosman et al., 2012), and folklore is a field for serious academic inquiry (da Silva and Tehrani, 2016). "Narrative" sounds more serious, particularly when rendered as a "phenomenological hermeneutical method for researching lived experience" (e.g., Lindseth and Norberg, 2004). We use the two terms interchangeably, as reflects popular usage (Fludernik, 2009), and our definition focuses on "series of thematically and temporally linked events" (Green, 2008), or put simply, characters experiencing events and coping with the consequences.

Stories have cognitive, emotional, and, perhaps most importantly, behavioral outcomes. Storytelling is argued to have evolved as an adaptation that promotes cooperation, spreads cooperative norms, and punishes norm-breakers (Coe et al., 2006). In one study of a modern hunter-gatherer society, the Agta people of the Philippines, people showed a strong preference to live with good storytellers over good foragers, which is remarkable in a food-sharing society (Smith et al., 2017). The same study also found that good storytellers have significantly greater reproductive success. These findings help explain, on a biological level, why this behavior evolved in humans. It is the psychological functions of storytelling that dominate our ongoing practices.

Narratives are also sensemaking devices. They are means by which groups of people collectively reduce their uncertainty, resolve ambiguity, attribute consequences, and assign blame, among other things. The term "sensemaking" comes from organization science and has been described as a largely invisible social process focused on "the ongoing retrospective development" of plausible rationalizations of what people are doing (Weick et al., 2005). This is a slightly convoluted definition, but it is useful because it focuses on (1) the fact that sensemaking is a perpetual undertaking, (2) that action nearly always precedes cognition, and (3) that talk is a uniquely powerful kind of action. As Weick et al. (2005) note, "Situations, organizations, and environments are talked into existence." Modern science is no exception.

THE EVIDENCE BASE FOR NARRATIVE APPROACHES

In the past 30 years or so, narrative has gained an increasingly high profile in science communication discourse (Norris et al., 2005; Avraamidou and Osborne, 2009; Dahlstrom, 2014), as well as within social research more broadly. Qualitative methods, such as narrative analysis, are particularly well-suited to disciplines that must take complex social and political realities into account to achieve their aims. Consider public health, for example. While quantitative methods can determine *how many* people comply with medical advice, qualitative methods can ask *how* and *why* compliance does or does not happen (Sutton and Austin, 2015). It is clear that effective, efficient interventions require both kinds of knowledge.

Yet to those focused on the natural sciences, narrative approaches still feel frustratingly understudied and perhaps oversold. The "establishment often points to what they consider to be a lack of rigorous evidence that narrative could be a superior conduit [for science messages]" (Murphy et al., 2013). There is, however, a growing body of empirical research directly comparing narrative vs. non-narrative communication—particularly within public health (e.g., Shen et al., 2015) and consumer engagement (e.g., van Laer et al., 2014).

Compared to evidence-based argumentation, narratives often are more engaging, more understandable, and more persuasive to audiences (Dahlstrom and Ho, 2012). Such outcomes align particularly well with the goals of science communicators (Besley et al., 2016, 2018), such as getting people interested or excited about science, ensuring that people are informed, and demonstrating the expertise of the research community. Stories are understood to achieve these ends by (1) reducing resistance or facilitating processing of new and/or difficult information, (2) encouraging cognitive and emotional states that strengthen attitudes, and (3) providing social models for behavior change (Murphy et al., 2013). All of these cognitive and emotional shifts happen during what audiences generally experience as an entertaining experience, if they think about it at all. When people sit down to read a text, or listen to a podcast, they do not ask, "Is this a narrative?" Instead, they focus on what's happening in the story world. What do the events mean for the protagonist? Why did a character make a particular choice, and how does the outcome compare to her intent? (Ryan, 2007).

This focus on characters is essential, particularly when those characters represent a diversity of personalities, perspectives, and experiences. As individuals, we may or may not personally identify with any given character, but collectively, characters represent social norms, which in turn influence identity and feelings of belonging (Greenwald et al., 2002). In educational settings, representation is positively linked with student achievement outcomes (Grissom et al., 2015). "Scientist Spotlight" coursework that incorporates Story Collider episodes has been shown to reduce stereotypical views of scientists and correlates with higher course grades, and increased interest in science generally, as well as in STEM majors specifically (Schinske et al., 2016).

Characters play an essential role in creating empathy and in making stories resonate with listeners' lived experiences (Dessart and Pitardi, 2019). It is that resemblance, the verisimilitude of the story, that matters. It matters so much that even fictional stories can have real-life consequences. One study found that reading fiction "significantly increased empathy toward others, especially people the readers initially perceived as "outsiders" (e.g., foreigners, people of a different race, skin color, or religion)" (Johnson et al., 2014). More broadly, reading literary fiction has been linked to improvements in both empathy and theory of mind, in both long-term associations and short-term experiments (Oatley, 2016).

TRANSPORTATION, NARRATIVE PERSUASION, AND INTERPRETATION

In both fiction and non-fiction, the feeling of being swept into a story is called narrative transportation. Unlike cognitive elaboration, which depends on propositional reasoning and critical thinking, transportation is "an integrative melding of attention, imagery, and emotion" (Green and Brock, 2000). Such transportation depends on numerous factors, including the skillfulness of the storycraft, the environment in which a story is consumed, and individual factors, such as prior knowledge or need for affect (Mazzocco et al., 2010). The Story Collider explicitly strives for narrative transportation in our live events and podcast episodes, because people who are highly transported exhibit greater attitude and belief change in response to stories than those who aren't (Green, 2004). The Story Collider is particularly interested in the power of personal stories to shift stereotypes about the identity and values of scientists. Our stories challenge old assumptions about who can do science, who can speak for science, and to whom science belongs.

The power of stories to shape beliefs can itself be a cause for concern. We know that stories can amplify ignorance and lead to the outright rejection of scientific data, as with anti-vaccine propaganda. While evidence-based argumentation "uses abstractions to infer about particular examples, narrative uses particular examples to infer abstractions" (Dahlstrom and Ho, 2012). Accordingly, The Story Collider considers the intent of the storyteller, the accuracy of the story content, and whether the story is broadly generalizable.

We have also borrowed and applied the concept of an "interpretive community." We know a narrative will never have a single, objectively true meaning that is understood by all audiences at all times, but "a community of readers who share a set of interpretive strategies, and who look at a text from the same frame of reference and with an agreed upon procedure for determining its meaning, can unite in a shared understanding of it" (Ceccarelli, 2010). As humanity faces climate change, pandemics, food insecurity, and so many other existential threats, instead of asking, "Why don't people trust science?" "How do we get them to believe facts instead of stories?" or even, "How can we tell better stories about science?" The Story Collider asks, "What happens when we reconceptualize audiences as essential members of our interpretive communities?" For example, our work with patient-led research organizations, such as the Rare As One network, positions patients and parents as equals and collaborators to clinicians and researchers. Our choices of storytellers flatten traditional hierarchies and challenge expectations of who has earned the right to speak and who needs to listen. This strategy aligns with dialogue-based science communication, principles of knowledge co-creation, and restorative justice approaches.

NARRATIVE IDENTITY AND MENTAL HEALTH

Although most discussions of storytelling in science communication focus solely on audience effects, some of the most interesting impacts of narrative are not on listeners, but on the tellers themselves.

"Stories can be a way for humans to feel that we have control over the world. They allow people to see patterns where there is chaos, meaning where there is randomness. Humans are inclined to see narratives where there are none because it can afford meaning to our lives—a form of existential problem-solving" (Delistraty, 2014). And perhaps the most existential of all questions are "Who am I? And who are you?" This is the question of identity.

Culture, language, and experience interact with introspection and conversation with others to weave a social being around a private self (Archer, 2000). This "reflexive self" is under constant revision. Students studying outside their home country, for example, experience moving from having a unified and stable identity to one that is "becoming fragmented, composed not of a single, but of several, sometimes contradictory or unresolved, identities" (Bond, 2019). A similar dynamic is created for anyone sacrificing parts of their identity to fit their own or other people's images of a successful scientist. Whether pressures are internal or external, implicit or explicit, fitting into science as a profession can lead individuals to minimize their culture, hide religious beliefs, remain in the closet, and/or change the way they dress, speak, or otherwise present themselves to the world. The result is chronic, low-level stress (Ryan et al., 2005), which may arise due to role conflicts, the strain of inauthenticity, and the cumulative burden of code-switching (modifying language or behaviors to suit different cultural norms, Cross et al., 2017). The toll is even greater for people possessing multiple intersecting marginalized identities (Crenshaw, 1989).

Self-identity and self-narratives are intimately involved in mental health. One study found that 40% of the science graduate students in their survey reported experiencing moderate to severe depression and/or anxiety (Evans et al., 2018). Similar data for faculty, senior researchers, and science industry professionals is unavailable, but careers marked by continual progress through "liminal and troublesome spaces" (Bond, 2019) pose ongoing challenges. In addition, people from marginalized groups disproportionately experience hostile work environments, institutional discrimination, financial concerns, and the weight of familial and societal expectations (Dyer et al., 2019; Santos-Díaz, 2019).

Mental health stigma, particularly negative beliefs about one's own symptoms and professional assistance, is a key barrier to seeking help. Authentic, personal stories can variously function as a means of reducing stigma, as a process for coping and/or healing, and as paradigms for recovery (Llewellyn-Beardsley et al., 2019; Nickerson et al., 2019). We borrowed from music therapy to speculate that live performance of such stories in front of an audience can raise awareness of social issues, transform perceptions, and may increase support and validation storytellers receive from their communities (Vaudreuil et al., 2019). Our evaluation program provides early support for these ideas. When asked "What is your most meaningful takeaway or experience from this workshop?" after participating in grant-funded 2-day intensive workshops, 30% of respondents cited the "value of the supportive community in the workshop." 25% mentioned realizing that everyone has a story to tell, and 18% mentioned introspection & self-reflection ($n = 59$, Sickler and Lentzner, 2020).

CONCLUSIONS

Some kinds of knowledge can only be generated from objective empirical observation. An electron has a mass of 9.109 ×10–31 kg, regardless of who observes it. There is, however, a slippery slope from specific observations to unexamined assumptions about science and scientists.

Science is often mythologized as a pure meritocracy dedicated to logic and the elimination of bias. Such claims ignore history, the output of disciplines from psychology to sociology, and the lived experiences of countless people. Science is penicillin and pasteurization, but it is also Mengele and Tuskegee. And despite increasing attention to issues of diversity, equity, and inclusion, science still largely reflects and promotes the interests of a privileged minority of people (Adams et al., 2015; McCoy and Rodricks, 2015; Gill, 2018). This will require substantial and ongoing investment to undo, and a key part of this work involves confronting the disconnect between idealized science and all the tacit understandings, customs, and taken-for-granted aspects of science as it currently exists. First-person narratives of science are uniquely suited to describing and disrupting this so-called "hidden curriculum" (Hafferty, 1998; Michalec and Hafferty, 2013).

The Story Collider produces hundreds of stories about science each year. Our tellers frequently challenge preconceived notions about how science works and who scientists are. Ten years of our experience, as well as a wide-ranging set of research findings and academic theories, support the idea that these stories are uniquely suited to help our audiences engage with the kind of dissonant, disorienting, or troublesome information that is the necessary first step in transformational learning (Timmermans, 2010).

Stories can be used to comfort or confront, to clarify or complicate. They help audiences gain new perspectives and explore new knowledge. They help tellers gain greater insight into their own experiences and motivations, and to find purpose in their lives. Finally, storytelling is a key part of any collective change. If individuals and institutions wish to bring a more representative, equitable, and just version of science into existence, they must attend to which stories are told, which stories are suppressed, and whose stories are centered.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Concept and data collection: LN and EB. Research: LN, SB, RM, KW, and MZ. Draft content: LN, SB, RM, KW, and MZ. Writing: LN. Editing: LN, MZ, SB, RM, and KW. All authors contributed to manuscript revision, read and approved the submitted version.

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Science for All? Practical Recommendations on Reaching Underserved Audiences

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In a world decisively influenced by scientific developments science communication grows ever more important to enable informed decision making and participation of citizens in society and political discourse. However, science communication, being it public talks, or participatory projects, often reaches only certain parts of society. While this problem is increasingly recognized, only some empirical results and practical recommendations on success-factors for promoting diversity and inclusiveness in science communication exist so far. If at all, many projects and reports focus on very specific areas with only a few aggregated and overarching best practices and guidelines. This article contributes to filling this gap and presents a set of practical recommendations on reaching and engaging underserved audiences of science communication activities. The proposed guidelines have been developed from the experiences and empirical evidence from the research and practice project "Science for All" in Germany, and are based on a review of existing guidelines and recommendations. They are corroborated by interviews with practitioners, scientists, and underrepresented groups. The seven recommendations include listening to underserved audiences, reducing the distance, illustrating the relevance of science for daily life, going where the people are, cooperating with stakeholders, and multipliers, as well as the problem of too much openness, and one-time activities. The guidelines are primarily addressed at practitioners in the field of science communication and meant to encourage and support a first step toward more diverse and inclusive science communication. However, they are limited wherever the roots of exclusion lay at the societal and political level and are open for discussion. While inclusive science communication alone cannot fix discrimination and inequality in society, a continuous self-reflection and improvement of the communication of science organizations, including the improvement of inclusion and diversity within the organization themselves, is an important contribution to a more equitable society.

Keywords: science communication, inclusion, exclusion, diversity, guidelines, discrimination, underrepresented audiences, marginalized groups

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INTRODUCTION

The formats of science communication and public engagement have diversified in recent years, now comprising science festivals, pub science events, citizen science, citizen dialogues, and various art, and science projects (Niemann et al., 2017). The audiences, however, are still much less diverse, with various groups in society feeling "disengaged" (Schäfer et al., 2018) and that science is "not for me" (Office of Science Technology Wellcome Trust, 2001).

Besides some in-depth studies on social inclusiveness in science communication [for example in the UK (Dawson, 2019) there are also a number of research and practice projects often focusing on specific excluded groups (e.g. ethnic minorities or persons with disabilities) or specific topics] [for example climate change, as addressed in the Six American's Project of the Yale Program on Climate Change Communication (Leiserowitz et al., 2009) or health communication (Kreps, 2005)]. While the focus of many of these projects and the corresponding specific societal and political conditions (such as party political polarization of an issue or a value-based conflict) pose a specific set of challenges as well as leverage points for science communication, few details are known in the wider science communication practitioners community about who overall does not participate in science communication, why that is the case and what could be done about it. At the same time, the issue is increasingly being noticed as "one of the most pressing problem[s] in science communication" (Scheufele, 2018, p. 3) by society and politics as well as the science communication community itself.

What is known, is that science communication only reaches certain parts of society. This holds for mediated forms of communication like traditional science-journalism, being it print, online, or through radio, or television (Schäfer et al., 2018). But also non-mediated forms, like public lectures, open days at universities, and even more creative, and entertainment-oriented activities mostly attract an audience that has a high formal education, is already knowledgeable, very interested in science, predominantly white, and is affluent (Borgmann, 2005; Gruber et al., 2010; Bultitude, 2014; Kennedy et al., 2017).

Since different mechanisms come into play for mediated and non-mediated science communication (for example media usage patterns or the details of face-to-face interaction between communicator and audience, a separate analysis for both areas is necessary, although there are likely some intersections). Thus, the following article and the presented guidelines focus only on one of the areas—namely non-mediated forms of science-communication to an external public—while leaving the specific consideration of science journalism for another study. Besides this focus, this article builds on a broad definition of science communication as "all forms of communication focused on scientific knowledge and scientific work, (…), including its production, contents, usage and impact." (Schäfer et al., 2015, p. 13). With this broad understanding, there is a large overlap to the consideration of diversity and inclusion in related academic fields such as the study of STEM education (Tsui, 2007; Allen-Ramdial and Campbell, 2014), public participation (de Freitas and Martin, 2015), or citizen science (Pandya, 2012). However, the focus here is on external science communication, primarily through science organizations.

Audiences of science communication activities can be excluded by a broad variety of factors—each coming into play in different aspects of communication processes and different intensities. Besides specific material exclusion factors, emotional effects play an important role (Humm et al., 2020). The identified factors can be grouped into three categories, as proposed in a typology developed within the project "Science for All" (Schrögel et al., 2018): First, individual factors (e.g., age, fears, educational background, income, literacy, and spelling skills); second, social factors (e.g., disabilities, ethnic background, gender, regional affiliation); and third, structural conditions (e.g., complexity, location, availability of supporting services at events).

In a world significantly shaped by scientific developments (Dawson, 2019, p. 2), this exclusion of various parts of society is problematic for individual lifestyle-decisions (The Royal Society, 1985, p. 10) with respect to health and risk-taking, for personal science career choices (Blanton and Ikizer, 2019, p. 155), for democratic decision-making and participation in public debates (Thomas and Durant, 1987, p. 5) as well as for informed public support for science (Thomas and Durant, 1987, p. 3) as a publicly funded undertaking.

Yet, the question remains: what can be done by scientists and organizations to reach those underserved audiences in the first place, learn about their interests and perspectives, provide relevant information, engage in a dialogue and, thus, form a communication relationship? While the concrete solutions are as diverse as the range of exclusion factors, some common principles for more inclusive science communication can be identified.

ASSESSMENT OF EXISTING GUIDELINES AND RECOMMENDATIONS

We took a holistic perspective and developed a set of practical guidelines as basic recommendations for enabling a more inclusive science communication. They illustrate what can work in reaching out to typically underserved audiences, although proposed measures and approaches alone, of course, do not guarantee immediate success.

The guidelines presented in the following article are built on a review of existing guidelines and recommendations and further corroborated by additional qualitative data from the research and practice project "Science for All"[1] in Germany.

The overall foundation is three-fold: first, a review of existing guidelines for science communication with underserved audiences; second, interviews with science communication practitioners and researchers; third, the analysis of focus groups and interviews with three exemplary underserved groups as part of the project "Science for All" (Schrögel et al., 2019).

Review of Guidelines and Recommendations

The review focuses on reports containing specific practical recommendations on reaching underserved or marginalized populations with science communication. General (policy) statements on the issue without further elaboration, as well as

[1]The project "Science for All" ["Wissenschaft für alle"] develops and evaluates science communication formats with underserved audiences. To that end, a typology of exclusion factors has been developed based on a literature review and new formats for science communication are developed and tested in a participatory process with three underserved audiences: Muslim youths with a migration background, socially disadvantaged people in marginalized neighborhoods and students in vocational school. The project "Science for All" is conducted jointly by the Karlsruhe Institute of Technology (KIT) and "Wissenschaft im Dialog" (Science in Dialogue) and funded by the Robert Bosch Stiftung.

primarily theoretical works, are not considered. In order to keep the review focused, guidelines beyond the realm of external science communication (i.e., science communication with a lay public, primarily through science organizations), such as science education for school children or communication in the cultural sector, were not considered in detail, too. These areas might be similar to external science communication and likely also have to address the same problems of exclusion, but there are nevertheless differences in the details and contexts posing inevitably the question of transferability.

Although the topic itself implies a large heterogeneity, an additional focus lies on an overarching perspective. Research with narrow applicability or individual case-studies for selected marginalized groups or single formats (for example science festivals or science slams, are not considered). The same applies to general science communication guidelines, which do not explicitly address reaching underserved or marginalized audiences.

In total, five publications meeting these criteria have been selected as most relevant and are examined further in the following. It is worth noting that two of the reports originate in Austria and two in the United Kingdom. No comparable publications could be found for other European countries, although there might be similar activities, probably not being as easily accessible.

Analyzed Reports and Studies

In 2010, the Science Center Network delivered a report to the Austrian Council for Research and Technology Development on "Basic characteristics and principles for the dialogue between science and society." "The focus thereby lies on so-called low-threshold dialogue formats, which are characterized by '(...) the degree of inclusion, openness for different target groups and age groups as well as through the property (...) that access to the topic is possible independent of the state of previous knowledge but at the same time all target groups are being challenged.'" (Gruber et al., 2010, p. 2). In the report, "low-threshold" is characterized as participation in an activity with as little effort and as few barriers as possible for participants (Gruber et al., 2010, p. 8). In the conclusion, various principles for a successful dialogue between science and society are presented. The recommendations on "deliberately overcoming social barriers" are (Gruber et al., 2010, p. 58):

- Offering (carefully selected) scientific input
  The input has to be accessible from the level of knowledge of the participants and gives them the tools to bring forward their arguments.
- Creating links
  This is done by creating connections between the topic and its relevance for the participants (for example through references to their everyday life).
- Addressing different types of learners
  Based on learning theories different types of learners shall be addressed by using a variety of methods.
- Using an informal setting in small groups
  In order to create a better atmosphere for discussions and mitigate participants' fears, small groups should be used.
- Using interactive gamification approaches
  When using interactive gamification then information and input should not be forgotten.
- Visiting "everyday spaces"
  Certain locations might invoke barriers; thus, one should use spaces familiar to the participants, (for example cafés or libraries).
- Audience led projects
  Organizers and institutions should commit to cooperation. This means amongst other things that recommendations of the addressed groups should be considered or the own team is diverse.

Especially the idea of visiting "everyday spaces" has been followed up on through the Science Center Network Vienna with the practical project "knowledge°rooms—science communication in local, welcoming spaces to foster social inclusion" (Streicher et al., 2014).

In the 2012 report for the Wellcome Trust "Review of Informal Science Learning" in the United Kingdom, the authors suggest five recommendations for engaging "challenging audience groups" (Lloyd et al., 2012, p. 5) based on a review of activities in the informal science learning sector:

- "making experiences and content relevant to audiences' interests, experiences, and backgrounds, increasing the likelihood of both initial and subsequent engagement and the development of ongoing relationships
- conducting preliminary research with difficult-to-reach audiences, to ensure the accurate tailoring of services and to identify and negotiate social and cultural barriers
- establishing partnerships with other organizations or groups already engaging with the target audience, to help understand audience needs and actual and potential barriers, and to act as trusted conduits between the provider and the audience
- using community outreach methods to engage with target audiences—which, although resource intensive, can lead to embedding an organization within its community
- ensuring experiences are stimulating, interactive and engaging for participants (particularly for young audiences), to stimulate initial engagement more broadly."

Furthermore, they concluded that "practice suggested that sustained engagement requires a strategic approach, working with challenging audiences through a range of activities over a sustained period of time" (Lloyd et al., 2012, p. 5).

As a follow-up, in 2014 the Wellcome Trust commissioned further research on reaching young people from lower socioeconomic groups, consisting of a literature review (Atkinson and Mason, 2014) and new research on the activities and interests of this population (Atkinson et al., 2014b). The results of this research are drawn together in a practical summary report. Key components are "10 steps to successful engagement" (Atkinson et al., 2014a, p. 5,6):

- "Know your objectives and audience:" Both what should be achieved and who is to be reached needs to be known beforehand to adapt the engagement strategies.

- "Engage a champion and be mindful of family influence:" Persons trusted by the audience can be effective multipliers where traditional authorities, like teachers, might be distrusted. Such multipliers could be coaches or youth workers. Additionally, the influences of the participants' social surroundings need to be considered.
- "Ensure the activity is young person-led:" Young persons and people who are in touch with them—e.g., teachers or peers—should be consulted from the very beginning and be involved in decision making.
- "Ensure the activity is relevant and pitched at the right level:" The activities should be linked to the interests of the intended audience and take their level of knowledge and skills into consideration.
- "Invest in long-term relationships for maximum impact:" Consistent engagement, which takes place on a regular basis, is key to build long-term relationships with young audiences and thus increase impact. Furthermore, the collaboration between institutions working with young people needs to be expanded.
- "Make it practical and interactive:" Hands-on experiences might resonate better with young people than non-interactive activities.
- "Facilitate socializing with friends:" Locations should allow young people to be with their friends.
- "Be financially and geographically accessible:" Trip costs, especially for young people from lower socio-economic backgrounds, can be hard to afford. Thus, locations should be easily accessible for the audience and provide a safe environment.
- "Celebrate and reward successes:" Activities should be (intrinsically) rewarding for the participants to increase their motivation and self-esteem.
- "Communicate carefully and through trusted channels:" The framing of activities, as well as the used communication channels, can influence what the intended audience thinks of them and the willingness to take part.

With the focus of the report, some aspects of the recommendations are youth-specific, at least to the degree of the influence (e.g., family influence), but most equally apply to other underserved or disengaged audiences.

Also, focusing on marginalized children and youth, Marschalek and Schrammel (2017) compiled another report titled "Social inclusion through and within science communication" for the Austrian Council for Research and Technology Development. Therein, they propose 10 guiding principles based on a literature review and qualitative data from workshops and interviews (Marschalek and Schrammel, 2017, p. 22–36):

- Location: Accessible locations should be close to people and have a welcoming design.
- Diversity: To reach a diverse audience it has to be actively invited (for example by respecting their interests and possibilities).
- Evaluation and self-reflection: Constantly evaluating and self-reflecting the inclusiveness within activities is needed.
- Translation and Imparting: Mediators and trusted relationships with the audience as well as a dialogue on par can lead to more inclusion.
- Relevance for daily life: Topics should be chosen according to the audiences' interests, experiences, and knowledge.
- Meaningful moments: Long-lasting activities with enjoyable experiences can create interest and motivation for further engagement.
- Informal learning spaces for science: These spaces should be in the accustomed environment of the audience and respect their mobility and different learning approaches.
- Empowerment: Empowerment might be more important than knowledge transfer.
- Cooperation and Sustainability: Cooperate with institutions already in contact with the intended audience can enhance the quality and sustainability of activities. Such institutions could be libraries, culture clubs, or schools.
- Society and Politics: In order to counter marginalization and exclusion from science communication, it is important to address structural problems and raise awareness of them.

The conclusion of the report includes a series of heterogeneous recommendations, which contain some of the aspects elaborated on before in the report. One repeating aspect is the resemblance to principles of classical community work, similar to the aspects described for the aforementioned concept of the "knowledge°rooms" also in Austria.

The last included publication is the dissertation of Vásquez-Guevara (2019), which has its focus on the United States and Ecuador. The author gives several recommendations for science communication "in culturally diverse scenarios in the Americas" (Vásquez-Guevara, 2019, p. 215–220):

- "Building trust and creating safe spaces and experiences for audience engagement"
  Science communication initiatives "first need to build trust with their audiences" (Vásquez-Guevara, 2019, p. 216). This should be done by involving scientists, who listen and collaborate with the audience, by creating safe spaces "that are comfortable and accessible" (Vásquez-Guevara, 2019, p. 217). Events should combine dialogue and participation with technological tools and platforms, like social media.
- "Designing the scientific content framing"
  Science communication should frame their messages in a way that resonates with the audiences' habits and lifestyle (for example by offering solutions to real-life problems or in terms of the used language).
- "Opinion leaders for science communication"
  Trusted and influential persons within the community such as NGOs, religious leaders or politicians, could connect with the audiences and their circumstances in order to boost engagement with science communication programs.

Comparison and Categorization

Overall, the five publications show many similarities in the provided recommendations, with differences primarily in the framing and structuring of the guidelines (see **Table 1**):

TABLE 1 | Comparison of the recommendations put forward in this paper and those identified in the review.

Recommendation:	Gruber et al. (2010)	Lloyd et al. (2012)	Atkinson et al. (2014a)	Marschalek and Schrammel (2017)	Vásquez-Guevara (2019)
1) Start with listening		Conducting preliminary research	Know your objectives and audience	Diversity (actively invited)	
				Evaluation and self-reflection	
2) Reduce the distance and be accessible	*Addressing different types of learners	Ensuring experiences are stimulating, interactive and engaging	**Ensure the activity is relevant and pitched at the right level		Designing the scientific content framing
3) Be relevant for everyday life		Making experiences and content relevant to audiences	Make it practical and interactive	Relevance for daily life	
4) Go where people are	Visiting "everyday spaces"	Using community outreach methods	Facilitate socializing with friends	Informal learning spaces for science	Building trust and creating safe spaces
			Be financially and geographically accessible	Accessible locations, close to people	
5) Cooperation is key	Creating links	Establishing partnerships with other organizations or groups	Communicate through trusted channels	Cooperation and Sustainability	Opinion leaders for science communication
	Audience led projects		Engage a champion and be mindful of family influence	Translation and Imparting: Mediators and trusted relationships	
6) Mind the "openness paradox"	Offering scientific input		**		
	*				
7) Implement long-term activities			Invest in long-term relationships	Meaningful moments, Long-lasting activities	
Not matched	(Informal setting in small groups)		(Reward successes)	Empowerment	
	(Interactive gamification approaches)		(Activity young person-led)	Society and Politics: address structural problems	

The mapping includes some overlap, since many recommendations include more than one aspect. In the most relevant cases, this is marked with stars in the table. Recommendations in parentheses at the end of the table are addressing only one specific detail and are not matched to the overarching recommendations.

- Two areas are addressed in all five recommendations: first, the importance of actively approaching underserved communities also in a geographical sense to lower barriers by choosing event locations within the communities, that are part of everyday lives instead of trying to invite underserved communities to unfamiliar academic spaces. And second, the importance to work together with communities and partner with familiar organizations and trusted actors to start building trust and a communication relationship oneself.
- Three other aspects are explicitly mentioned only in some of the guidelines, although they are partially or implicitly mentioned within other recommendations respectively: building knowledge on the audience and reflecting your activities, creating accessible and engaging activities, and the importance of making connections to everyday life.
- Two more areas with a wider relevance are only included in one or two publications: First, the importance of long-term engagement, and second the aim to achieve a more basic impact by focusing on empowerment and structural problems.
- Some recommendations, despite still being relevant for successful work in the respective contexts, are not fitting into wider areas and focus operational aspects (e.g., rewarding successes) or are only focused on specific groups or approaches (e.g., gamification approaches or young person led activities).

Although not examined further in-depth here, a comparison with recommendations for reaching underserved audiences in other fields [for example in public administration (Froonjian and Garnett, 2013), adult education (Bremer and Kleemann-Göhring, 2011), or public health (Soom Ammann and Salis Gross, 2011) confirms the underlying core aspects].

Corroborating Qualitative Data

To deepen the understanding of the exclusion processes and the proposed solutions, we corroborated the results of the review with qualitative data collected in our research. These data stem from the project "Science for All" ["Wissenschaft für alle"] in which science communication formats with underserved audiences are developed and evaluated. To that end, a typology of exclusion factors has been developed based on a literature review (Schrögel et al., 2018) and new formats for science communication are developed and tested in a participatory process with three underserved audiences: Muslim youths with a migration background, socially disadvantaged people in marginalized neighborhoods, and students in a vocational school.

Interviews With Practitioners and Researchers

On the one hand, the data consist of interviews with science communication experts from Germany, Switzerland and Austria working with not reached groups. The interviews were conducted in the first quarter of 2018. A total number of 11 scientific and practitioner experts have been interviewed in a semi-structured phone-interview[2]. The interview partners were chosen because they work with underserved audiences either as practitioners or researchers, come from different fields representing different institutions—e.g., museums, political education, science communication. The selection does not claim to be representative for the international expert landscape. The group consisted of six women and five men all of which have an academic background. Although no further data on socio-economic status and other demographics have been formally collected, it has to be critically reflected, that the background of the group itself probably represents the prevailing limited diversity within academia.

Focus Groups and Interviews With Underserved Audiences

On the other hand, focus groups and interviews with three exemplary underserved groups were conducted. The groups were chosen by an advisory board as exemplary case studies of underserved audiences in science communication. The three groups are each characterized by one of the identified exclusion factors, however, it is important to note that they are a statistical group of people with one common attribute, rather than a social group (Vester, 2009, p. 80–81) with a self-identification as a group.

1. Students in vocational training
   They are usually not considered as target groups for science communication, as they are neither addressed by science communication focusing on recruiting future university students nor are they addressed by typical science communication formats for adults. The specific project partner was a vocational school for plumbing and heating in the city of Karlsruhe, Germany. Two focus groups were conducted in September and November 2018. The first consisted of teachers (2), committed students (7) and a scientist researching political participation of vocational students. The second focus group consisted of seventeen students from one class.
2. Socially disadvantaged people in marginalized neighborhoods
   Socio-economically disadvantaged and marginalized urban communities are often concentrated in specific city quarters (Otto et al., 2006), which statistically have an above-average unemployment rate, lower formal educational backgrounds, and less scientific, educational, and cultural infrastructure. In this situation, only limited direct contact to science (communication) is available besides mass media channels. Our project partner was the urban development area Falkenhagener Feld East and West in Berlin-Spandau, where the percentage of residents receiving transfer income, the unemployment rate as well as the percentage of children in poverty is well-above the average for Berlin (GeSop mbH, 2019a,b). We conducted one focus group with five engaged persons[3] in July 2018 and guided interviews with 18 residents over the following months.
3. Muslim youths with a migration background
   Especially for Muslims in current Europe, religious affiliation (or even just the externally assumed religious affiliation) can be a target for discrimination against. The religious beliefs often do not even play an actual role, but are a proxy and discrimination is targeting actual or perceived migration backgrounds (European Union, 2017). Such experiences of discrimination are also relevant for the field of science communication, as shown in a UK study (Dawson, 2019). But also for Germany, this discrimination has been reported for young Muslim persons independently of their cultural or family background (El-Mafaalani and Toprak, 2011). Furthermore, religious beliefs indeed also can influence actual or perceived attitudes toward science and science communication (Hagay et al., 2013). For this part, we organized two focus groups in cooperation with two Muslim youth organizations in Berlin, both in April 2019, one with 10 and the other with six participants.

The aim of the focus groups and interviews was to learn more about the respective underserved groups: their everyday lives, their interest, and attitudes toward science and science communication, and their (potential lack of) participation as well as discrimination experiences[4]. The qualitative data from the interviews and focus groups are used to illustrate and complement the recommendations derived from the review of guidelines and recommendations.

ACTIONABLE RECOMMENDATIONS

We synthesized seven actionable recommendations from our review of guidelines and recommendations and the corroborating data, which play an important role in reaching underserved and marginalized communities with science communication.

The recommendations are presented in the following with concrete starting points for science communication practitioners.

[2] A detailed list of the interviewed experts is provided in the **Supplementary Material (Table 1)**.

[3] "Engaged persons" (more specifically: socially engaged persons, e.g., community representatives, social workers, teachers, and stakeholders) play important roles in their communities. They were included to gain better access to the communities and to provide a broader experience and an additional reflected perspective, that interviews with individual community members could depict.

[4] A detailed list of the conducted interviews and focus groups is provided in the **Supplementary Material (Table 2)**.

Recommendation 1: Start With Listening

If science communication activities are not to be planned solely based on assumptions and stereotypes, a reflection on one's activities and goals is necessary. Above all, precise analysis and knowledge of the audience reached and not reached so far is required. For this, it is important to listen and ask questions first: How do others perceive science, science communication, or even individual research topics? Which needs do they express? What do they wish for? Even if the answers are not formulated ready for implementation, open discussions can bring many insights. It is important not only to listen but also to respect these wishes. Especially, it is important to respectfully accept a "no" for an answer. It can happen that initially there is no interest in a certain topic within a community, although this might have high relevance for people. For example, if people are facing acute financial challenges, a discussion event on the importance of future technologies in 10 years might be of little direct relevance to them.

Do not expect people to change and become "like you". Rather, "the intention must be to seek out and embrace, on their own terms, the ingenuities that continually arise in the shadows or as subversions of the established narratives" (Coffee, 2008, p. 271; cf. Archer et al., 2016).

This implies that you have to be able to adapt your plans to the needs and wishes of the communities and self-critically reflect the contents you want to communicate and how they are communicated. This process of (self-) reflection and adaptation should be done regularly throughout the particular project (Aguirre, 2014, p. 11; Marschalek and Schrammel, 2017, p. 25–26).

Letting people talk and actively listening to them can empower them and be a fruitful tool to integrate them without patronizing them. This has been shown for example in the project "Diamond," which used "digital storytelling" in a museum context (Da Milano and Falchetti, 2014). The connection has also been brought up during our interviews. As one expert put it:

> "It is about showing people that, with whatever knowledge and know-how, they understand such things. It is about empowerment and arousing interest, about the exchange, but also about the recognition of different positions, and the perception of and listening to different positions." (Expert 10)

Recommendation 2: Reduce the Distance and Be Accessible

The second key point is closely linked to the first. Both in the existing guidelines and our work, there was a consciously or unconsciously perceived distance between communicators and underrepresented groups. One vocational student described this distance as a difference in the social environment:

> **Student 1**: "Most of them come from the Hauptschule or Realschule [secondary school or middle school] and we simply have a completely different environment[5]."

While one participant from the group of young Muslims spoke explicitly of the elitist image of science:

> **Participant 1**: "It is also very often, that is to say, science, as I said earlier that it is very white, I actually associate it directly with exclusion, so it is something very elitist[6]."

This distance can be expressed on many levels: be it as an academic or upper-class language with respect to vocabulary, idioms, or references, a condescending and instructive attitude, or the display of and insisting on academic titles—in short, a certain habitus (Bourdieu, 1982). Since this distance is often the result of one's own—especially socioeconomic—living conditions and the educational system, it will not be possible for a science communication project to overcome it easily. But there are strategies to at least narrow the gap.

For example, you could formulate language in a casual, humorous, and colloquial way. However, at the same time you have to remain authentic and not play an artificial role—that's the challenge as one of the interviewed experts said:

> "I need to understand the language, the code. I have to reduce my scientific results without telling scientifically wrong things." (Expert 11)

The use of humor can be a helpful method of making science accessible. This was explicitly recommended in one of our focus groups as one of the central points for reaching them with science communication:

> **Student 1**: "One could make jokes to get closer to people and not to make oneself as important and to behave like the person next to you so that they take you seriously[7]."

It is also important to consider the time and financial resources of the target group, which are sometimes—e.g., for shift workers—quite different from those in the academic milieu.

The dialogue should take place at eye level. Our experience shows that (scientific) expertise is respected—titles and references to organizations alone not necessarily:

> **Participant 1**: "Well, I mean, the children and teenagers, so if they have a person who knows what he or she's talking about and can also convey things in an interesting way, then that's respected and recognized, and that's not through a title, expert XY, but through an emotional approach. So the person is measured by what he or she says. And if an expert really conveys things in a substantiated way and is also able to adapt the language[8]."

Initially, the aim should be to sound out emotions, attitudes, and values to create a common basis on which further discussion and knowledge transfer are possible. Current socio-psychological studies on values and emotions in science show that certain attitudes are driven by values and emotions to such an extent

[5]Taken from a focus group with students from the Heinrich-Meidinger-Schule Karlsruhe (vocational school) on 9/25/2018.

[6]Taken from a focus group with young Muslims in Berlin on 4/27/2019.

[7]Taken from a focus group with students from the Heinrich-Meidinger-Schule Karlsruhe (vocational school) on 9/25/2018.

[8]Taken from a focus group with engaged persons in Berlin-Spandau on 7/26/2018.

that one cannot achieve anything with information events alone. Dan Kahan, for example, described this observation, which is discussed under the heading "Cultural Cognition" (Kahan et al., 2010b), for information on vaccination (Kahan et al., 2010a).

To this end, it is "necessary to honestly question one's own goals and how they could be achieved" (Marschalek and Schrammel, 2017, p. 26) in advance. How should results be dealt with? Is there even a need for concrete results or a comprehensive transfer of knowledge, or is the exchange itself a goal?

It is advisable to take an open approach: This means making an offer and moderating debates without having a too narrow idea of what should ultimately happen in the minds of the participants. However, it should be taken into account that too much vagueness can also hinder communication (see recommendation 6).

Recommendation 3: Be Relevant for Everyday Life

> **Student 1**: "The [scientific] topics are simply too far away for us[9]."
> **Student 6**: "We're just craftsmen, we need to see what we are doing. Just listening to a lecture—many just don't understand it. [...] Bringing theory to practice [...][9]"

We often encountered statements such as these in our conversations with people in a marginalized part of the city and with vocational school students. Science in general and thus also science communication seemed to them to be remote from their everyday life, inaccessible, complicated and correspondingly uninteresting.

For this reason, concrete topics or hooks that tie in with already existing interests or life situations contribute decisively to the success of science communication. In vocational schools, this can include, for example, job-related technical interests:

> **Moderator**: "Are there any other scientific topics that you are particularly interested in?"
> **Student 6**: "Yes, I'm interested in renewable energies. This is also part of our profession. You should know something about that.[9]"

Establishing these links "between their homes, personal lives, communities, and science are important" (Archer et al., 2016, p. 936), as experiences from other projects show, too. For example, Marschalek and Schrammel (2017, p.28), state that in their project "exhibition objects or exhibition themes with a relation to the everyday life of the target group, create particular interest and encourage coming back" (cf. Streicher et al., 2014). The same holds for connections to the cultural background and other experiences of the underserved audiences (Archer et al., 2016, p. 936).

The relevance of topics cannot be measured solely by whether they relate to everyday life in terms of content. Starting points can also be found in more pragmatic aspects not related to the topic, for example in a scientific holiday program for children, which offers free care as a benefit[10], or in an entertaining scientific event that offers an interesting leisure activity away from daily struggles.

In many cases we have noticed that science hardly plays a role outside very concrete benefit considerations—for example, to support career plans or as education for their children:

> **Interviewee 7**: "I want my kids to learn how to do research and have fun with it [science][11]."

This is usually not a rejection, but a low priority compared to other topics (see recommendation 1), as the following quote from one of our interviews in Berlin-Spandau illustrates:

> **Interviewer**: "Is it right then to say that for you other things are more important that have to be changed before you get to grips with science?"
> **Interviewee 8**: "Yes, exactly. If other things were settled, then my interest would increase[12]."

Recommendation 4: Go Where People Are

If you want to address groups that have not been reached so far, it is helpful to also approach these groups quite literally in a spatial sense. You should use places and buildings that are familiar, easily reachable and accessible for the group—"localities in the everyday environment of the people" (Marschalek and Schrammel, 2017, p. 22), because "socially inclusive science communication has to take place where people spend most of their time—within their communities" (Streicher et al., 2014, p. 1). This holds true for science communication as well as for other areas of community building and engagement. In our focus groups, a vocational student explicitly expressed this demand:

> **Student 4**: "If you—in the job, for example—have a lot of school during the apprenticeship, then rather the people from universities should simply come to the school, give lectures[13]."

In concrete terms, this means organizing events in the district center, the village pub, or vocational school instead of the university or research institute—which often are perceived as closed-off areas. For example, Streicher et al. (2014) used empty salerooms in socially disadvantaged areas of Vienna to open up so-called "knowledge°rooms."

This approach has also been echoed by one of the interviewed experts, who stated in an interview, that

> "you always have to go into the neighborhood and sometimes you also have to invite people first. Or another experience we had with refugees, you have to go there and sometimes you have to accompany the people to bring them to the museum." (Expert 4)

[9]Taken from a focus group with students from the Heinrich-Meidinger-Schule Karlsruhe (vocational school) at 9/25/2018.

[10]In Switzerland, for example, this is the concept of the so-called Camp Discovery, which addresses children with little contact to science and from low-income families (Science et Cité, 2010).

[11]Taken from a guided interview with a resident in Berlin-Spandau on 9/8/2019.

[12]Taken from a guided interview with a resident in Berlin-Spandau on 9/8/2019.

[13]Taken from a focus group with students from the Heinrich-Meidinger-Schule Karlsruhe (vocational school) on 9/25/2018.

In addition to closeness and physical accessibility, (for example for people in wheelchairs, other exclusion mechanisms can also play a role). There are places some people just won't go because they feel that these places are "not for them" (Dawson, 2019, p. 100–102). Specifically for science communication, both a fenced research center with guards and admission controls and a classicist science building (which already seems to signal on the façade that you can't get very far here without being able to have fluent conversations in Latin) for example do not appear welcoming to many people (Marschalek and Schrammel, 2017, p. 22). Thus, it seems important to mind easy accessibility and reachability of the location, as well as a familiar and open atmosphere, a direct dialogue with the community and multilingual information and offerings (Archer et al., 2016, p. 936; Streicher et al., 2014).

This so-called outreach approach can also mean connecting to existing events with a communication format, for example being represented with a booth at a block party or giving a lecture at an event of a local initiative or an association.

Recommendation 5: Cooperation Is Key

Wherever possible, cooperation with local stakeholders, and engaged persons is recommended. They can be found in neighborhood management, social work, libraries, associations, schools, educational initiatives, and self-help groups—or in committed members of the target group itself (Lloyd et al., 2012, p. 55; Marschalek and Schrammel, 2017, p. 34; Smithsonian Institution Office of Policy Analysis, 2001, p. vi–vii).

They know the situation and the needs of the people and thus make insights and approaches possible in the first place. They can advise on the relevance of topics, working approaches, and avoidable pitfalls. Often, they are trusted persons for the community and their word carries weight in the group. This turns them into door openers building up trust, which is often a prerequisite to successful communication projects (Marschalek and Schrammel, 2017, p. 27, 35).

This is also true for communicating via mass media, as the following statement from one expert illustrates:

> "This goes through emotionalization, it is identification with the peer, because we just do peer-to-peer communication. This means that they are peers or only slightly older influencers who have a similar life reality, who know the needs, wishes, and topics of their community on the channel and with whom we clearly talk about what are the approaches to this topic. How does it affect you?" (Expert 1)

Another possibility is that researchers with connections to the target group play an important role in a communication project. This could be scientists who live in a neighborhood or region, have the same cultural background or come from a non-academic home. Based on their own experience, they can advise on the preparation and planning of communication projects and participate as credible and authentic speakers in their implementation.

Furthermore, in the existing guidelines as well as in our work it turned out that potential cooperation partners have only very limited time and financial resources (Marschalek and Schrammel, 2017, p. 34). They understandably want to focus these few resources on their respective core tasks. Even if the requested contribution is "only" limited to counseling and facilitating access to the community, it is another project that requires at least some coordination and attention.

It is therefore crucial that potential cooperation partners are not simply regarded as service providers. Their interests and their limited time should be respected and the extent to which they can benefit from cooperation in the short and long term should be taken into account:

> "You also have to look, what is the ultimate benefit for stakeholders when they participate in such programs? So where do you practically take their interests into account?" (Expert 5)

In this context, Dawson (2019, p. 92) describes a striking example of bad cooperation:

> "Maria from the Latin American group told me a similar story about how frustrated she had been when her community group were asked by a prestigious London museum to be part of their Day of the Dead celebrations. No language provision was made for her friends who were less fluent in English and community artists (dancers and musicians) were expected to perform for free, without even their food or travel expenses covered."

Recommendation 6: Mind the "Openness Paradox"

The "Science for All" project started with a very open and participatory approach: Following an engagement paradigm and understanding science communication as dialogue, we wanted the participating groups to be able to make independent decisions on the kind of science communication format, its contents and its implementation.

However, that openness made it harder for us and the participants at first, even if this sounds paradoxical. The more open the project, the more prior knowledge, and initiative the participants need. The joint development of the topic and format was difficult to communicate, whether to potential project partners or the groups themselves. This challenge is not only based on specific knowledge gaps, but maybe even more so on differences in cultural and science capital. Participatory formats are much more inviting and accessible for communities that have experienced self-efficacy in shaping their careers and being part of a political and scientific discourse.

With a concrete institution as a sender (such as a university or an association in a district), a goal defined by it (e.g., a topic-specific educational mission) and a topic set by it (which derives from the work of the institution, e.g., basic scientific education), the prerequisites would probably be more favorable.

This is true for interaction, too. Interaction is often praised as a tool for making science communication more attractive (e.g., The Science Museum, 2016; Sievert and Purav, 2018), but interaction also requires an understanding of how it works and how to make the best use of it on the participants' side. This makes it less accessible especially for people with low literacy (Dawson, 2019, p. 114).

However, this does not mean the first advice—listening—is superfluous. You should still be open to the needs and interests of the people and adapt accordingly, but at the same time not ask too much of them.

Recommendation 7: Implement Long-Term Activities

Project financing is often limited to one-off activities and pilot projects, especially driven by an increasing short-term and only project-based funding in science instead of a basic financing of independent scientific institutions. If these projects are designed accordingly, these can indeed develop an experiential character, attract attention, and create a first approach. However, if it stops there, the effect will quickly fizzle out and lead to frustration among the groups addressed. This even applies if local intermediaries support the project. It might still not be perceived as an authentic initiative from within the community and with a long-term perspective and lasting impact. In the end, it can be very time-consuming to build the trust between the science institutions and communicators and the people addressed, which is often a prerequisite to reach them (see recommendation 5).

While this recommendation would apply to many other forms of communication, it is particularly relevant for engaging underserved communities with a history of being marginalized. Dawson (2019, p. 92) shows how one-time activities—even when they are well-intentioned—can backfire by describing that one of her interview partners "argued everyday science learning activities tailored to her community during Black history month were tokenistic, angrily stating, 'we're not invited the rest of the year!"

It would be ideal if an institution or initiative with a concrete local reference (such as the district or the environment of a university) or group-specific contacts (self-help group, community association) started a project, instead of an intervention from the outside. This should also have at least a medium-term perspective so that the start-up phase necessary in all projects can then be used to generate further interest and participation.

DISCUSSION AND CONCLUSION

The structuring of the recommendations is aimed at being broadly applicable across different contexts and projects. The wording was chosen to be less technical and instead memorable to aid the dissemination and take-up of the recommendations by science communication practitioners and the leadership at science institutions.

The synthesized seven recommendations are arranged in a project logic ("Starting with listening" at the beginning, "Implementing-long-term activities" as perspective at the end). They include six of the common areas identified in the review (see section comparison and categorization and also **Table 1**): Starting with listening (1), reducing the distance (2), relevance for everyday life (3), going where people are (4), cooperation (5), and implementing long-term activities (7). Theses aspects were not only presented in the literature but were also corroborated by expert statements and most importantly voiced by members of the three underserved audiences themselves which were interviewed within our project.

The seventh recommendation "minding the 'openness paradox'" (6) was no major part in the reviewed guidelines and only mentioned indirectly. However, we consider this an important aspect that needs special attention. The ideal of modern science communication has shifted from an outdated "deficit model" (which nevertheless still is prevalent in many institutions and approaches) toward a model of dialogue and participation. But while we welcome this shift, it might create new barriers and exclusion by requiring skills and knowledge as well as cultural and science capital to join an interactive exchange with science. This needs to be addressed in the design and implementation of participatory science communication.

Besides the more project-specific and operational recommendations being left out in the synthesis of the seven recommendations presented here, it is worth noting that one of the wider areas identified in the review, empowerment, and structural problems, is not considered explicitly. While this is probably one of the most important overall aspects to promote inclusion and an equitable society, it rather represents a mindset and a long-term strategic goal than an actionable recommendation that can be addressed within one project. These issues need to be tackled on a societal level and require systemic changes (cf. Birmingham, 2016; Marschalek and Schrammel, 2017, p. 35–37; Dawson, 2019). For example, in our focus groups with young Muslims, participants complained about discrimination in the educational system:

> **Participant 7**: "What I thought was really bold was that in the 10th grade we got a vocational counseling to which somehow everyone had to go once, and everyone was recommended to do an apprenticeship and not to continue the Abitur [university-entrance diploma]. That is so bold and cheeky simply, where I think, so I go … Before she asks me what I want to do at all, she says, yes, I would definitely recommend you this and that, this apprenticeship. Where I think, so hey, I want to do Abitur and so on[14]."
>
> **Participant 1**: "My teacher's reason was also that my parents come from a working-class and are construction workers and I should also go in this direction and not study, which means that you are very quickly excluded before you have even spoken the word science[15]."

Indeed, the proposed guidelines can be understood as a "weak form of inclusion" (Dawson, 2019, p. 137), only addressing a limited set of the intersecting exclusion factors present in the field of science communication (Schrögel et al., 2018). Thus, one should always consider what exactly has prevented people so far to take part in science communication activities—and how these exclusion factors might intersect. For example, Dawson (2019) describes that people working in precarious jobs not only have a

[14] Taken from a focus group with young Muslims in Berlin at 4/9/2019.
[15] Taken from a focus group with young Muslims in Berlin at 4/27/2019.

low income but also at the same time often have little free time at their disposal. Thus, scraping the entrance fee for museums in the UK addressed the low income, still left the time issues unsolved, so that in the end "getting rid of upfront entrance costs did little to change the visitor profile to these museums" (Dawson, 2019, p. 95).

Nevertheless, we think the recommendations might be useful for projects with limited scope and resources—both regarding time and finances—in broadening "access and accessibility" (Birmingham, 2016, p. 955) and as a starting point for more fundamental changes. Inclusion of broad segments of society into science communication and the discourse about science is highly relevant, considering that being included is an important prerequisite for participation in modern society [for example as a support for evidence-based individual decisions (The Royal Society, 1985, p. 10), for personal career development (Blanton and Ikizer, 2019, p. 155), or the informed participation in democratic processes and public debates (Thomas and Durant, 1987, p. 5)].

It has to be acknowledged that the proposed guidelines as well as the reviewed material have a strong European or Western focus. This choice has been made deliberately to raise awareness and drive change in science communication in this domain. However, it is important to also keep global perspectives and global engagement with science in mind, especially considering the global impact of science and the need for science-based solutions to global challenges. Furthermore, the guidelines presented here are not absolute truths. Their usefulness and practical implementation depend on the concrete circumstances in which the communication of science takes place. There might be further useful recommendations missing here, too.

Additionally, taking part in inclusion or diversity training can sensitize for and deepen the understanding of exclusion mechanisms and how to tackle them (Archer et al., 2016, p. 936; Marschalek and Schrammel, 2017, p. 28) and create the essential awareness for inclusion:

> "What we have noticed time and again, however, is that already on the organizers' side there must be a certain awareness of the need to reach such target groups at all. So if they have no idea at all how diverse their potential target group is, then it is also difficult to set diversity for individual offers or targeted communication measures." (Expert 6)

Science communication for and with underserved audiences is always a balancing act between trying to be as inclusive to as many people as possible and specializing in the needs of certain groups. While most efforts to connect with marginalized communities will make science communication more inclusive for the whole society, undoubtedly some will conversely exclude some other people and therefore require thoughtful decisions and open discussions. Overall, many small steps in changing the common practices of science communication can together create a meaningful impact.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2020.00042/full#supplementary-material

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Images as Information: Context-Rich Images and the Communication of Place-Based Information Through Increased Representation in Environmental Governance

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Practitioners widely acknowledge the importance of including local and Indigenous knowledge in environmental research and decision-making. Nevertheless, it remains a challenge to achieve this integration in a meaningful way. The pilot study reported here was a necessary step toward developing improved methods for communicating local and Indigenous knowledge to decision-makers, with a focus on public sector practitioners as audience and visual content as medium. The proposed methodology extends previous research on climate change adaptation in the Alaskan Arctic, and it examines the effect of a reporting approach that introduces two components outside of general conventions in public sector information dissemination; (1) the application of context-rich images to help convey the social and cultural nuances of place-based information, and (2) multiple evidence base (MEB) reporting which engages information from both Western science and local/Indigenous knowledge systems. Context-rich images—defined here as detailed visuals that address the particularities of specific environments and cultures—are explored given their potential merits in expressing place-based concepts, such as social life and lived experience quickly and concisely when presented in tandem with text. With a focus on practical application, public sector conventions for reporting place-based information to decision-makers are investigated, including the benefits, and limitations associated with these conventions. Insights from both theory and practice informed the research methodology, and the design of a sample report and online questionnaire tested with upper-level public sector practitioners who have influence on environmental decision-making. Pilot study results indicated significant benefits of using context-rich images in addition to quotes about lived experience for reporting information about the local context and experience of Northern environmental changes. When presented alongside research from Western science, neither local observations in the form of quotes, nor context-rich images posed negative impacts on the perceived credibility of the report. The pilot study revealed the proposed methodology to be particularly beneficial for a target audience of practitioners who may lack expertise in the local context or field of research being reported. Additionally, several potential improvements to the content and design of research materials were identified for the benefit of future studies.

Keywords: boundary objects, communication, context-rich images, decision-making, governance, information, local knowledge, social-ecological systems

INTRODUCTION

Collaboration, negotiation, and decision-making undertaken in the interest of adaptation to climatic and social change bring together diverse stakeholders from a range of disciplines and cultural backgrounds. On Alaska's North Slope this includes representatives from local tribal communities, regional (North Slope Borough-wide) organizations, state and federal agencies, industry, and academia. While higher government levels play a key role in establishing the institutional capacity (legal, regulatory, policy, and funding initiatives) for adaptation, collaboration and knowledge exchange at the local scale are essential for relevance, feasibility, and broad stakeholder engagement (Trainor et al., 2017). However, given the dominance of technical information in Western decision-making arenas, differentiated sources of information including local and Indigenous knowledge are often underrepresented (Lemos, 2008). This can leave decision-makers with inaccurate or insufficient information, which may lead to biased decisions that ultimately harm North Slope communities.

Scholarship in the sustainability sciences has extensively described the boundaries that exist between different cultural groups. However, the field needs to expand its discussion of the communication-related dimensions which vary depending on the context in which they occur and the groups involved (McGreavy et al., 2013). The pilot study presented here pilot-tested a methodology for exploring the effect of a reporting approach intended to address this need within the context of public sector environmental management and decision-support tools. The proposed approach introduces two components that are outside of general conventions in public sector information dissemination; (1) the application of context-rich images to help convey the social and cultural nuances of place-based information, and (2) the integration of information from both Western science and local/Indigenous knowledge systems within the same report (MEB reporting). In a similar vein, this research also addresses a need in the social sciences for visual tools that are better aligned with constructivist epistemologies concerned with contextual detail rather than abstracted and generalizable concepts. The pilot study methodology is based on theory from sustainability science, as well as media communication and visual studies. It is also informed by semi-structured key informant interviews with public sector practitioners, and guidance from the project's local community partners in the Native Village of Wainwright, AK. A questionnaire, context-rich images (including photographs, montage, and Native art commissioned for the project), and a series of sample reports were developed and then tested with upper-level, public sector practitioners. Here we describe and report the following; (1) how the pilot study is framed through the lens of sustainability science and knowledge gaps impacting the management of complex social-environmental systems, (2) a summary of key concepts in visual theory that makes the case for context-rich images as tools to help overcome information biases plaguing transdisciplinary governance efforts, (3) the Images as Information Pilot Study setting and methodology as an offshoot of the parent, Wainwright) Study, and informed by key informant interviews, which collectively shaped materials and procedures, (4) pilot study results; and finally, (5) practical recommendations for reporting techniques in public sector environmental management, and for future studies attempting to understand the potential of MEB and visual reporting approaches.

THEORETICAL BASIS

Sustainability Science and Environmental Governance

This research is grounded in the field of sustainability science, a transdisciplinary endeavor that seeks to engage complexity in social-ecological systems (McGreavy et al., 2013). The management of complex social-ecological systems involves consideration of both human and non-human interests, as well as the interaction of these components across time (e.g., short-term, long-term) and spatial (e.g., local, regional, national, international) scales (ibid.). Collaborative efforts that span disciplinary and cultural boundaries are also part of this process, with a potentially broad range of stakeholders (e.g., local communities, academia, industry, public agencies, and NGOs) contributing to policy development and implementation (McGreavy et al., 2013). An increasing interest in the potential of collaborative rather than top-down policy processes in environmental management is underscored by a shift in discourse from "government" to "governance," which encompasses the coordinating and steering activities that enable cooperative efforts (Pahl-Wostl, 2009). While environmental management refers to activities such as monitoring, developing, and implementing measures to achieve or maintain desired environmental conditions, environmental governance takes into account broader social contexts that enable the management of complex systems (Folke et al., 2005; Pahl-Wostl, 2009). This includes the system of organizations and institutions (e.g., rules, laws, regulations, policies, social, and cultural norms) involved in governing environmental resources (Chaffin et al., 2014) with a focus on negotiating and decision-making processes undertaken by networks and individuals.

Knowledge Gaps in Environmental Policy and Decision-Making

Environmental governance relies on information about the state of the environment and human-environment interactions. Given the tradeoffs inherent to decision-making processes, resource managers require knowledge about individual and social values to adequately understand the likely effects of their decisions on valued outcomes (Dietz et al., 2003). Among information sources generated, shared, and used for decision-making, "formal science" grounded in positivistic methodologies, remains authoritative (Eden et al., 2006; Lemos, 2008; Adger et al., 2009). The post-positivist paradigm reflects most quantitative research today (Gray, 2013). Post-positivism aspires to separate values from scientific questions of fact, and uses purportedly objective methods to study phenomena in an effort to derive a causal explanation that closely approximates some universal truth in terms of measurable outcomes and relationships (Ulin et al., 2005; Greene, 2007; Gray, 2013). Though it is an oversimplification, positivistic research is commonly referred to as quantitative research in popular discourse. In keeping with this convention, the terms are used interchangeably throughout this paper.

Preferences for quantitative information in environmental decision-making are upheld at the expense of qualitative findings and other differentiated information sources, such as local and Indigenous knowledge (Martin, 2007). This paper uses the definitions of local and Indigenous knowledge put forth by Berkes (2012) who defined local knowledge as the relatively recent, place-based knowledge of a group of people, and indigenous knowledge as local knowledge held by Indigenous peoples, or the local knowledge unique to a given culture or society (Berkes, 2012, p. 9). Scientists and decision-makers trained in positivist epistemology may distrust or reject alternative knowledge sources that do not adhere to positivistic standards of rigor (Martin, 2007). For example, rigor in quantitative research is reliant on external validity, the extent to which the findings of one study can be applied to other situations. Meanwhile, qualitative research adhering to the constructivist paradigm understands truth and meaning to be constructions resulting from the interaction between individuals and their social world (Ulin et al., 2005). In other words, universal truth is unlikely to exist. It follows that the findings of qualitative social science research are based on lived experience, which is usually specific to only a small number of particular environments and individuals (Shenton, 2004). The same example can also be extended to Indigenous knowledge, which is consistent with many of the tenets of constructivism in its rejection of the positivist belief in context-free generalizations and valueless inquiry (Berkes, 2012). For simplicity, the term place-based knowledge is used in this paper in reference to knowledge from both qualitative social science, and local and Indigenous knowledge.

The challenge of operationalizing diverse knowledge systems in governance is informed in this research by the *Multiple Evidence Base* (MEB) approach, which emphasizes both the separateness and complementarity of Indigenous, local, and Western knowledge systems for decision-making (Tengö et al., 2014). An overreliance on information derived from a single paradigm (positivist, constructivist, Indigenous, or other) may not convey the full range of knowledge necessary for environmental governance efforts (Ascher et al., 2010). This information deficiency constitutes a bounded rationality bias, whereby people make reasonable decisions based on the information they have, despite having imperfect or insufficient information. Particularly deficient is knowledge about parts of a system that are spatially or conceptually distant from one's own frame of reference (Simon, 1972; Meadows and Wright, 2008). Conventions that marginalize place-based research and local and Indigenous knowledge can lead to decisions that have negative environmental outcomes or cause disproportionate harm to underrepresented groups (Martin, 2007). Other practical justifications for increased representation of local and Indigenous knowledge in research and decision-making processes are to encourage more active participation from previously excluded voices, to generate culturally appropriate adaptation responses, and to increase local support of resulting initiatives (Nelson et al., 2007; Lemos, 2008; Ascher et al., 2010).

Boundary Objects as Decision-Support Tools

Shortfalls in the accurate assessment and use of knowledge are often related to information that is difficult to quantify, or more specifically, that practitioners lack the tools to properly evaluate (Meadows and Wright, 2008). This is particularly true of Indigenous knowledge, where face-to-face discussions and other efforts to translate between local and scientific experts are often fraught with misunderstanding due to differences in perception (Eira et al., 2013). *Boundary objects* are a useful theoretical concept to understand the types of tools that may help mitigate such differences. Boundary objects, originating from Leigh Star and Griesemer's work in the sociology of science field (Leigh Star and Griesemer, 1989), are scientific objects that inhabit several intersecting social worlds while satisfying the informational requirements of each. A wide range of material and processual elements may qualify as boundary objects given they are flexible enough to adapt to the differing information and work requirements of particular groups, yet robust enough to maintain a common identity across sites (Leigh Star, 2010). Diverse groups may use or interpret the same object different ways. In addition to having interpretive flexibility, boundary objects are defined by action in that social groups can readily move between specific applications tailored for their particular needs, and general applications that enable cooperation across boundaries (ibid.). For example, *coincident boundaries* are a category of boundary objects comprising objects that have the same boundaries but different internal contents such as two maps of the same geographic area that each highlight a different topic of focus (e.g., transportation networks vs. topographic features).

A *standardized form* is another category that includes agreed upon methods of common communication across dispersed working groups. *Ideal types*, originating from German sociologist and philosopher Weber (1904), are another broad category including heuristic tools that provide a simplified or abstracted version of reality and are employed by users to gain a better understanding of empirical reality (Swedberg, 2018). Among ideal types, visuals provide a means of communicating and cooperating symbolically. For example, maps are considered useful ideal types because they create a common ground from which all participants can build understanding (Leigh Star and Griesemer, 1989; McGreavy et al., 2013). Visuals and their potential contributions as decision-support tools are a key focus of this reported pilot research.

The production of visuals and other boundary objects is vital to *boundary work*, a concept which describes the work of organizations and individuals who actively facilitate collaboration across disciplinary and cultural boundaries as they seek to mediate between knowledge and action (McGreavy et al., 2013; Clark et al., 2016). Clark et al. identified multiple contexts for the performance of boundary work based on the sources of knowledge (single or multiple communities of expertise) and its potential uses (enlightenment, decision-making, and negotiation) (Clark et al., 2016). The context of this reported pilot research features knowledge from multiple communities of expertise (e.g., local and Indigenous knowledge, natural science, social science) for use in environmental policy and decision-making. Within this context, knowledge is more likely to be useful to the extent that it is perceived by decision-makers as satisfying criteria for both credibility (scientific validity/adequacy of evidence and arguments) and salience (relevance to decision-making needs) (Cash et al., 2003; Clark et al., 2016). Legitimacy (the sense that knowledge was generated in a fair, neutral, and representative manner) is another component integral to processes that link knowledge and action in environmental decision-making (Cash et al., 2003). The perception of knowledge depends to a large extent on the process by which it is generated and also the means by which it is represented. The role of visuals in the explanation and transfer of knowledge has been thoroughly investigated in sociology, semiotics, and media studies, but far less so in sustainability studies.

Visuals in Quantitative and Qualitative Research

Visual representation is the selection, transformation, and presentation of data or qualitative concepts in a visual form that facilitates exploration and understanding (Lurie and Mason, 2007). Visual tools are defined within this project as the range of products (e.g., maps, drawings, photos, flowcharts, animations), which can be assumed to have different functions and uses in meaning construction (Meyer et al., 2013). For example, graphic displays and tabular displays are suited to different kinds of information. The structure of displayed data in graphs creates visual patterns, while the visual appearance of tables is not affected by the characteristics of the data displayed (Meyer et al., 1999).

According to philosopher, anthropologist, and sociologist, Bruno Latour, advancement in the sciences is enabled by images and inscription. Each scientific discipline has a standardized language or code that enables what Latour termed "immutable mobility," the ability to send information to spatially or temporally distant places with meanings and logical relations intact while simultaneously allowing for new transformations and articulations (Latour, 1986, 1999). Scientific visuals have the quality of being "flat" or abstracted, with detail-rich observations of reality turned into generalizable scientific information in the form of charts, diagrams, and technical line drawings with limited color, texture, and perspective (Kress and Van Leeuwen, 1996). Latour comments, "If scientists were looking at nature, at economies, at stars, at organs, they would not see anything… Scientists start seeing something once they stop looking at nature and look exclusively and obsessively at prints and flat inscriptions" (Latour, 1986, p. 15). That is to say, ideal types like models and diagrams allow scientists to focus on a piece of the whole, thereby minimizing distraction and helping to convey understanding.

Explanation in scientific writing is achieved using a combination of images and inscription (Latour, 1986, 1999). Though the natural/physical sciences and the social sciences are grounded in different epistemologies, the systems of explanation employed by each are notably similar. Latour notes, "there is no detectable difference between natural and social science, as far as the obsession for graphism is concerned" (Latour, 1986, p. 15). Quantitative images are consistent with positivistic concerns for generalizable "truths" and "hard facts," with ideally all detail subtracted save for what is necessary to fulfill their descriptive intent (Kress and Van Leeuwen, 1996). However, when the topic of explanation is entangled with local values and connection to place—concepts difficult to quantify or generalize—contextual detail in imagery is necessary. Visual artifacts, such as color, perspective, and typography, enhance the potential to express identities and values, thus augmenting the explanatory capacity of text and narrative (Van Leeuwen, 2011). Furthermore, visuals have the added benefit of communicating complex concepts with an "immediacy of reception and a memorable impression of the essence of the message," which is difficult to achieve with concise text (Meyer et al., 2013, p. 496).

Context-Rich Images in Boundary Work

This research posits that context-rich images may enhance systems of explanation employed within the social sciences and, in doing so, improve the ability mobilize place-based knowledge in boundary work. The term "context-rich image" is applied in this study to describe visual tools (boundary objects) that contain an abundance of detail and address the particularities of specific environments and cultures. For example, an unmanipulated photograph is a detailed naturalistic image that contains multiple "embedded analytical processes" (Kress and Van Leeuwen, 1996, p. 50). That is, beyond the primary subject of a photograph, the audience may also obtain information about numerous other details such as weather, time of day, and cultural norms (e.g., clothing). Abstracted images like maps, diagrams, collages, and other informational devices can also be created to convey rich context by embedding them with elements of local culture (e.g., people, activities), highlighting the unique environmental character (e.g., temporality, morphology), or by emphasizing interconnections within the regional social-environmental system.

While there are a host of ways to describe and analyze visuals, this study employed an analytical framework that focused on their denotative and connotative functions (Barthes, 1978). That is, respectively, what each image describes about the subject depicted, and the way the image is interpreted in the context of environmental decision-making in the Western world view. The key focus related to denotation is informed by Latour (1986) who contends that the value of specific inventions in writing and imaging is their contribution to the content and clarity of a message. For the purposes of this study, the value ascribed to context-rich images is determined by the extent to which they can provide additional layers of detail beyond what could be made available in concise text, including information about the local environment and people's relationship to it.

With respect to the connotative functions of context-rich images, the primary focal point is the audience (public sector resource management practitioners) and their reception of the images. The messages conveyed by media cannot be assumed to be static or singular (Livingstone, 1998). Instead, the reception of media is dependent on the audience and its cultural context (ibid.). Among users of environmental information, diverse actors with different mental modes of understanding—an individual's set of assumptions for how the world works—often disagree about what constitutes reliable and useful knowledge (Van Wyk et al., 2008; McGreavy et al., 2013). Differences in the reception of visuals between the general public and the scientific community have been explored in the field of social semiotics. Kress and Van Leeuwen (1996) assert that, while the general public ascribes greater truth to naturalistic images like unmanipulated photographs, academic audiences accord greater truth to abstracted images of generalizable scientific information (Kress and Van Leeuwen, 1996). While Clark et al. (2016) highlighted the importance of credibility and salience as criteria for evaluating the usefulness of knowledge for decision-making, the connotative aspects of images underscore the fluidity of these criteria given their interpretation is dependent on the audience and its cultural context (Livingstone, 1998). The Images as Information Pilot Study, reported here was a corollary of a parent study (Wainwright Study) focused on exploring adaptation to climate change in northern communities, conducted in collaboration with the Native Village of Wainwright. The following describes: (1) the parent, Wainwright Study, and how it engendered this pilot Images as Information Pilot study; and (2) the methods used to develop and implement the study.

MATERIALS AND METHODS

Parent Study—Wainwright Study

This Images as Information Pilot Study was an off-shoot and used data drawn from the parent, Wainwright Study conducted with the Native Village of Wainwright on Alaska's North Slope. The project, reported in Curry (2019), was an iterative and participatory process developed and conducted in partnership with the Wainwright, Alaska Traditional Council and with guidance from a project steering committee comprising three local leaders.

Wainwright (traditionally Ulġuniq) is a coastal community located about 120 kilometers (75 miles) by air southwest of Utqiaġvik (Barrow), AK (**Figure 1**). With a population of about 550 (Department of Labor, 2018), it is the third largest village in Alaska's North Slope Borough. Ninety percent of its residents are Iñupiat. Wainwright's climate is Arctic marine, characterized by long cold winters and short, cool summers.

The Wainwright community has undergone significant changes throughout history. Today, while many features of the Western lifestyle pervade local culture, traditional values continue to play a central role in day-to-day life. The Iñupiat residents of Wainwright live a mixed cash and subsistence lifestyle that remains dependent on fishing, gathering, and hunting on land and in the ocean for physical and cultural nourishment (Village of Wainwright, 2016).

Like many of Alaska's North Slope communities, Wainwright is experiencing the effects of climate change. Seasonally reduced and thinning sea ice is causing shifting animal migratory patterns, eroding shorelines, and a number of other environmental changes (Brubaker et al., 2014). Uncertainty related to these changes is further compounded by the varied economic challenges and opportunities (e.g., arctic shipping, tourism, resource extraction) that create a complex dynamic for Wainwright decision-makers to address.

The Wainwright Study involved conducting semi-structured interviews with long-term Village of Wainwright residents (Denzin and Lincoln, 2011). Interviews focused on each participant's observations of change throughout their lifetime as well as family and community scale adaptations in response to unexpected events, environmental changes, economic development, and other factors. For additional details on participant selection, data collection, and analysis protocol please see Curry (2019).

The contextual analysis of interviews yielded rich information. The most endorsed, environmentally influenced challenges causing concern to participants included challenges related to whaling (e.g., timing of migration, thinning ice), and seasonal change (e.g., timing of seasons, late freeze-up/early break-up of ocean and rivers). Throughout the study, emergent themes and their operationalizations were presented back to the Wainwright Traditional Council. In addition to assessing the credibility of the findings, Wainwright partners discussed the importance of using visual images to help communicate research findings regarding environmental change. As described by Kress and Van Leeuwen (1996), it was proposed that the inclusion of Native artwork would provide images from a local perspective and outside the compositional structures of Western culture (Kress and Van Leeuwen, 1996).

Based on this supposition, funding was secured to create visual representations of major themes that emerged from the Wainwright Study. Context-rich images were developed via Native art, photographs, and photomontage. Through a solicitation process to commission artwork by a North Slope

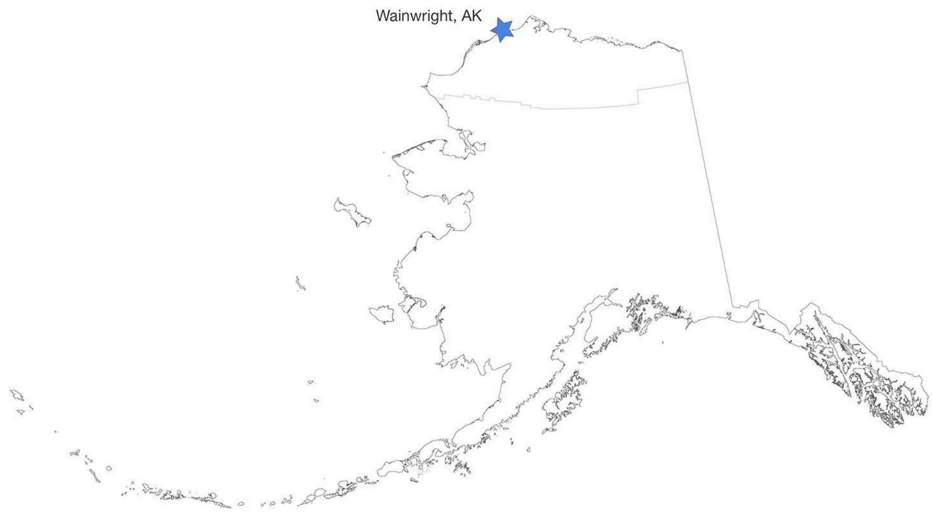

FIGURE 1 | Wainwright, Alaska, and the North Slope Borough boundary line.

FIGURE 2 | "Duck hunting in spring." George Leavitt, 2017. Hunters must exercise caution when traveling along shore ice in the early spring. It is best to travel with a partner.

FIGURE 3 | "Getting close to the lead," painted scene on baleen. George Leavitt, 2017. Depicts Iñupiat whalers breaking trail to open lead. Decreased sea ice leads to increased winds, which in turn push pressure ridges against village shorelines, making trail-breaking hard work.

artist of Iñupiat heritage, the artist, George Leavitt of Utqiaġvik (name used with permission), drew inspiration from the Wainwright interview themes and direct quotes related to seasonal change, sea ice variability, and their impacts on hunting and transportation. Examples of Mr. Leavitt's work used in the project are shown in **Figures 2**, **3**.

Further, additional context-rich images were derived from photographs depicting Iñuit hunters and their relationship to sea ice. For example, the series of photographs below creates a narrative of the mobility of ice floes and attempts to illustrate the challenge presented to hunters by increasingly distant floes as a result of declining sea ice (**Figure 4**).

Finally, photomontage images were developed to combine the abundant detail of a photograph, with the abstracted reality and descriptive function of a diagram. In **Figure 5**—The photograph shows the visible aboveground, and the diagram is an artificial depiction of the "invisible" sub-surface. The photograph in this case was chosen to convey scale and magnitude, including the enormous mass of a bowhead whale and the substantial number of people involved in the whaling process. The photo also serves to emphasize the relationship between people, whale, and sea ice. The diagrammed portion is intended to draw the reader's attention to the important dynamics below the sea ice surface, in particular the minimum thickness needed to sustain the whale's weight for a safe and successful harvest.

Images as Information Pilot Study

The Images as Information Pilot Study was developed to assess the benefits and limitations of context-rich images and multiple evidence based (MEB) reporting for conveying place-based

FIGURE 4 | Sea ice coverage impact on walrus hunting. Walrus remain in the vicinity of coastal villages as long as there is pock ice nearby. This important food source is less accessible to hunters when ice floes ore for out to sea (a) USFWS 2006, (b) USGS 2010, (c) Photo of Willie Hoogendorn by Boogies Johnson, taken east of Cape Nome, May 2018.

FIGURE 5 | Sea ice thickness and whaling. A minimum 3–4 feet of ice thickness is needed to support the weight of a whole.

information to public sector resource management practitioners. This involved the following: (1) conducting key informant interviews to develop the pilot study; (2) developing data collection materials, including three versions of issue briefs that varied in content (baseline, baseline + place-based quotes, and baseline + quotes + context-rich images); and (3) data collection with participants reviewing each report, indicating their preferences via an online questionnaire, and taking part in a follow-up semi-structured interview.

Key Informant Interviews to Develop the Pilot Study

Five key informants provided insights during interviews that lasted between 30 and 60 min. Participants included two senior-level wildlife scientists and one senior-level social scientist from federal agencies in Alaska, and two information/decision support specialists working for two Alaska-based boundary organizations. The goals of the key informant interviews were to answer the following questions: What is the conventional treatment of place-based information for decision-making within environmental management agencies? and What should be considered when choosing boundary objects that are useful to decision-makers?

Key informants discussed a generally recognized need for place-based information, including local and Indigenous knowledge, for planning and decision-making in Alaska. However, the extent to which practitioners actually utilize this information in their own work depends on their responsibilities. For example, inseason fishery managers are concerned with catch rates, the status of stocks, and species quotas within a particular season. Based on this information, they announce fishery openings/closures and may prohibit the retention of certain species to ensure the amount caught does not exceed the annual set limit. These decisions are often made "on the fly" with limited time for deliberation and consultation. As such, inseason managers work almost exclusively with quantitative data and see little need for place-based information. However, place-based information is believed to be more integral for post-season assessment, which attempts to understand the impacts of inseason management decisions on the fishery. Public meetings are held to obtain stakeholder feedback, which then becomes part of inseason policy for the next season.

While some tasks are inherently more quantitative than others, adherence to accepted information sources within an organization is seemingly also driven by bias. While inseason fishery managers may not consider place-based information beneficial for their work, there may be occasions where additional knowledge of context has an influence on the way data is interpreted. Conservatism (adhering to what is perceived to be "normal") and complexity are the principal factors affecting the use of differentiated information sources (Rayner et al., 2005). Conservatism is reinforced by organizational reward structures that motivate practitioners to adhere to industry standards and procedures, making them resistant to experimentation with new approaches (ibid.). Similarly, complexity makes new information difficult to integrate into existing decision-making tools that are well-ingrained within the organizational culture (Rayner et al., 2005).

Place-based information is typically reported in agency documents using descriptive text and direct quotes from research participants. One key informant expressed frustration that many of her quantitative-minded colleagues were unwilling to engage information in this format or to accept it as reliable. While she assigned a high level of importance to data in the form of written quotes, others perceived it as anecdotal and untrustworthy. She reported having greater success summarizing the same information in table format. By adapting place-based information to quantitative representational techniques, the original data lost some richness but was able to reach more people. When asked for examples of visuals used to convey place-based information, all key informants cited familiarity with the use of photographs for this purpose. No other images types were referenced.

Additionally, key informants reported they did not typically see local and Indigenous knowledge presented alongside formal science. These distinct information sources were frequently included in different sections of the same report, but rarely together. For example, environmental assessments, conducted as part of the National Environmental Policy Act (NEPA) review process, typically separate the evaluation of the physical environment, the biological environment, and the social and economic environment into three distinct sections. Information sourced from local and Indigenous knowledge is generally organized into the social and economic section. In contrast, Ascher et al. (2010) suggest that the presentation of environmental information to decision-makers should avoid segregating knowledge based on different approaches to minimize the likelihood that decision-makers will ignore or neglect differentiated sources of information and the values it reflects (Ascher et al., 2010).

Key informants identified agency personnel of mid- to upper-level seniority as a target audience given individuals in these positions have broad job responsibilities that necessitate a wide range of information sources, and the authority to make decisions based on that information. Key informants noted that, due to time constraints, these administrators are more likely to rely on summarized information in tables, graphs, and charts, with text functioning as a secondary, albeit necessary, source of information. This was an indication that context-rich images could be particularly useful for those managers who lack sufficient time to engage with detailed place-based information.

Pilot Study Materials and Methods

Key informant insights were incorporated into the materials used in the Images as Information Pilot Study which included three versions of a two-page report on sea ice variability and its impact on hunting and transportation in coastal North Slope Alaska communities (see **Figure 6**). Report A (baseline) was designed to follow current norms with text that summarizes knowledge from the natural sciences, and conventional graphics (e.g., tables, graphs, charts, and maps). Report B (baseline + place-based text as quotes) was an MEB version of Report A with the addition of quotes from Wainwright residents (Curry, 2019). Report C (baseline + place-based text as quotes + place-based images) was a second MEB report containing the same information as B with the addition of context-rich images.

Images developed based on themes from the Wainwright Study were selected for inclusion into the sample report materials based on their ability to provide useful information and assist in advancing the reader's interpretation. Additionally, the visuals had to be presentable, readable, and combinable with text in the format of an otherwise conventional report (Latour, 1986). These production decisions were made based key informant guidance regarding how a hypothetical recipient in the target audience (public sector resource management practitioners) would likely perceive the material. It was further informed by theories in social semiotics (Kress and Van Leeuwen, 1996). Additionally, the selection of visuals for this study was determined by other practical considerations such as the social (Curry, 2019) and natural science (various sources) research they were intended to augment, and a desire to include multimodal media for the sake of comparison.

Study participants were practitioners who possessed: (1) expertise in environmental policy, planning, and/or decision-making, and (2) decision-making influence within their agency or organization. Participants were identified based on recommendations from senior managers at Alaska state and national agencies/organizations involved in environmental management and research.

Participants were asked to complete an online questionnaire (see **Supplementary Materials**), which involved the sequential review of three versions of the two-page report and prompted responses to questions that focused on the following: Participant's background, perceptions of each report (A, B, C) in terms of overall credibility of information provided, and salience of the place-based quotes and context-rich images. Ultimately, participants were asked to choose which of the reports (A, B, C) they preferred given the intended purpose; "To provide an understanding of current knowledge on key components of sea ice variability on the North Slope of Alaska as well as an understanding of the local context and experience of these changes." After completing the online questionnaire, participants had the option to also complete a semi-structured follow-up

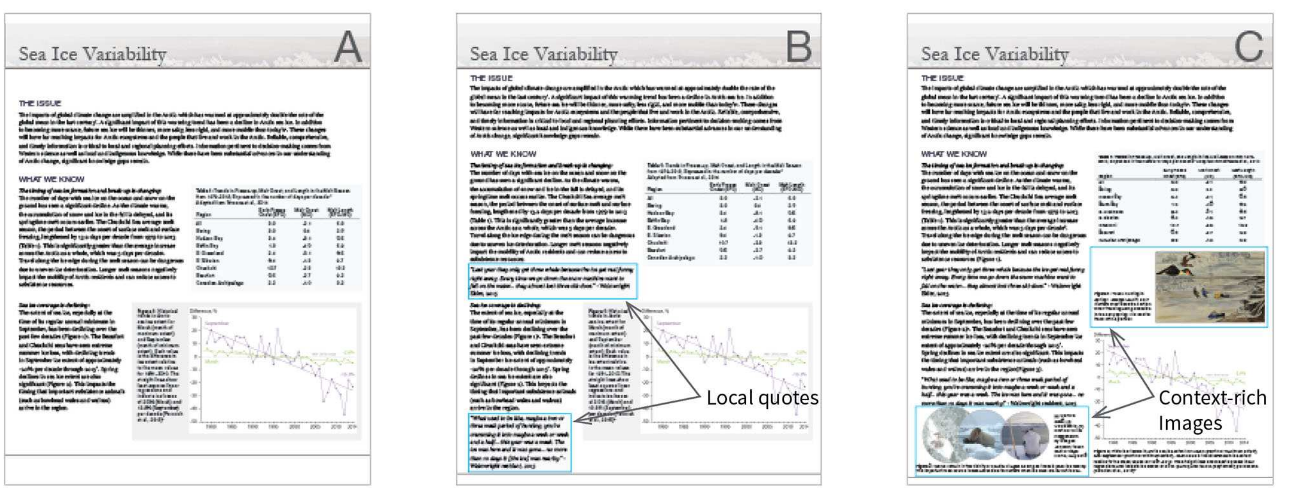

FIGURE 6 | Sample reports **(A–C)**.

TABLE 1 | Follow-up interview questions and rationale.

Question	Rationale
1) Do you have any thoughts about the topic (knowledge communication and the integration of different sources of information for environmental management) or the questionnaire itself that you'd like to share?	Opportunity for participants to discuss any thoughts they have at the outset of the interview
2) In a few instances in the questionnaire you were asked how the inclusion of quotes or locally-based photos and artwork impacted your understanding of the issues described in the report if at all. Please tell me your interpretation of what the phrase "impacted your understanding of the issues" means.	A diversity of responses to questions with the phrasing "impacted your understanding of the issues" prompted the inclusion of follow-up questions to verify whether or not participant's interpretation of the question matched that of researchers
3) Did the images in Report C provide any additional nuance or detail that wasn't available in the text or quotes (Reports A and B)?	Responses to questionnaire questions about information conveyed by images in Report C above and beyond Reports A and B were generally not distinct from responses related to questions about improved understanding of existing information. The question was asked again but rephrased in the follow-up to include the terminology additional nuance or detail in place of information.
4) Report B (baseline + quotes) and Report C (baseline + quotes + images) represented a couple approaches to combining information from natural science with social science and local observations. How effective were each of these approaches? Is there a better way to achieve this integration? Is this a challenge you have dealt with in your work?	Regarding the challenge of integrating knowledge from Western science and local and Indigenous knowledge to inform environmental decision-making, the questionnaire asked about how the inclusion of quotes and images impacted the perceived credibility of the sample reports. Additional insights on this topic were requested during follow-up interviews.
5) Do you have any additional insights on prioritizing report content when considering page limit guidelines?	Constraints in sample report length were dictated by brevity as a major consideration for information used by upper-level environmental managers. Participants were asked for additional insights on this topic

TABLE 2 | Questionnaire background question summary.

Background questions	Mean/% (n = 8)
How would you rate your familiarity with environmental issues on the North Slope of Alaska? **Scale:** 1 (Not at all) to 5 (Very)	4.13
How would you rate your familiarity with social issues on the North Slope of Alaska? **Scale:** 1 (Not at all) to 5 (Very)	3.63
How would you rate your level of experience working with Indigenous peoples in Alaska? **Scale:** 1 (Not at all) to 5 (Very)	3.63
Local and/or Indigenous knowledge are among the information sources I use in environmental planning **Scale:** True/ False/ Not-applicable	75% True 25% Not applicable
Local and/or Indigenous knowledge are among the information sources I use in environmental decision-making **Scale:** True/ False/ Not-applicable	50% True 50% Not applicable
How valuable do you think local and/or Indigenous knowledge are as sources of information for environmental planning/decision-making? **Scale:** 1 (Not at all) to 5 (Very),	4.50
Given your rating of the value of local and/or Indigenous knowledge, how much attention do you believe it receives in environmental planning/decision-making? **Scale: (**1) Not enough, (2) Just enough, (3) Too much	1.25
The number that best describes your learning preference is: **Scale:** On a scale from 1 (Highly textual) to 5 (Highly visual)	3.25

interview that encompassed five open-ended questions as well as probes to allow participants to clarify and elaborate on details provided in their initial questionnaire responses, and to provide constructive feedback regarding the Research Topic and study design. Follow-up interview questions and the rationale for their inclusion are provided in **Table 1**. Questionnaire data were analyzed using Microsoft Excel. Interviews were audio recorded (with permission), transcribed, then coded and analyzed by the lead author using NVivo (version 12) qualitative data analysis software. The following reports the results based on analysis of both the questionnaire and follow-up interviews.

RESULTS

Eight practitioners from six public agencies participated in the online questionnaire, which took an average of 40 min to complete. Responses to background questions are reported in **Table 2**. On average, participants rated themselves good (4.1 out of 5) regarding their familiarity with *environmental* issues on the North Slope of Alaska and fair to good (3.6 out of 5) in terms of their familiarity with *social* issues in the region. Participants on average rated local and Indigenous knowledge as being high (4.5 out of 5) in terms of its value as an information source for environmental planning and decision-making. Respondents on average rated themselves neutral (3.25 out of 5) in terms of their learning preference (textual to visual). Six participants also completed a follow-up interview (30 min average) to further clarify their questionnaire responses, particularly with regard to the credibility, salience, and potential efficacy of MEB reports in practice.

Credibility

Credibility refers to the perceived adequacy of the evidence and arguments presented. When asked their impressions of Report A (baseline), participants called the report "clearly written," "straightforward," "balanced," "basic," and "organized to be a quick read." Participants were asked sequentially to rate the perceived change in credibility for each version of the report. The MEB documents [Report B [baseline + quotes] and Report C [baseline + quotes + images]] were perceived to be equally

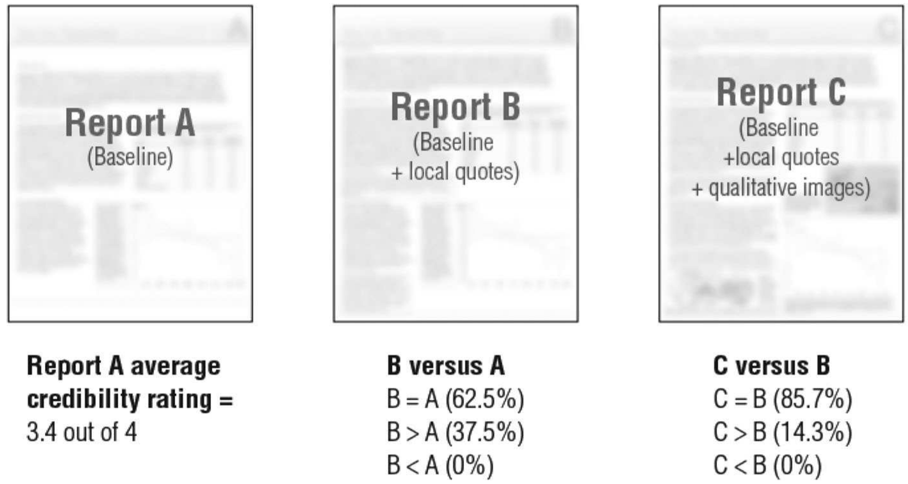

FIGURE 7 | Report credibility comparison.

or more credible than the Report A (baseline). The results are summarized in **Figure 7** and detailed further below.

Report A (baseline) was rated on average as being relatively high (3.4 out of 4) for credibility (**Figure 7**). Open-ended questionnaire responses provided insight into participant ratings, which were based on the presence of citations from peer-reviewed literature, statistic trends, and the inclusion of information about gaps in current knowledge related to the topic.

Participants rated Report B (baseline + quotes) as either equally (62.5%) or more (37.5%) credible than Report A (baseline) (see **Figure 7**). One respondent noted:

> *"[Report B] would certainly be more credible to a wider audience, and adds human, on-the-ground verification of the scientific findings." (Questionnaire participant #6)*

While the inclusion of quotes may have increased perceived credibility, one participant was critical that there was not sufficient information to demonstrate the legitimacy of the quotes:

> *"I like report B better because it presents information about the social relevance of the issue. Because the information is in the form of individual quotes without evidence that the statements have been corroborated by others in the region, I hesitate to call it more 'credible"' (Questionnaire participant #1)*

Participants rated Report C (baseline + quotes + context-rich images) as either equally (85.7%) or more (14.3%) credible than Report B (baseline + quotes). One respondent explained:

> *"For me, these particular images don't add or detract from the credibility, though they do add some really key perspective." (Questionnaire participant #2)*

Salience

Salience refers to the relevance of the evidence to the needs of decision-makers. Referring to the importance of place-based information for decision-making, one participant noted managers and policy-makers are concerned not only with scientific facts, but also with societal relevance, which the quotes and context-rich images provide. When asked to choose which, if any, of the reports (A, B, C) was preferred given the intended purpose (to provide an understanding of current knowledge as well as the local context and experience of Northern environmental changes), seven of the eight participants chose Report C. The remaining participant chose Report B. Participants' preference for the MEB documents is reflected by the following quotes:

> *"For the first part of the purpose, you only need report A and/or B. To meet the second part of the purpose (i.e., both context and experience), you must have report C" (Questionnaire participant #2)*

> *"Sometimes there are measurable changes that don't impact communities. The quotes are really key in demonstrating that the documented changes are impactful. Not all off the pictures necessarily increase the credibility of the document or provide key information—some do—but they all provide visual context to the statements and quotes so that the reader can picture what is going on, even if they have not been to the North Slope." (Questionnaire participant #1)*

As the above quote suggests, some of the images were more successful than others at enriching the information in the report. **Figure 5**, the montage image illustrating the importance of sea ice thickness, was perceived to be the most successful. Its ability to place the trends of declining sea ice described by the report into a clear context was the primary beneficial quality cited.

"[The figure] reinforces the statement it's paired with quite well, and nicely draws the connections between the academic text and the quote" (Questionnaire participant #2).

The lowest rated image was **Figure 2**. The figure was characterized as not quite the appropriate image to describe sea ice formation and break-up trends that it was intended to support.

"I think the figure is slightly misleading, as it illustrates a landfast ice case, yet the report is about the pack ice. Ideally, figures would be consistent with the text" (Questionnaire participant #4).

Figure 2, while representative of quotes from Wainwright interviews, was not a perfect match for the specific content of the report. One respondent noted:

"... graphics are really helpful, but I think it just has to be the perfect one" (Follow-up interview #6)

MEB Reports and Context-Rich Images as Boundary Objects

The potential for MEB documents and context-rich images to function as boundary objects was evaluated based on criteria established by Leigh Star and Griesemer (1989) and Leigh Star (2010). By definition, boundary objects have (1) flexibility to adapt to differing information and work requirements, (2) sufficient robustness to maintain a common identity across sites, and (3) both general and specific applications that different groups working together or separately can move between.

Interpretive Flexibility

The MEB reports (Reports B and C) were a synthesis of findings from the natural sciences and from place-based research. Study participants noted the relevance of the information provided for both expert and non-expert audiences. One participant who self-identified as an expert on the science topics covered in the sample reports pointed to the benefit of illuminating the "human element" to audiences while dually gaining the reader's fascination:

"The inclusion of the photographs and artwork didn't affect my understanding, but I think they're a valuable addition because they add to the human element provided by the quotes, and they get the attention of the reader. This might be particularly important for the non-expert reader, who might be more encouraged to read more if the photographs and artwork act as an initial hook" (Questionnaire participant #5)

Additionally, participants also noted the potentially valuable role of MEB documents for alerting disciplinarily siloed practitioners to the importance of other types of information. According to one participant, many people at environmental management agencies that become decision-makers are from a natural science background and tend to be wired toward hard science. One of the advantages of reporting local and Indigenous knowledge together with Western science is that it reminds decision-makers about other important factors to consider (Follow-up interview participant #6). The same participant who was a Western-trained wildlife biologist singled out **Figure 3**, a painted scene on baleen (a keratin-based system inside the mouths of baleen whales used to filter food such as krill from the ocean) for its lack of interpretive flexibility (e.g., incongruity with her academic worldview). She described the image as "just too flowery" for the document and its intended audience (Follow-up interview participant #6).

Robustness

The robustness of the MEB documents was a function of the visual legibility of the report contents across multiple formats (e.g., print, web) and the fidelity of the information being reported across Reports A, B, and C. Prioritizing content given document length restrictions is a challenge in summary-style reports. One questionnaire respondent noted that, in practice, there are non-negotiable page limits and, often times, adding images means sacrificing allotted space for informative text, which would reduce credibility (questionnaire Respondent 1). In Report C, some legibility was unintentionally sacrificed for the ability to maintain a consistent amount of textual detail when context-rich images were added to the document. As questionnaire respondents noted, the scale of **Figure 2** was too small to clearly make out the scene being depicted (two young men struggling with a snow machine that has broken through ice). This had a negative impact on the robustness of the report and limited the amount of information the figure itself was able to convey. Still, other participants highlighted some distinct advantages of using images in concise communication. One respondent mentioned the adage:

"A picture is worth 1,000 words, and there's a lot of truth in that... it takes a long time relatively to read 1,000 words vs. look at a picture" (Follow-up interview #5).

Other comments indicated that stronger image captions could help improve the robustness of context-rich images with the potential added benefit of expanding the quantity of information they are capable of transmitting. Information about the time period represented in the images and more explanation about the actions and relationships being depicted were examples cited in open-ended questionnaire responses.

In relation to the fidelity of the messages being conveyed in the report, the paintings seemed to add unintended noise. The paintings were divorced from this context when scaled down to fit a standard letter sized page. The inclusion of paintings was characterized by one participant as "distracting" because the reader then had to engage with and make value judgements about the art that were not related to the core message of the report. While an audience might ponder such things freely in an art gallery, the pages of the report were not considered the proper venue. The paintings led the participant to wonder if there was some other underlying message being conveyed with their inclusion, a perception that could mute the potential for these particular images to convey information for decision-making, and ultimately reduce the credibility of Report C. The same participant stated:

"I would say that the artwork [paintings], makes the report less credible, while the other photos/graphics add to one's understanding." (questionnaire participant #6)

General and Specific Application

Interpretive flexibility enables the specific application of MEB documents and context-rich images while their general application is determined by their usability in collaborations or negotiations between groups. Focusing on the dissemination of knowledge for decision-making, the reported study did not examine their active use as boundary objects at the interface between diverse groups. However, participant comments provided insight into a potential general application. One participant noted that effective techniques for integrating Western science and place-based information such as MEB reporting would be useful for both internal and external agency communications. For example, internal briefing papers about the Arctic could be sent to people in headquarters offices in Washington D.C. who are far removed from changes on the North Slope. This group is likely to understand the value of local and Indigenous knowledge more if its contribution of context to Western science is made more visible. Concurrently, in the interest of transparency, agencies must demonstrate how they are using the local and Indigenous knowledge they collect. Formatting techniques that appeal to broad audiences can illustrate how agencies are integrating these knowledge sources in their work (Follow-up interview #4).

DISCUSSION

The reported pilot study was undertaken to address deficiencies in current reporting conventions that can impede the translation of place-based information like local and Indigenous knowledge across disciplinary boundaries. The reported research utilized MEB assessment as a boundary work scenario where knowledge from multiple communities of expertise was assembled into a report with the intent of providing a holistic understanding of the reported issues for public agency decision-makers. The sample reports and the context-rich images within them were evaluated based on their ability to function as boundary objects that facilitate the transmission of information to decision-makers. Additional criteria for the evaluation of these objects was derived from the work of Clark et al. (2016) who highlighted credibility and salience as key factors influencing the usefulness of knowledge in scenarios similar to MEB assessment.

The integration of context-rich images into MEB documents may be considered unconventional. As such, for new approaches to become adopted as standards, it is necessary they be congruent with existing conventions that are already well-accepted (Rayner et al., 2005). Pilot study participants rated the MEB documents equally or more credible than Report A (baseline). This finding implies the MEB approach to reporting information to public agency decision-makers had no adverse impact on the reception of that information among study participants, and adds support to increased application of MEB approaches in practice. Where current conventions often separate place-based information and formal science into different sections of the same report, MEB documents are an alternative approach to present other relevant knowledge sources on equal footing with Western science, thereby minimizing the likelihood that decision-makers will neglect or ignore it (Ascher et al., 2010).

The reception of context-rich images among study participants was mixed. Report C (baseline + quotes + context-rich images) was rated as equally or more credible than Report B (baseline + quotes). Where Kress and Van Leeuwen (1996) posited that scientifically trained audiences are likely to ascribe greater truth to abstracted images of generalizable scientific information, our findings reveal that the same audience may also find context-rich images to be trustworthy. Non-positive comments related to the credibility of context-rich images focused on the paintings in particular (**Figures 2**, **3**). The paintings were included in the sample report as Native artwork that could potentially convey local information or experience in an authentic way that was outside of the compositional structures of Western culture. While the paintings may have excelled in transmitting experiential information, they also shifted the tone of the document to a degree that caused one participant to question the objectivity of the information being presented. While this finding does not altogether negate the potential benefit of paintings and other similar context-rich images as boundary objects, it is an indication of a potential threshold denoting the bounds of acceptable information for this particular target audience.

Salience was a key factor determining the potential usefulness of the MEB documents and context-rich images for decision-making. Participant comments indicated that the integration of local quotes in Report B (baseline + quotes) provided additional useful information that was not included in Report A (baseline) such as evidence that the statistically detectible environmental changes summarized in the report are significant enough to have a perceptible impact on local people. Phenomena that are detectable in the data are not always perceptible to humans, yet the quotes provide an indication that observed changes are having an appreciable impact on people's lives. Participants also commented that both the images and the quotes were beneficial because they show the societal relevance of the science and help readers understand what environmental conditions mean to people who live and work in the Arctic. Additionally, positive comments indicated that the sample context-rich images were a useful tool that aided quotes in the explanation of local context and experience of Northern environmental changes to outside audiences. This benefit might be particularly helpful for readers who are visual learners (Felder and Silverman, 1988).

Some participant comments indicated that particular context-rich images were not successful at providing additional useful information. The strength of the association between the figure and the information it was paired with was key in this respect, highlighting a major concern for the selection and application of context-rich images in MEB reporting. Technical documents are largely composed with verbal text in mind (Salinas, 2002). This means that visual design is restricted to the coordination of visuals as secondary to text in layout and document design (ibid.). An alternative approach might consider the larger cultural impact of images, which are primary to how we read and communicate today, particularly in the realm of electronic media (Salinas, 2002). However, the ability of images to take a primary role as drivers of content in this study was limited by the lack of high resolution scientific observations available for the Arctic region, especially in the near-shore environment, which is the area most relied-upon by local people (Carmack et al., 2015). The lack of high resolution data available via remote sensing has been identified as a challenge for local scale planning and decision-making in relation to Arctic environmental change (Vargas-Moreno et al., 2016).

A similar challenge in place-based research stems from the difficulty of acquiring images that adequately and precisely communicate place-based research findings (e.g., the social context within which the results occur) after data collection activities have concluded. However, the fields of anthropology and sociology offer the complementary photo-elicitation method, which is likely to provide benefits both in relation to the above challenge and toward the generation of rich discussion during research interviews. Simply described, photo-elicitation involves inserting a photograph (or other visual) into an interview, which has the effect of stimulating participants and evoking responses unlikely to be obtained otherwise (Harper, 2002). In photo-elicitation, research participants themselves may be asked to provide an image for discussion, which ultimately satisfies a dual purpose of both promoting discussion and helping the researcher collect context-rich images through which study findings can be more precisely communicated.

The perceived legitimacy of the MEB documents and context-rich images is also an important concern. The question of who gets to decide what information is relevant and how it should be presented to decision-makers is indicative of the level of agency afforded to local and Indigenous people in decision-making processes. This reported pilot research contributes to the development of communication approaches intended to strengthen local agency by increasing the prominence and accessibility of local and Indigenous knowledge among information used by decision-makers. The place-based information and context-rich images included in the sample reports were verified by local Indigenous advisors from the Wainwright Study (Curry, 2019). However, local advisors were not involved in the curation of information that resulted in the final sample reports for this pilot study. The Western researchers who produced the original technical data included in the sample reports were also not consulted in the curation of the reported information. This process is reflective of how research is often synthesized for decision-makers in practice where the breadth of available information goes through levels of screening and framing before it makes its way to senior administrators (Ascher et al., 2010) who have many decisions to make within a limited timeframe. Those responsible for screening and framing activities might be knowledgeable experts or they might be entry-level personnel. In either case, there is potential for bias to unintentionally guide the selection and interpretation of information. A likely means of reducing such bias and improving the legitimacy of MEB sample reports and context-rich images is by validating the synthesized product with relevant experts such as the Indigenous knowledge holders and Western researchers from whom the information was sourced (Shenton, 2004).

CONCLUSION

The Images as Information Pilot study furthers the proposed methodology designed to evaluate an MEB reporting approach that integrates quantitative environmental research and place-based research. The pilot study findings indicate that context-rich images might improve communication of place-based information beyond the potential of basic text (e.g., quotes, narrative), which has beneficial applications for environmental decision-making and for place-based research in general. Furthermore, an MEB approach to reporting information from two separate knowledge systems may have no adverse impact on the reception of that information, and could offer a means to present alternative knowledge sources on equal footing with Western science. This is a necessary consideration given the persistence of organizational norms and disciplinary conventions that privilege quantitative Western science over other sources of information (Rayner et al., 2005; Martin, 2007; Lemos, 2008).

Overall, this pilot study supports the validity of the reported methodology for the evaluation of visual tools and reporting formats intended to addresses a need for proven methods of knowledge brokering and communication that facilitate the transmission of place-based knowledge for decision-making (Lemos, 2015). The two-phase mixed methods approach, informed by key informant interviews, applied the strengths of questionnaire and interview data enabling not only the identification of patterns across participants, but also the verification of findings and the collection of rich information (Shenton, 2004). Given its small sample size, the results of the pilot study cannot be generalized. Still, it is a point of departure for future research, which is significant given the persistent challenge of interfacing underrepresented knowledge sources in environmental governance efforts (Raymond-Yakoubian et al., 2017). Further research is necessary to determine if the anticipated benefits of the tested MEB techniques are realized in practice, especially considering the potentially diverse range of topics and organizational settings in which they might be applied. An ideal setting for the next iteration of this research would be in collaboration with ongoing reporting initiatives within environmental resource management agencies, particularly involving communication between local/regional offices and their counterparts in state/national headquarters that are far removed from the local impact of environmental changes. Such experiments in communication can be relatively low-cost and would provide valuable insight about the effectiveness of new techniques aiming to increase the usability of underrepresented knowledge sources in environmental governance.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author. Information may be withheld pursuant to the terms of the Wainwright Study and Pilot Study informed consent agreements.

ETHICS STATEMENT

This study was conducted in accordance with the recommendations of the Institutional Review Board (IRB) of the University of Alaska Fairbanks (IRB approval numbers: 767319-5 and 1343902-1).

AUTHOR CONTRIBUTIONS

TC and EL made substantial contributions to the conception and design of the work, approved the final version to be published, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. TC and EL were involved in the analysis and interpretation of data for the work. TC drafted the work and EL revised it critically for important intellectual content. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2020.00043/full#supplementary-material

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Using Data Sonification to Overcome Science Literacy, Numeracy, and Visualization Barriers in Science Communication

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Sharing the complex narratives within scientific data in an intuitive fashion has proven difficult, especially for communicators endeavoring to reach a wide audience comprised of individuals with differing levels of scientific knowledge and mathematical ability. We discuss the application of data sonification—the process of translating data into sound, sometimes in a musical context—as a method of overcoming barriers to science communication. Data sonification can convey large datasets with many dimensions in an efficient and engaging way that reduces scientific literacy and numeracy barriers to understanding the underlying scientific data. This method is particularly beneficial for its ability to portray scientific data to those with visual impairments, who are often unable to engage with traditional data visualizations. We explore the applications of data sonification for science communicators and researchers alike, as well as considerations for making sonified data accessible and engaging to broad audiences with diverse levels of expertise.

Keywords: data sonification, science communication, science education, visual impairment, science literacy, numeracy, data visualization, multidimensional data

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INTRODUCTION

Conveying complex scientific narratives to a broad audience has been an ever-present challenge for science communicators and educators. The magnitude of this challenge has grown as studies in the sciences and social sciences have become increasingly more interdisciplinary in their exploration of systems and interactions (Klein, 2004), requiring both depth and breadth of knowledge across multiple fields to appropriately characterize the scope and impact of phenomena, such as climate change. Richer, more multidimensional datasets present new challenges: a three-dimensional plot, for example, reduces interpretability in comparison with a two-dimensional one (Amini et al., 2015).

In public communication, lack of scientific literacy and numeracy compound this problem. We suggest that a change in modality, from graphical representations to auditory ones using a process called data sonification, can reduce these barriers by creating an alternate way to engage with complex scientific data. This experience can be enriched by, but does not require, prior scientific expertise. Sonified data has also been theorized to require less time in training compared to visual data (Hegg et al., 2018). Data sonification's ability to convey a number of dimensions at once, as well as its potential to highlight local interactions between variables, makes it a powerful tool for data exploration for not only educators, but also scientific researchers. We will explore both of these applications, as well as sonification's unique potential to convey scientific data for the visually impaired, for whom graphical representations present greater challenges.

We regard any mapping between data and sound as a data sonification (Lodha et al., 1997; Dunn and Clark, 1999; Vickers, 2016). Such a mapping may exist in a scientific context, as an auditory graph, or in a musical context, as a work of data-driven music (Scaletti, 2018). To illustrate evaluative criteria of both these contexts, we focus on a project undertaken as both a scientific data sonification and a work of data-driven music.

DATA SONIFICATION: A PRIMER AND CASE STUDY

Reporting on data sonification for the National Science Foundation, Kramer et al. (2010) summarized the method clearly as the "transformation of data relations into. . .an acoustic signal," with sonar and the Geiger counter among the early notable examples; the field progressed significantly during the 1980s and 1990s (Frysinger, 2005). The nature of that transformational process may directly map data to sound or may apply more creative and open-ended mappings. The results can be as diverse as a stream of numbers changing a sine wave's frequency, in the case of an auditory graph, or, in a musical context, an orchestral composition that renders the data through conventions of music theory.

For science communication purposes, the translation from data into audio reveals changing variables to the listener through changes in sonic dimensions, such as frequency, pitch, amplitude, and location in the stereo field. In musical contexts, data can map to these sonic dimensions, as well as higher-order musical dimensions, such as tempo, form, and timbre. It is relatively easy for us to attend to changes in each of these elements simultaneously, as many aspects of hearing are intrinsically multidimensional (Hermann et al., 2011). As a mental exercise, think of a song you like, and speed it up or change the instruments it features. Because a sonification must play out over time, many sonification examples represent time series data, such as salmon migration patterns (Hegg et al., 2018), and brain wave fluctuations (Parvizi et al., 2018).

When undertaken in a musical context, data sonification may facilitate or augment the learning process. A range of studies (reviewed in Rickard et al., 2005) have found that passive and active music listening improve performance on a range of cognitive tasks including reading comprehension, mathematical and general IQ test performance, visual-spatial tasks, and learning and memory.

For a more detailed case and thought experiment, we can walk through our sonification of an ecological study (Oakes et al., 2014) on the effects of climate change on the Alaskan yellow cedar tree. The audio can be found here - http://stanford.edu/~sawe/alaskanyellowcedarsonification.wav. Oakes et al. painstakingly surveyed thousands of trees across 50 vegetation plots, including five conifer species with over 30 documented variables per tree. While there was not an explicit time series element to the data, geographic latitude became a proxy for time in what is called a chronosequence: climate change had longer to impact the southern range of the forests, and so effectively, north to south told the temporal story of climate change's impacts on the forest composition. As Oakes et al. traveled south along the Alaskan coastline, the yellow cedar died off, replaced by western hemlock. This sonification maps the data to several sonic parameters, with the twin goals of rendering audible patterns in the data and creating an aesthetically satisfying musical experience that tells the story of the Alaskan forests.

To sonify the data, we chose Western orchestral instruments to represent each of the five conifer species. The yellow cedar, the central figure in the narrative, played the piano; the western hemlock was the flute. The Sitka spruce, with its wood often used to create stringed instruments, played the cello, the mountain hemlock played the violin, and the shore pine played the clarinet. Every tree was represented by a note, and the note's characteristics reflected those of the tree: the height of the tree was mapped to pitch, and its diameter was mapped to velocity (the force with which the note was struck). The fullness of the tree's crown was reflected in the note's duration. If a tree was dead—as many of the yellow cedars were in the southern plots—it was instead represented by a musical rest (silence). The form of the sonification maps direction to time: beginning with the northern-most plot and ending at the southern-most plot, it traverses the experiment's fifty tree plots from north to south, devoting an equal amount of time to each.

Explaining these mappings takes less than 30 s and anchors the listeners with a concrete understanding of what transpires within the data. When the yellow cedar's piano grows increasingly sporadic and quiet as the sonification proceeds, and the western hemlock's flute rises to prominence, listeners have the potential to grasp the study's core narrative at a visceral and intuitive level. Ability to comprehend a graph or regression table is unnecessary. And because the ecological variables were mapped to palpable musical parameters, such as loudness and rhythmic event density, listeners are able to directly infer individual tree characteristics and localized forest species compositions, details which are otherwise obscured when aggregated in the study's journal figures, and inaccessible in their complexity when viewed in raw data tables. The accessibility of the sonification led to widespread coverage by media outlets (Kahn, 2016; Nijhuis, 2016; Rassler, 2016).

LEARNING AND THE SENSES: TEACHING MODES AND VISUAL IMPAIRMENTS

The idea that individuals have different holistic "learning styles" determined by predominant reliance on one of the senses (visual, auditory, and kinesthetic) has been widely mythologized; yet experimental evidence does not support such claims (Pashler et al., 2009; Riener and Willingham, 2010). However, presentation modes that leverage differing aspects of senses can still aid in the understanding of data, with differing receptivity across individuals. Statistical learning improves when presented through an auditory modality rather than vision or touch (Conway and Christiansen, 2005). Similarly, the ability to recognize patterns in information is improved in auditory over visual modalities (Rubinstein and Gruenberg, 1971), a result not altogether unsurprising given our frequent engagement with musical rhythm and meter.

Combining visual and auditory presentation modes is also likely beneficial. According to the modality effect, presenting some information in visual format and other elements in audio can effectively expand working memory capacity, reducing cognitive load while facilitating the integration (and hopefully retention) of information (Mayer, 2014). Sound has been shown to facilitate visual learning, arguing for multisensory training for new skills (Seitz et al., 2006), and to augment visual interface tasks (Brewster, 1997). Adding visual monitoring to an auditory monitoring task has been shown to impair performance transiently, with performance returning to normal relatively quickly (e.g., ∼25 task trials) (Peres and Lane, 2005). However, in data sonification experiments, combining the modalities increased response time in listeners attempting to comprehend modeled ecological data, and the majority of listeners reported that the visuals were unhelpful or even detrimental to interpretation, competing for their attention (Hegg et al., 2018). Further research may identify the optimal ways to combine both methods for data interpretation and retention.

An obvious benefit of data sonification is its interpretability for those with visual impairments who may not be able to readily obtain analogs of traditional data visualizations. Informal learning environments (ILEs), such as museums, zoos, and aquariums, where data sonification could complement existing methods of instruction, rarely have accessible exhibits for the visually impaired. In a national survey of ILEs, 51% of respondents reported that fewer than a quarter of their exhibits were accessible to the visually impaired (Tokar, 2004). This has led visually impaired individuals to avoid ILEs, stating that there are not sufficient activities for them to engage with (Landau et al., 2005), a finding that led a group of Georgia Tech researchers to create tools for sonification and auditory displays in ILEs (Walker et al., 2006). Data sonification would also obviously benefit education across age groups within more formal learning environments, providing an additional, more tangible tool for the visually impaired to interpret textbook studies.

However, most instances of sonification research for the visually impaired are for assistance with daily life and navigation (Velázquez, 2010; Mascetti et al., 2016), and studies of engagement with the sonification of geographic or scientific (e.g., gas particle models) data show promising results but are often in the exploratory or small-sample-size stages (Delogu et al., 2010; Levy and Lahav, 2012; Weir et al., 2012). While further research into data sonification can help to quantify the learning benefits for both sighted and visually impaired individuals, the modality certainly offers engaging ways for the visually impaired to interact with informal learning environments and scientific textbook studies that would otherwise be inaccessible to them.

CHALLENGES WITH SCIENTIFIC AND GRAPHICAL LITERACY

Exacerbated by demographic and socioeconomic factors, deficits in public science literacy, graphical literacy, and numeracy impede scientific understanding (Allum et al., 2018). There is also a large degree of heterogeneity in whether individuals prefer graphically or numerically represented data, and which they find more accessible and intuitive (Politi et al., 2011), due perhaps to differing capacities for visual literacy (Avgerinou and Ericson, 1997).

Individuals with low science knowledge may feel improperly equipped to parse the scientific content they encounter, leading to disengagement or feelings that it is "too difficult" to grasp. In a survey by Pew Research Center and the Smithsonian, a representative sample of over 1,000 US adults were asked the key reason that young people avoid careers in math and science. The most common answer (46%) was that science and math were "too hard" (Monmaney, 2013). Scientists must create ways to overcome this perception and make STEM material more accessible and relatable without additional science literacy requirements, to engage individuals who do not feel qualified or empowered to navigate that material.

In a 2019 Pew Research Center report, 29% of the US respondents studied were categorized as possessing low scientific knowledge, scoring 0 to 4 correct answers out of 11 test questions (Kennedy and Hefferon, 2019). The International Literacy Survey places approximately half of Americans without the minimal numeracy skills required to utilize numbers in printed materials (Kirsch et al., 2002). This negatively impacts the ability to make decisions about their own health, finances, and other everyday decisions, compromising the ability to grasp risk magnitudes, percentages and proportions, and probabilities (Hibbard et al., 2007; Peters et al., 2007). Experiments have shown that presentation formats which reduce the required cognitive effort and improve ease of interpretation aid in complex decision-making, particularly for those with lower numeracy skills (Gurmankin et al., 2004).

As science and social science data complexity has grown over time (Klein, 2004), an understanding of multivariate datasets has also become increasingly relevant for parsing current events and assertions from news sources (Engel, 2017). Educators advocate for earlier education in data science and statistical literacy in order to foster an engaged and informed citizenry (Engel, 2017). If an engaging, holistic, and even emotional grasp of trends in multivariate datasets can be obtained through sonification, however, this creates a cognitive shortcut to understanding for individuals whose educational institutions may not yet provide such data science training. Mathematics education professor Joachim Engel asserts:

> Making sense of multivariate data does not necessarily involve advanced sophisticated multivariate statistical procedures as often applied in social science research (e.g., factor analysis or logistic regression). Rather, it involves understanding multivariate *phenomena* and is based on developing sound

heuristics, including awareness of biases and fallacies (Engel, 2017).

Data sonification can provide one of these sound heuristics by revealing the structure of underlying data and reshaping prior misperceptions.

In doing so, sonification creates an alternative or complement to the graphical representations otherwise necessary to understand large-scale data, which require different interpretive skills than those traditionally taught in current curricula that focus on smaller sample sizes (Engel, 2017). Graph literacy is a skill that correlates highly with numeracy, and in the US, with education (Galesic and Garcia-Retamero, 2011). However, about a third of low-numeracy individuals are helped greatly in data comprehension by the presence of graphs (Galesic and Garcia-Retamero, 2011), indicating that varied presentation methods can help surmount deficits in understanding of core data concepts. Graphical literacy is highly subject to individual differences (Politi et al., 2011), and so supplementary graphs are unlikely to be a cure-all for data comprehension. The degree to which data sonification can aid in data comprehension for those with low numeracy or low graphical literacy, and the proportion of the population whose data comprehension would benefit from this modality, remain open questions.

While individual differences may inform which methods of data presentation are most beneficial to understanding, baseline comprehension of science and math is unfortunately not distributed equally. With structural, geographic, social, and economic factors that combine to compromise much of the US population's interactions with scientific data, science communicators should be vigilant in searching for accessible ways of conveying that data that depend as little as possible on prior experience and preconceptions, while still offering the potential to dive deeper and more substantively into the data for those who so desire. Below, we offer a way of thinking about how to sonify data for accessibility, so that science communicators can best determine how the method might share their knowledge with a wider audience.

SONIFICATION MAPPING DESIGN CONSIDERATIONS

The nature of the data itself constrains possible sonic mappings: categorical variables (differences of kind) that do not change in time can only map to discrete parameter choices that do not vary during the sonification, such as instrumental timbre, while continuous variables (differences of scale) may translate into frequency or tempo, which may change continuously in time (Walker and Nees, 2011). Hegg et al.'s data sonification experiments found that participants were most sensitive to transitions in pitch and timbre, yielding the recommendation that the most important elements of the data should be mapped to these elements given their primacy (Hegg et al., 2018). Psychoacoustics literature can provide an empirical roadmap—for example, showing how we cue to pitch perception over space perception (Deutsch, 1975)—but a great deal of flexibility remains in the sonification process. Accessibility concerns must also be considered; for example, sighted and congenitally blind listeners experience pitch height differently (Eitan et al., 2012). Science communicators therefore need to strike a balance in the sonification of their data between four key but interrelated elements: fidelity to the data, level of complexity, aesthetics, and accessibility.

Data Fidelity

How closely does the sonification represent the original scientific data? Some cases draw a clear relationship between data and sound: in a time series mapping of brain activity to pitch to hear seizures in epileptic patients, a simple power law relationship traces the microvolt amplitude of brain activity using pitch height (Parvizi et al., 2018). However, in instances where there is no clear variable to map to pitch, given how strongly we cue to this element of sound (Hegg et al., 2018), one might imagine a sonification composed of chord progressions, the structure of which is defined by higher-order moments in the data (e.g., slope, skewness, kurtosis) or weighted averages of multiple variables. While such mappings might provide a clear holistic picture of the shape of the scientific data, or draw attention to specific aspects, the relationship between the raw data and the audio becomes increasingly abstracted, potentially increasing the difficulty in conveying the science behind the sound. Sonification mappings range from the direct to the symbolic or metaphorical, with varying outcomes in ease of interpretability and learning (Keller and Stevens, 2004).

When scientific data remains unintuitive or requires too high a knowledge level, some aspects of scientific data may need to be eschewed entirely. Confidence intervals and compounding uncertainties are examples (Jones, 2000); we respond non-linearly in the subjective weightings that we assign to probabilities and expected rewards (Hsu et al., 2009; Winman et al., 2014), and we are strongly influenced by uncertainty (Wu and Gonzalez, 1999), which has presented challenges for the Intergovernmental Panel on Climate Change. In some cases, science communicators may need to consider aspects of the way this information is traditionally processed, and assess whether to counteract or reinforce these perceptual and cognitive biases.

Complexity

While sonification offers a favorable medium for conveying multivariate datasets, science communicators must still critically assess the degree of complexity in the narrative they are relating. How many dimensions are represented? What is the scale of the dataset? Are there ways to simplify, or sample from a subset of the data, while still accurately representing the whole? Can trends be used in place of individual data points? How do documented perceptual thresholds and boundaries of sound and music cognition constrain the narratives that one might construct?

The linear, time-dependent presentation of sonification data mitigates this complexity and keeps it in a digestible format: by slowing down the rate at which data is translated into audio, science communicators can provide listeners with the necessary time to process and interpret that data. Here, too, lies a trade-off, as one should not assume a captive audience, or one with the luxury of time. Thought should be put into the delivery method and audience surroundings. How many people can access the sonification at the same time? What are the attentional and cognitive demands on the audience? These pragmatic constraints will lend insight into how ambitious the data complexity should be for a given setting. For example, the IceCoreWalk project (Chafe, 2019) is a narrated sonification that traverses 800,000 years' worth of CO_2 and temperature data in the time it takes to walk the length of the ice cores that provided the data (3 km). Self-directed pacing keeps the data manageable: the listener can walk with a group or solo, can move continuously or make stops, and can take in their surroundings while absorbing the data. Additionally, voiceover narration can help draw the listener's attention to key changes in sonic parameters.

Aesthetics

With so many sound design choices available, thinking carefully about aesthetic decisions is crucial. Are acoustic or synthesized sounds used? Are traditional musical instruments employed, and if so, from what culture and genre? Do the authors intend the sonification to be used as an auditory graph, or to be experienced as a musical composition, gallery installation, or soundwalk?

Data sonification need not necessarily be musical in nature, and many scientifically-useful auditory graphs are not particularly musical, or even pleasant to listen to. There are some rationales for abstracting the sonification (as we'll see in our discussion of musical choices below), and abstraction can bring some interesting choices to the communicator. For instance, audio connected to the dataset itself (e.g., whale sounds) can tie the listener more directly to the content. Likewise, sonifications may employ sounds that are "signal-referent" but indirectly related, such as using the sound of a striking match to represent a fire (Keller and Stevens, 2004). These indirect representations rely more strongly on the listener's associative memory to draw connections between data context and sonification (Keller and Stevens, 2004). A range of creative virtual studio technologies (VSTs) plugins and sound libraries offer a wealth of opportunities for such mappings, such as Soniccouture's *Geosonics*, which morphs field recordings of glaciers calving and frogs chirping into playable instruments. Searchable online databases of public domain audio files, such as freesound.org and BBC Sound Effects Beta, enable scientists to efficiently find, listen to, and utilize iconic domain-specific audio in their projects. The abstraction of less familiar sounds may come at a cost, however, decreasing the interpretability or relatability of the piece or prompting disengagement by the listener before they have fully understood what the sonification was trying to communicate. On the other hand, synthesized sounds can change in more subtle and precisely mapped ways than many sample-based western orchestral sounds can, due to the difference between pre-recorded and synthesized sound.

Imposing norms and structures informed by music theory onto the data has both benefits and disadvantages. The choices of scale, range, instruments, tempo, and so forth will heavily influence the interpretation of the data by the listener. For instance, we utilized the d minor scale in our sonification of the yellow cedar data, knowing that the underlying dataset characterized the decline of an iconic species, and that minor scales correlate with the emotion of sadness (Juslin and Laukka, 2004). Yet the yellow cedar's decline is counterbalanced by the rise of the western hemlock as the piece continues; viewed through this lens, one could easily frame the story as one of emergence and change, and instead play the piece in a key meant to evoke opposite emotions. Science communicators need to be cautious in such decisions. Because music evokes affective states, deciding how strongly to connect the data to emotional characteristics of the sonification, and in what ways, must be a conscious choice and responsibility. The affective states that data sonification may elicit—even while faithfully representing a dataset via a systematic and direct mapping rubric—hold the potential to exacerbate issues of science communication as advocacy or even, in the extreme, manipulation, all without using a single word. This opens up the possibility for both more ambiguous and more misleading implications, depending on the way the data is represented.

Aesthetic data interpretation choices may also influence the extent to which the data sonification facilitates improvements in cognition. Spatial-temporal task performance in the presence of music was found to depend on the tempo and mode of the music (which relate to psychological arousal and mood, respectively), with a preference for fast, major mode pieces (Husain et al., 2002). Thus, particular mapping approaches may better facilitate different types of learning goals.

Peer group determines musical preferences that echo from our formative years into adulthood (North and Hargreaves, 1999; Creed and Scully, 2011). A number of studies have analyzed those broad preferences to identify the separate factors that help determine those preferences (Colley, 2008; Delsing et al., 2008; Rentfrow et al., 2011). Individual differences in musical preferences determine what types of musical representations best suit a particular audience, and whether genre choice may be alienating. In interactive sonification contexts, such as museum exhibits, it may be possible to compose multiple translations of the same dataset to convey the same information across a range of musical genres, styles, moods, and instrumentations, leaving the choice to the listener. However, this might place undue emphasis on these musical aspects over the data itself, distracting from the narrative of the scientific data.

Benefits for Science Exploration

Data sonification can help tell the story at the heart of the data to not only the general public, but scientific experts as well. The auditory system has been theorized to be especially well-suited to trend identification (Walker and Nees, 2011), with similarities between trend and melodic contour (the abstracted shape of a succession of sonic frequencies in time). This capacity of the auditory system for pattern detection, as well as its excellent temporal resolution, can facilitate data exploration (Walker and Nees, 2011). Our hearing is well-suited to identify and contrast periodic and aperiodic events, as well as detect small changes in frequency within continuous signals, enabling us to extract complex data that might be embedded deeply within both static and noisy signals (Kramer et al., 2010).

The capacity of data sonification for simultaneous representation of many data dimensions is one of its greatest strengths for data exploration. Various traditional ways of engaging with data, such as regression analyses, can encounter problems with collinearity that compromise the ability to include the full array of variables from a rich data set. Similarly, standard graphing techniques represent only a few dimensions at once. These shortcomings can make it more likely for researchers to miss complex interactions between several variables, especially if they were not posited *a priori*, or if they occur only under certain conditions, such as within certain time windows. Data sonification allows researchers to stumble upon new patterns and questions when exploring their data. In this way, data sonification performs much the same function for scientific experts as it does for the general public: sonification clarifies the data's narrative and suggests a path forward for inquiry.

CONCLUSION

As interdisciplinary explorations of rich datasets in the sciences and social sciences uncover vast interconnections between many variables that explain the systems we observe in the world around us, the challenge for science communicators attempting to balance data complexity, fidelity, and comprehensibility is more difficult than ever. The scientific narratives that result from such exploration need to be conveyed clearly and accurately, in ways that faithfully represent the underlying data while still remaining engaging the general public. Because scientific knowledge, numeracy, and graph literacy are not equitably distributed across the population, traditional visualization methods may require skills and knowledge that present a barrier to engagement for many individuals who science communicators desire to reach.

Data sonification offers a unique tool in the toolkit of science communicators that can surmount some of these challenges, thanks to the unique ways in which our auditory system processes information and detects patterns, as well as the medium's creative and aesthetic opportunities for facilitating engagement (e.g., through musical renditions of data sets). It also enables those for whom traditional visualization methods are inaccessible, such as the visually impaired, to engage meaningfully with rich data sets. It is data sonification's potential for more accessible science communication on a variety of fronts, while enabling exciting new opportunities for data exploration, which warrants its application in a wide array of science communication contexts, from articles to classrooms to informal learning environments. There are many ways to tell the stories underlying scientific data, and as science communicators, we should endeavor to ensure that those stories reach as many ears as possible.

AUTHOR CONTRIBUTIONS

The manuscript was written by NS, with additions from CC and JT, and revised by NS and JT. The Alaskan yellow cedar data sonification project used as an example employed an algorithm by NS to transform data to music, this was rendered into a MIDI music data file by CC, and into musical notation by JT for a previous publication.

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The SciCommDiversity Travel Fellowship: The Challenge of Creating a Sustainable Intervention

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Diversifying a community requires outreach, recruitment, and retention which in this case targets the science communication (SciComm) workforce. Establishing a strategy to accomplish such diversification includes designing, launching, and sustaining the new intervention. Here we review the 6-years history of the DiverseScholar SciCommDiversity Travel Fellowship. This intervention was designed to build a community of minority science communicators that would interact with experienced professionals at the ScienceWriters conference. The travel fellowship reduces the financial burden of conference attendance while introducing the fellows to mentors who facilitate networking and knowledge-building during the event's professional development opportunities. The first two years of the fellowship were catalyzed by Idea Grants from the National Association of Science Writers—producers of the ScienceWriters event. Two strategies were used to engage potential fellowship applicants. First, we sought minority journalists interested in STEM topics who wished to extend beyond their standard reporting beats (tech, politics, etc.). Such student and professional journalists were found by networking with and producing conference panels at the National Association of Black Journalists and the Native American Journalists Association annual events. For the second strategy, we found minority scientists who were interested in exploring how to convert their social media and blogging activities to professional writing/reporting careers. We attracted such individuals through our activities at annual conferences such as the Society for the Advancement of Chicanos and Native Americans in Science as well as the Annual Biomedical Research Conference for Minority Students. Overall, one particular challenge of an intervention is financial sustainability once catalytic (grant) funds end. Here, we describe our model for a sustainable and synergistic intervention that positions the SciCommDiversity Travel Fellowship within the overall program of DiverseScholar's doctoral recruiting services. The fellowship is now funded internally from advertising sales revenue from the DiverseScholar MinorityPostdoc.org career portal. The website, though, is more than just a job board since the travel fellows contribute original reporting to the online magazine. Thus, beyond just reducing financial barriers, the fellowship's mentoring, and publishing opportunities can advance a fellow's entry into the SciComm profession.

Keywords: science journalism, environmental journalism, health journalism, science communication, SciComm, workforce diversity, ethnic/racial underrepresented minority

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INTRODUCTION

A national call-to-action asks how "science communication [can] reach and be tailored to meet the needs of audiences that vary by race, ethnicity, language status, income, and education level" (National Academies of Sciences Engineering and Medicine, 2017). In describing the complexities of communicating science, the same report notes "that certain communication channels, modes, *messengers*, or messages are likely to be effective for communicating science with some groups and not others." We emphasized the word "messengers" in this quote to underscore that the diversity of the science journalism/communication workforce will be important for reaching specific audiences within the United States such as people of color who will tip the nation to be majority-minority by the 2050's (Pew Research Center, 2008). This demographic change is driven by the growth of the Latinx/Hispanic population which is estimated to reach one-third of the country's total population within a few decades.

Articles in the recent *Frontiers in Communication* "Inclusive Science Communication in Theory and Practice" collection argue for a new approach to public engagement that is sensitized to the needs of historically marginalized and minoritized peoples. A symposium has catalyzed a community of scholars and practitioners to work toward this goal (Canfield et al., 2020). In that report and others, fundamental definitions, goals, and theories map out the relationship of diversity, equity, and inclusion (DE&I) ideals to science communication (Polk and Diver, 2020). Furthermore, specific practical advice for science communicators is explained for reaching the multicultural audience that will become the norm in the United States (Landis et al., 2020). Our own contribution to this movement is the creation of a diversity fellowship to encourage minority participation in science communication.

For this community case study about our fellowship program, we use "science communication" (SciComm) to refer to the work of both news reporters and STEM researchers who inform the public about science, health, environment, and other related topics primarily through a written medium. This narrow definition of science communication reflects the applicant pool targeted for our fellowship intervention and so does not include informal education conducted in museums, nature centers, out-of-school time programs, etc.

We have not found specific controlled studies in the science communication empirical literature exploring the effect of communicator-audience diversity (mis)matching with respect to science news. However, testimonials describe the benefit to a reported story when a science journalist practices inclusive SciComm, for example (Kleyman, 2013; Mandavilli, 2013; Howard, 2014a; Crow, 2016; TON Editors, 2018; Haelle, 2019a,b). We suspect DE&I underlies "trust" issues in source-communicator-audience relationships (Fiske and Dupree, 2014).

SciComm practitioners can learn from the DE&I-related literature in the field of informal science education, for example (Streicher et al., 2014). A qualitative study examined the participation of low-income, minority ethnic individuals in science museum activities in the United Kingdom (Dawson, 2018). The study found that marginalized minorities experienced exclusion due to cultural imperialism and powerlessness since their SciComm interactions reflected the values and practices of dominant groups at the expense of the marginalized. More recently, a study interviewing underserved audiences in Germany described material and especially emotional factors that play a role in excluding certain groups from science communication engagement (Humm et al., 2020). This raises the concern that science journalism also replicates these potential inequities leading to exclusion.

Notably, some scholars are promoting an improved socially inclusive practice of science communication (Massarani and Merzagora, 2014; Canfield et al., 2020). Since "the public" is not a monolithic, homogenous population, who then are the reporters and communicators that are attuned to the (science) needs and interests of the heterogeneous "publics?" This is a particular concern for niche audiences that consume ethnic media. Indeed, there is an urgent call to reach underserved audiences who are "beyond the choir" that current science communication is often preaching to (Scheufele, 2018).

Journalism Diversity

According to a newsroom census, the wider journalism workforce is largely a white, male monoculture (American Society of News Editors, 2018). In the United States, specific culturally-minded professional societies serve to diversify the journalism workforce (Bravo and Clark, 2020). Relevant organizations for our work reported here include the Native American Journalists Association (NAJA), the National Association of Hispanic Journalists, and the National Association of Black Journalists (NABJ). As an example, we briefly describe the media ecosystem that informs NABJ's advocacy work.

Social justice-based news coverage in media outlets that target African-American and Black audiences often fail to see how STEM access and science literacy is a social justice issue. Opportunities to report on recent discoveries at Historically Black Colleges and Universities or by African-American scientists has largely been overlooked by the media that targets African-American audiences (Lee, 2010, 2013e). Additionally, lack of news coverage by ethnic news organizations on important topics such as energy, the environment, technology, product safety, personal health, and other science issues is partly due to the unease general news reporters may have in covering science-intensive stories (Lee, 2010) or the lack of freelance journalists pitching science news to these outlets (Lee, 2013e).

The African-American and Black community's relationship with science and medical research communities has been fraught with many challenges. News of African-American patients being used as unwilling research subjects or being left untreated by care professionals has been a widely known problem since at least the Tuskegee Syphilis experiment contributing to a sense of mistrust of science (Freimuth et al., 2001; Scharff et al., 2010). These misgivings about science continue among multiple generations of African-Americans (Lee, 2014d). However, we encourage an increased commitment to communicate both basic and applied science to African-American audiences. This may yield not only a better informed public but may also attract more diverse individuals to science and science communication careers (Lee, 2010, 2012, 2013e).

With a membership of more than 4,000, the National Association of Black Journalists may be the largest ethnic affinity professional journalism association in North America. The organization is charged with supporting the professional development of Black journalists as well as critiquing whether the news media covers the Black community fairly and inclusively. Founded in 1975, the membership is subdivided into professional divisions called Task Forces. Over a dozen NABJ Task Forces offer professional development and career preparation for its membership. Task Forces are sub-groups of professional and student journalists who work in Print, Broadcasting, and Digital Media or who cover common beats such as Arts and Entertainment, Politics, or Sports. More recently, focal topics have established Task Forces that bring attention to LGBT issues, Global Journalism, or Black Press (Lee, 2011b). Moreover, there is a history of social justice engagement among the NABJ membership at its annual meetings and at special events. Although news related to health disparities and environmental injustice experienced by African-Americans has attracted attention, NABJ has yet to establish a Science Communication Task Force (Lee, 2011b).

Science Journalism Diversity

Membership society demographics can act as a proxy of the diversity of the science-specific journalism workforce in the United States. The Society of Environmental Journalists (SEJ) states that its membership was 7% people of color (Nauman, 2015). The Association of Health Care Journalists (AHCJ) membership is 6% Asian-American/Pacific Islander, 3% Hispanic/Latino, 3% African-American/Black, 3% Multiracial/Mixed, and 1% American Indian/Alaska Native (Association of Health Care Journalists, 2019). Finally, a demographic survey of the National Association of Science Writers (NASW) described its membership as 2.8% Asian/Pacific Islander, 2.5% Hispanic/Latino, 2.1% South Asian, and 0.8% Black or African-American (Davis, 2015). We caution against any definitive conclusions or comparisons of those statistics between organizations since the surveys were conducted independent of each other. Furthermore, it is unknown if domestic vs. non-domestic residents were disaggregated for the various ethnic groups, (e.g., U.S.-born Hispanics vs. Latino/a citizens from Central and South America since these organizations attract an international membership).

This lack of diversity has motivated interventions to improve minority recruitment and retention in the science journalism workforce. A grassroots survey of minority science writers found that financial concerns were a reason why minorities may be underrepresented in science journalism (Diep, 2014). Such financial barriers are addressed by fellowships and travel award initiatives. The American Association for the Advancement of Science offers the Minority Science Writers Internship. SEJ has a Diversity Travel Fellowship for its annual conference. An Ethnic Media Health Journalism Travel Fellowship exists for the AHCJ annual meeting. The Metcalf Institute had a National Science Foundation funded Diversity Fellowship in Environmental Reporting. Lastly, NASW has offered a summer internship supplementary Diversity Fellowship. To our knowledge, none of these fellowships have been described in the peer-reviewed literature thus leaving a gap in how such diversity interventions are conducted and evaluated.

Hosting a Travel Fellowship

The lead author of this report, Roca, founded the non-profit DiverseScholar (fiscally sponsored by Community Partners) with the mission to diversify higher education faculty (Roca, 2011). Roca and co-author Lee conceived of the diversity travel fellowship to bring minorities to the annual ScienceWriters conference co-organized by NASW (Lee, 2014b). The operational overview of DiverseScholar illustrates how the travel fellowship is currently sustained (**Figure 1**). Co-author Coleman joined the DiverseScholar Advisory Board to add academic expertise about science communication to the project as well as her perspective about American Indian and Native American issues (Coleman, 2012b). This complements Roca's and Lee's practitioner SciComm experience since their formal education is in biochemistry and biology, respectively. Finally, co-author Haelle joined the application review committee and served as a mentor to the fellows drawing from her experience as an independent journalist and active NASW and AHCJ member (Haelle, 2019a,b).

DiverseScholar's MinorityPostdoc.org web portal serves as a career advice site and job board targeted to the audience of diverse PhD graduate students and postdocs. The monthly email newsletter to 1,100+ postdocs and the original articles of the online *DiverseScholar* magazine are additional communication channels. The DiverseScholar Doctoral Directory is a database of *curricula vitae* and resumes sourced from the listserv membership. Finally, similar to that of a diversity science professional society, the DiverseScholar Postdoctoral Conference is a mentoring and recruiting event meant to prepare PhD trainees for their careers and to introduce them to employment hiring managers, especially faculty search committees (Rodriguez and Roca, 2017). Importantly, all these activities generate revenue through website/newsletter advertising, database subscriptions, and event exhibitors/sponsors (**Figure 1**).

In this report, we describe our DiverseScholar SciCommDiversity Travel Fellowship, our outreach and diversity advocacy activities, as well as review relevant DE&I literature, advocacy, and testimonials. Much of the review cites practitioners publishing in online media/blogs.

TRAVEL FELLOWSHIP INTERVENTION

Our long-term goal is to diversify the science communication workforce in both the private sector and academia. Nurturing a talent pipeline to diversify a workforce requires outreach, recruitment, and retention of minority students and professionals. In the United States, many initiatives for diversifying the STEM and biomedical workforce (National Academies of Sciences Engineering and Medicine, 2011) can serve as models for interventions to affect the SciComm community. Such models and our own personal experience informed the design of our travel fellowship.

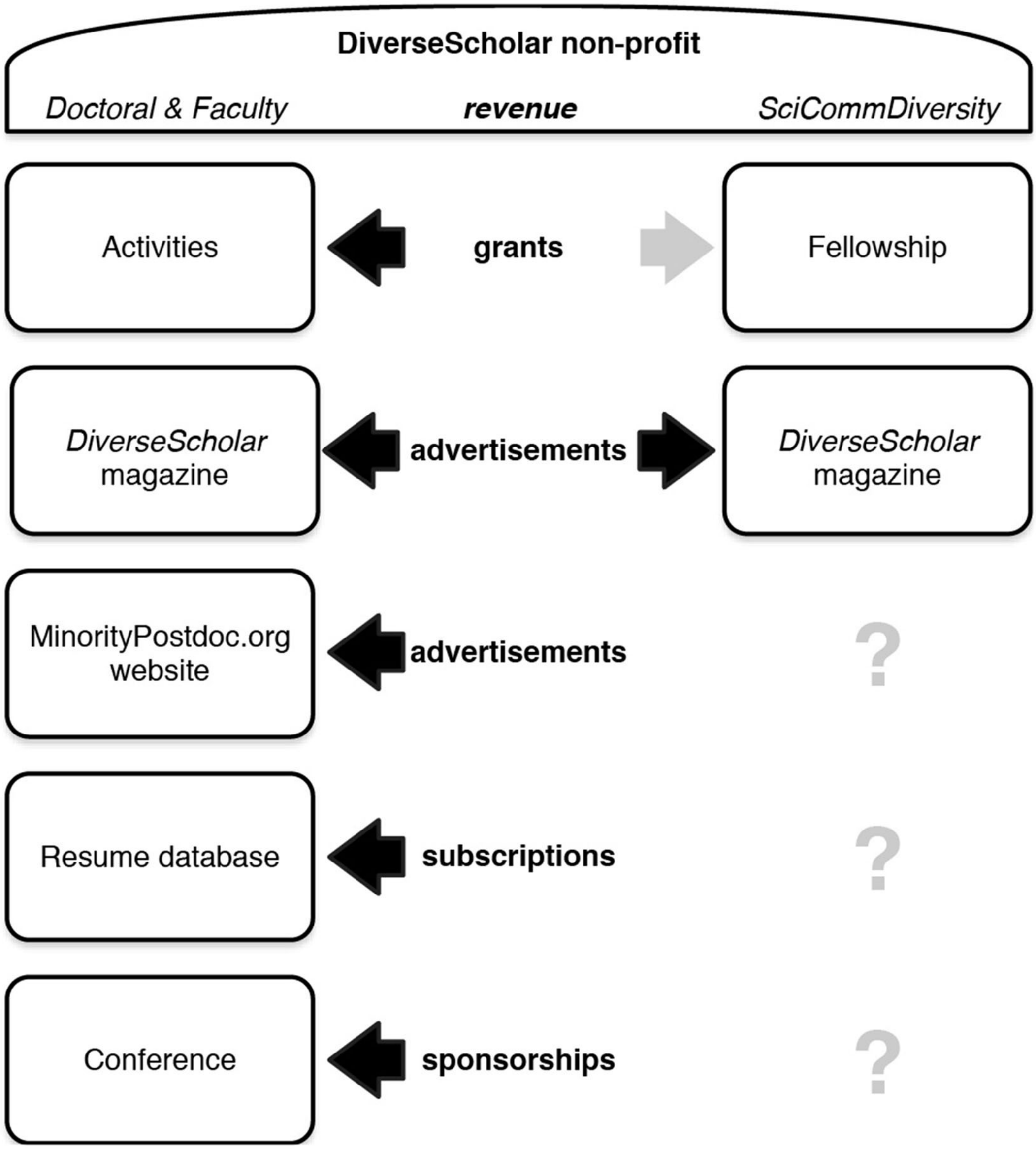

FIGURE 1 | Schematic of the relationship between the DiverseScholar non-profit and its projects. The MinorityPostdoc STEM doctoral activities (left column) are complementary to the SciCommDiversity Fellowship (right column) but the former has established revenue streams that are currently subsidizing the fellowship since the Idea grant ended after the first 2 years.

A logic model of the SciCommDiversity travel fellowship describes the intervention's inputs, activities, outputs, and outcomes (**Table 1**). This simplified model describes basic aspects of the intervention that the DiverseScholar non-profit administered allowing fellows to attend the ScienceWriters conference. This annual 5-days event is co-produced by NASW—a professional society of over 2,300 members consisting mostly of science journalists (Davis, 2015). The specific practical objectives of the SciCommDiversity fellowship are to reduce any financial and networking barriers to full ScienceWriters conference participation. This allows fellows to learn informally from the professional development sessions that discuss craft, to be recruited by hiring employers, and to meet experienced journalists who can mentor a fellow's career. The networking includes the opportunity to interact with editors to pitch story ideas so that news outlets can diversify their pool of freelance reporters. Thus, our theory of change is that the fellowship intervention facilitates the short-term career prospects for the fellows enabling a more diverse SciComm workforce in the long-term.

Note that we lacked the capacity to conduct a formal evaluation of the fellowship intervention. Furthermore, it was beyond the scope of the current report to conduct a social science study of the experience of the fellows. We leave that

TABLE 1 | Simplified logic model of the SciCommDiversity fellowship that the DiverseScholar (DivSch) non-profit administered allowing fellows to attend the ScienceWriters (SciWri) conference.

Inputs	Activities	Outputs	Outcomes
Applicants	Informal learning	Fellows	*Short-term:* improved career prospects
Mentors	Mentoring	Knowledge	*Long-term:* diversifying SciComm workforce
Funds	Networking	Relationships	
DivSch staff & volunteers	Peer-to-peer interactions	Psychosocial support	
SciWri event	Reporting assignment	Top-edited articles	

to future work drawing upon the theory and studies in science communication such as those about training (Schmidt, 2017; Menezes, 2018; Newman, 2020) as well as DE&I especially in higher education (Smith, 2009) and STEM (National Academies of Sciences Engineering and Medicine, 2011; Segarra et al., 2020).

The fellowship online application consists of a questionnaire collecting contact information, career stage, personal/professional demographic characteristics, and a *curriculum vitae* that includes citations to their published writing portfolio. The consideration of an applicant's publication portfolio underscores that this fellowship emphasizes writing skills. The application also required a 500+ word essay describing the role of diversity in journalism, summarizing the applicant's diversity advocacy experience (if any), and describing how ScienceWriters conference attendance would advance their professional career goals. The applicants were made aware that these essays would be considered for publication as *DiverseScholar* magazine articles for the final awardees.

The judging of the applications was conducted by the four co-authors Haelle, Coleman, Lee, and Roca representing their perspectives as a freelance science/health writer, science communications faculty, social media (#SciComm) advocate, and STEM diversity advocate, respectively. Each judge independently reviewed the applications and ranked their top choices. Roca combined the results and finalized the awardee selection process. As a new activity, we had no formal rubric for judging applicants. Considerations for ranking an application included the following questions. How was the quality of the writing? What was the applicant's experience or potential as a journalist? Who was most likely to contribute actively toward diversity as a journalist or science writer? How much did applicants depend upon the travel funds to attend the conference? Who would benefit most from the learning and networking opportunities at the conference? Whose essay demonstrated a clear understanding of DE&I? Which individuals would represent communities underrepresented in the science journalism workforce?

The SciCommDiversity.org webpage maintains a complete public roster of fellows, their biographies, and their social media accounts so we do not reproduce that information in this report. From 2014 to 2017, we awarded 20 travel fellowships. During the first 2 years, the fellowship was supported by two 1-year NASW Idea Grants with five fellows in 2014 and 10 fellows in 2015. The latter cohort was larger because more grant funds were allocated to the fellowships in the second year. In 2016, four fellows were funded using a combination of internal advertising revenue, donations raised from the DiverseScholar advisory board, and a contribution from science author Steve Olson. In 2017 and 2019, a single fellowship was awarded each year to an Honorable Mention awardee from previous application cycles using advertising sales revenue from DiverseScholar. Each fellow received $1,000 as a reimbursement toward their registration, travel, and lodging expenses incurred during their ScienceWriters conference participation.

During 2014–2016, 15 individuals were awarded an Honorable Mention—a "runner-up" category with an honorific title but without funding. The title also represented applicants who had scored well by the judges but ultimately were not able to attend the conference. Strategically, this category allowed us to identify future awardees in subsequent years without administering a full competition which we used to identify fellows in 2017, 2018, and 2019. Note that the single 2018 awardee canceled their conference participation which then voided the fellowship that year.

We wished to support both individuals still in training (i.e., bachelors or masters students), as well as those professionals already in the workforce. However, the lack of experience among students made it difficult to compare those applicant types especially with respect to the quantity of their published articles. Thus, within each awardee cohort, we attempted to balance the number of students and professionals supported by ranking them separately.

Among the fellows, eight of the 11 professional (non-student) awardees were freelancing for their writing work. This underscores the financial barrier that may exist for participation among journalists who do not have an employer to cover conference expenses. NASW offers their own travel fellowships funded by the Authors Coalition of America derived revenue which is the same funding source for the NASW Idea Grant competition now known as the Peggy Girshman Idea Grant (National Association of Science Writers, 2018).

Eighty-two individuals had applied for the fellowship between 2014 and 2016 yielding an overall award rate of ∼24%. The personal demographics of the applicants was not made available to the judges except for Roca who managed the entire application process. Among the 74 applicants who reported their age, the average was 31 ± 11 years old. Approximately 27% of the applicants identified as males while 85% of the applicants were U.S. citizens. All but two applicants self-identified their race/ethnicity (**Figure 2**) and were allowed to select more than one category such that the following numbers do not add to 100%: 37% Black or African-American, 33% Hispanic American, 17% Asian-American, 17% White or Caucasian (non-Hispanic), 6% American Indian or Alaska Native, and 4% Other. These racial/ethnic statistics were not drastically different when the non-U.S. citizens were removed from the calculation except that the "Other" category was reduced to 0%. We also collected affinity characteristics representing other categories of representation as follows for the applicants: 29% low socioeconomic background,

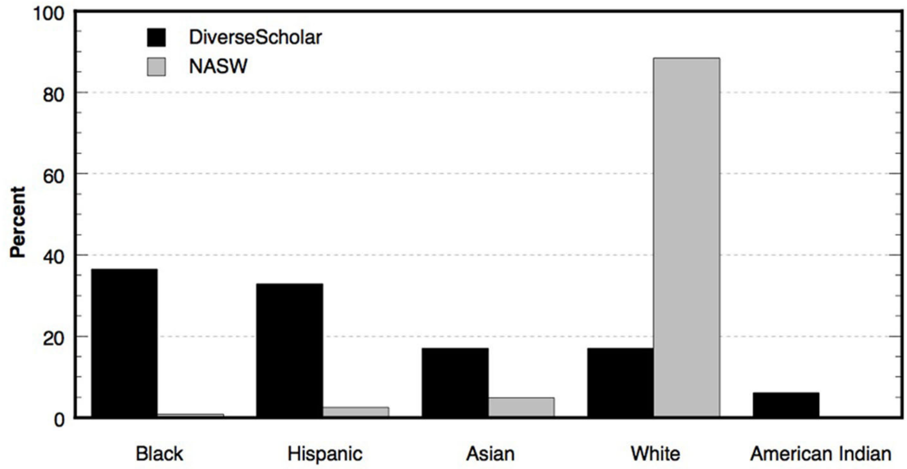

FIGURE 2 | Comparison of the ethnic/racial diversity of the DiverseScholar fellowship applicant pool (black) vs. the NASW membership (gray). The fractional percentage of the 82 fellowship applicants is compared to the ∼1,100 NASW membership survey respondents for the indicated ethnic/racial groups. Note that the depicted NASW "Asian" category combines the reported statistics for both Asians and South Asians since the DiverseScholar travel fellowship application combined these two groups.

27% first generation in higher education, 11% LGBTQ, 6% disability, and 2% military service / veterans. Finally, the disciplinary interest of the applicants was distributed as follows: 46% Life Sciences; 35% Environment; 32% Health; 39% Physical Sciences; 26% Education; 23% Social, Behavioral and Economic Sciences; 22% Career; 20% Tech; 17% Traditional Knowledge; 16% Clinical Research; 16% Engineering; 11% Agriculture; 9% Animals; and 7% Mathematics/Statistics.

At the ScienceWriters conference, fellows attended professional development and science-specific sessions that were of interest to them. An expectation of the fellowship was a reporting assignment chosen by Roca that typically focused on a particular conference session negotiated after a fellow's interests became clear. At a reception or group meal, fellows engaged with each other and designated mentors (**Figure 3**). The mentors were experienced science freelance or staff journalists drawn from our professional networks. When possible, we matched fellows and mentors based upon their primary science specialty. Mentors were instructed to serve as a resource about career insights especially for fellows new to the profession. Importantly, the mentors provided developmental editing critiques of the fellow's reporting assignment both during and after the conference by reviewing a draft article. When Idea Grant funds were available, mentors received a nominal honorarium for this editing work. We are very grateful to the mentors who volunteered their time. Some mentors were members of NASW's new Diversity Committee so our SciCommDiversity Travel Fellowship and NASW shared mutual goals and complementary activities.

The fellowship reporting assignment was designed to capture a fellow's conference experience, to document activities around a DE&I topic, and to allow a fellow to practice their science reporting skills. In some cases, published articles included a fellow's diversity essay from their application. The articles were edited by either the fellowship selection committee and/or the mentors. Such top-edited and bylined articles published in the *DiverseScholar* magazine add to a fellow's portfolio that can be especially critical for student's beginning their career. We note that NASW student membership requires two top-edited articles. Also, NASW demands membership application endorsement by two sponsors which our mentor-fellow introductions can address. Thus, our intervention helps the fellow meet expectations toward professional qualifications for formally joining the NASW community.

A selection of the article assignments demonstrate that the fellows are contributing to the discussion about science communication/journalism's diversity, equity, and inclusion challenges (**Table 2**). The published assignments also include original science reporting facilitated by the ScienceWriters conference's joint CASW New Horizons in Science seminars. Some of the fellows were assigned a particular seminar/topic but were also expected to include a DE&I angle to fall under the *DiverseScholar* magazine mission. The perspective could be relating a science discovery to a marginalized community (Landry, 2015; Wang, 2015; Parks, 2016), finding a story source about underrepresented minorities from an expert's research group (Hill, 2015; Park, 2016), or describing the state of the discipline's diversity/inclusion (Shastri, 2015; Skibba, 2015).

As *DiverseScholar* Editor, Roca helped the fellows identify a diversity angle by drawing upon his experience thinking of STEM-related story ideas (Roca, 2018) that began when co-curating the Diversity in Science Blog Carnival series (Lee, 2009; Roca and Yoder, 2011). The carnival series and the fellow's articles can serve as examples for how allies can refine their own science reporting to cater to the interests of minorities. Notably, some of the fellows went beyond just producing written science deliverables for a typical U.S. audience. One fellow produced an audio story adding to DiverseScholar's emerging multimedia offerings (Martel, 2016b). Some of the

FIGURE 3 | Group photo from the 2015 ScienceWriters conference including 10 DiverseScholar SciCommDiversity Travel Fellows. The three mentors pictured are Tara Haelle (2nd from left), Maggie Koerth-Baker (6th from left), and Dr. Matthew Francis (3rd from right). DiverseScholar Advisory Board member, Dr. Cynthia-Lou Coleman, is at the far right. Mentor Nidhi Subbaraman is not pictured. Note that written informed consent was obtained from the identifiable individuals for the publication of this image.

articles included an accompanying Spanish translated version thereby expanding the reach of our potential audience (Gonzalez, 2014a; Rodriguez Mega, 2015). Finally, we highlight one fellow's leadership achievements who went on to become a member of the NASW Diversity Committee as well as guide the San Diego Science Writers Association (Skibba, 2018).

SCICOMM OUTREACH

A fellowship intervention only succeeds if there are applicants, which requires reaching a target audience of underrepresented people of color, for example. We were operating under the assumption that there were two potential applicant pools: (1) minority journalists who could consider science reporting, and (2) minority scientists who could consider SciComm careers (**Figure 4**). We tailored our in-person outreach efforts accordingly.

We first used internet channels for publicizing the fellowship opportunity such as the ScienceWriters conference webpage. We marketed through our online web presence such as the MinorityPostdoc.org website, the *Scientific American The Urban Scientist* blog (Lee, 2014b), and our Twitter social media accounts—@MinorityPostdoc and @DNLee5, for Roca and Lee, respectively. Organizations that also publicized our call for applicants included Ciencia Puerto Rico, Culture Dish, Red Comuniciencia, and the NABJ Digital Journalism Task Force. The DiverseScholar non-profit also made announcements via its monthly email listserv to over 1,100 postdocs including historically underrepresented populations.

To accomplish in-person direct recruiting, the NASW Idea Grants subsidized our participation at diversity conferences to meet minority students and professionals from either the journalism or science sectors. Below we describe these efforts centered on our SciComm sessions that also discuss relevant DE&I issues.

National Association of Black Journalists

Since 2009, NABJ has sponsored a conference programming track called Healthy NABJ that hosts panels, major presentations, seminars, technical training, and professional development workshops at the annual convention and separately at the NABJ Media Institute (Dodson, 2013; Johnson, 2013). Although not a Task Force, the Institute serves a very similar role in drawing attention to health disparities and news coverage about health-related issues about African-American and other minority audiences. There is a small but passionate contingent of NABJ members who advocate about science, health, and environmental topics, with respect to access, disparity, and inequity.

We attended the 2013 NABJ meeting and participated in a "Science Journalism 101" session that focused on helping NABJ members cultivate relationships with media-ready African-American scientists and engineers and identify science-related news stories (Lee, 2013a,d). The panel included Dr. Ivan Oransky, Global Editor Director, *MedPage Today*; Dr. Robin Lloyd, News Editor at *Scientific American*; Dr. David Kroll, Director of Science Communications, North Carolina Museum of Natural Sciences, Raleigh, NC; and co-author Dr. Danielle N. Lee who had proposed the session. The panel was moderated by long-time NABJ member Jamila Bey, East coast radio show host.

In attendance were NABJ members who cover health, environment, technology, and weather news as well as those who served as information and outreach officers for health-related institutions. Despite their experience, many of these journalists had not self-identified as science communicators or connected their work with science communication in any form. This is why the outreach efforts of the session were critical—to help minority journalists identify

TABLE 2 | Fellow's reporting assignments documenting diversity issues and published as *DiverseScholar* magazine articles.

Title	References
Hispanic Audiences and Diversity in Science Journalism	*Gonzalez, 2014a
Culture Dish Diversity Mixer: Building Connections Between Science Writers	Gonzalez, 2014b
Science, Health, and Environmental Reporting for Indian Country	Hansen, 2014a
Applying "Diversity in Science Writing" to Native Journalists	Hansen, 2014b
A Tough Newsroom Discussion: Why Diversity Is Needed in Science Journalism	Howard, 2014a
Science, Journalism, and Diversity: What Science Writers Are Doing About That Diversity Problem	Howard, 2014b
Engaging the Science-Poor	Sobowale, 2014a
Enlightening Testimonials from Diverse Science Writers	Sobowale, 2014b
Black Journalists Pitch Their Stories to Advance Science	Cofie, 2015
Missed Opportunities for Inclusion at Science Writers: #SciWri15 #SciWriWomen reaction	Hotchkiss, 2015
Science Is Only Half the Story: Know Your Audience	Quevedo, 2015
Is *America Latina* Present in Science Journalism?	*Rodriguez Mega, 2015
How to Communicate *Ciencia* to Bicultural Audiences	Martel, 2016a
Science Journalism in Latin America: Perils and Possibilities	Rodriguez, 2017
Writing as a Japanese-Mexican American Woman	Takemura, 2019a
The Real Dangers of a Diversity Deficit in Science Writing	Takemura, 2019b

The indicated articles (*) included an accompanying complete Spanish translation.

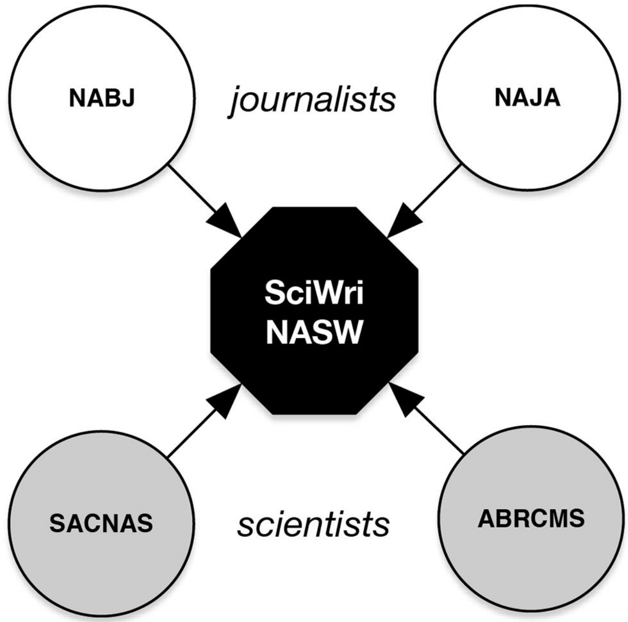

FIGURE 4 | Schematic of the two minority populations targeted as applicants for the travel fellowship to attend the ScienceWriters (SciWri) annual conference that is produced by the National Association of Science Writers (NASW). Minority journalists were solicited from the National Association of Black Journalists (NABJ) and the Native American Journalists Association (NAJA). The fellowship opportunity was also publicized among minority scientists of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) as well as the Annual Biomedical Research Conference for Minority Students (ABRCMS).

additional professional and networking opportunities for their existing work.

The following year, the Healthy NABJ programming track hosted three professional panels (Lee, 2013b, 2014c). The panel "Using Social Media for Informed and Influential Reporting" offered important advice for journalists of all specialties, including how to use social media responsibly when covering sensitive topics, how to include your personal brand in your reporting, how to protect yourself legally while using social media professionally, and what is on the horizon for new technology. Another panel was "Reporting to Readers, Viewers, and Listeners for Better Health: The Politics of Health in the Midterms." The panel discussed the importance of reporting on health issues to impact policies that affect minority women disproportionately and Black women's experiences specifically. Finally, Healthy NABJ track featured a presentation by academic leader Dr. Louis Sullivan, President Emeritus of Morehouse School of Medicine.

In 2015, the NABJ conference included a "Science and Health Pitch Slam." Modeled after the professional development workshop offered at the annual ScienceWriters meeting, this panel presented a rare opportunity for NABJ participants to pitch work directly to science and health editors looking for new talent (Cofie, 2015). This networking opportunity can catalyze employment opportunities for some freelancers. Editors on the panel included Laura Helmuth (Science and Health Editor of *Slate* magazine), Mary Hoff (Editor in Chief of *Ensia*), Jenny Bogo (Executive Editor of *Popular Science*), Becky Lang (Senior Editor of *Discover* magazine), and Tim de Chant (Senior Digital Editor of *Nova*). Freelance science writer and NASW Diversity Committee member, Maggie Koerth-Baker, served as the moderator. Participants received pertinent advice for developing their science reports while editors indicated strong interests in these culturally-focused health, environment, and science news ideas.

Our goal was to build relationships with diverse journalists and media outlets who attend this national convention to network with colleagues and to promote our SciCommDiversity Fellowship. We understand that presenting science-related news stories in a way that is timely and culturally-relevant influences who participates in science, health, and environmental careers and policy conversations surrounding these topics. We anticipate that attending this conference also helped to foster conversations about potential relationships between NASW and NABJ.

Native American Journalists Association

At the 2015 Native American Journalists Association annual conference, Roca produced the session "Culture Matters: Best Practices for Science & Health Reporting in Indian Country" (Crane, 2016). Roca moderated the panel that included co-author Cynthia-Lou Coleman, Ph.D., Terri Hansen (correspondent of the Indian Country Today Media Network and SEJ member), and Teresa Lamsam, Ph.D. (Associate Professor of Communication at the University of Nebraska at Omaha). The panel discussed reframing the ways that "science" is reported in Indian Country. News coverage of science, health, risk, and environmental issues is usually framed as merely reporting the facts leaving the audience to make its own, rational decisions. Instead, we argued that coverage should reframe science news so that culture, not science, is central to the reporting. One example is the reporting about Kennewick Man, which has been widely characterized in mainstream media as a battle between science and Native American religion (Coleman and Dysart, 2005). By contrast, reporting should embrace American Indian ways-of-knowing, sometimes categorized as "Traditional Knowledge," so that indigenous perspectives are legitimized. Session participants also received professional development advice about how to enter health, science, and environmental journalism careers either as a freelancer or staff reporter. Specifically, we presented community resources for career advancement such as the NASW, AHCJ, and SEJ professional societies as well as our SciCommDiversity Fellowship.

Science Diversity Conferences

The NABJ and NAJA sessions represent our efforts to recruit minority journalists to consider science beats. The complementary outreach method for the SciComm profession and our travel fellowship specifically is to recruit minority scientists to consider communication/journalism careers (**Figure 4**). In higher education in the United States, there are over 70 diversity professional societies many of which are in the STEM disciplines and most are stratified by specific cultural identity such as the National Organization of Black Chemists and Chemical Engineers or the National Organization of Gay and Lesbian Scientists and Technical Professionals. The MinorityPostdoc.org Stakeholders page maintains a roster of these organizations as well as their annual conferences.

Building on our previous efforts in STEM workforce diversity (Roca, 2005), the NASW Idea Grant funds allowed us to produce a SciComm session at the 2014 conference of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS). Since the primary outcome of the SACNAS event is to recruit minority undergraduate students into science graduate programs (Chemers et al., 2011), our session proposal was pitched as a SciComm skills training opportunity. The session "Science Writing to Support Your Career: from Blogging to Journalism" included speakers Dr. Coleman and Dr. Lamsam (introduced above) as well as Daniela Hernandez, Ph.D., Reporter and Community Manager at *Wired Digital* and a University of California, Santa Cruz Science Communication Program graduate. Roca moderated a discussion about how writing online can promote a scholar's science and career. Panelists described how they used social media such as blogging and Twitter to discuss science, engage the public, and publicize accomplishments. We promoted our travel fellowship and also advised how to translate SciComm skills into a journalism career covering topics such as science, tech, and health. This panel followed Roca's earlier work at the 2011 SACNAS conference with his session on "Blogging, Tweeting, and Writing: How an Online Presence can Impact Science and Your Career" (Hernandez, 2011).

Roca has produced similar sessions at related conferences that attract large Black and African-American audiences such as the NIH-centered Annual Biomedical Research Conference for Minority Students (ABRCMS) as well as at the NSF-centered Emerging Researchers National Conference in STEM (ERN) that was catalyzed by the NSF Historically Black Colleges and Universities—Undergraduate Program. For these sessions, Black academics such as co-author Dr. Lee and Michael Johnson, Ph.D. (Assistant Professor of Immunobiology, University of Arizona) would describe their SciComm and social media experience to a largely student audience.

Since role models can inspire a student's journey in learning a skill or in pursuing a career, in these sessions Roca promotes his online roster of Diversity Bloggers published at the MinorityPostdoc.org website cataloging over 70 individuals/blogs. Other useful resources are the online #BLACKandSTEM Twitter community and the book *Science Blogging: The Essential Guide* to which two of the co-authors contributed chapters (Lee, 2016; Roca, 2016). With nearly 100 other professional development sessions vying for the attention of thousands of attendees, we crafted session titles and abstract descriptions to be engaging. The event public agenda can serve to educate about skills/careers to even those conference delegates who did not attend our sessions. Thus, we included the specific resources mentioned above in the online panel descriptions which incorporate the easily memorable and search engine optimized labels of MinorityPostdoc and SciCommDiversity for more information.

DIVERSITY OUTREACH AND ADVOCACY

There are challenges in using the aforementioned conferences to disseminate awareness about SciComm opportunities/careers. While those conferences consist of a large attendee pool which may populate a minority talent pipeline, none of these annual events focus exclusively on SciComm diversity topics and interventions. The conferences are either for minority journalists or minority scientists but not the intersection of diversity in science communication. Thus, there is no guarantee that those event's Program Committees (particularly of the journalism conferences) will accept or continue sessions on the SciComm topic. In fact, during the Idea Grant time period, our proposal for the National Association of Hispanic Journalists was rejected on the topic of "Building Skills and Diversity in Health/Science Journalism." Similarly, the co-authors have not had the success or capacity to repeat these sessions at subsequent NABJ or NAJA conferences. Conversely, while the SACNAS conference does have a SciComm track of sessions, that diversity conference does not attract any substantial number of journalism students or professionals.

We have not explored using sponsorship/exhibitor opportunities at these conferences mostly because of time and funding limitations. It is also not clear that the return-on-investment would be reasonable when many exhibit booths are competing for conference attendee's attention especially from corporations with direct employment opportunities. Capacity restrictions also prevent exploring the diversity journalism organizations that separately cater, for example, to the Asian-American, South Asian, and LGBT communities.

An alternative strategy would be to network at recruiting events that are specific to SciComm diversity. However, to our knowledge, none exist that have the size or the publicity/marketing channels of established professional societies/events similar to the ones described above, (i.e., with thousands of attendees). Perhaps the new ReclaimingSTEM (Valdez-Ward and Cat, 2019) and InclusiveSciComm (Canfield et al., 2020) events can grow to achieve such status. Parenthetically, DiverseScholar is a sponsor/advisor to ReclaimingSTEM and Roca presented at InclusiveSciComm about our fellowship project.

DE&I sessions have occurred at general SciComm events. For example, from 2011 to 2014 at the now defunct ScienceOnline annual conferences, the co-authors Lee and Roca were involved in producing panel discussions on the topic of "Broadening the Participation of Diverse Populations in Online Science" that featured general discussions (Clancy, 2011; Lee, 2011a, 2014a; Roca, 2014) or particular themes as representative speakers from the LGBT (Lee, 2013c) and Native American (Coleman, 2012a,b; Lee, 2012) communities were invited. Separately, Dr. Lee was a panelist for the topic "Communicating with Diverse Audiences" at the 2016 national ComSciCon workshop. Similarly, we had a panel on "Practical Strategies for Science and Health Journalism Diversity" at the 2016 ScienceWriters conference (Crow, 2016) which coincided with the last year of our open call for applicants to our SciCommDiversity travel fellowship. With the lack of diversity in the science journalism profession, though, it is unclear how effective these venues are for *increasing* minority participation in the absence of direct interventions such as our own travel fellowship.

Since 2017 after the NASW Idea Grant funds were expended, DiverseScholar general funds became the funding source to offer a travel fellowship to a past Honorable Mention awardee so that one individual could attend the ScienceWriters conference. We anticipate continuing this model until another SciCommDiversity-specific grant/sponsor source can be identified to return to a larger open call for applications. More importantly, DiverseScholar general funds are being used to create and to sustain the SACNAS, ABRCMS, and ERN sessions described above. Also, a new initiative has been explored where general funds are used to sponsor the ComSciCon workshop (Houston, TX site) as well as the SciCommCamp event in Los Angeles, CA. The funds for the SciCommCamp event subsidize their travel scholarships therefore serving as a smaller model of our SciCommDiversity fellowship (Francis, 2018). Finally, participants of DiverseScholar's annual Postdoctoral Conference practice SciComm skills for both technical and public audiences (Rodriguez and Roca, 2017). In particular, the 2019 conference had a specific plenary on "Using SciComm Skills to Achieve STEM Diversity" by Dione Lee Rossiter, Ph.D., former Director of the AAAS Mass Media Science Fellows Program (Rossiter, 2019). Thus, these events serve to continue building a community of diverse SciComm practitioners.

DISCUSSION

As an academic endeavor, interventions require more long-term resources than typical scholarly research deliverables. Namely, a particular research project objective can end after a few years with a peer-reviewed publication outcome that will stand on its own as a knowledge milestone and dissemination vehicle. By contrast, a training or education intervention needs sustainability to continue serving new cohorts year after year. Specifically, while the SciCommDiversity travel fellowship was catalyzed by NASW Idea Grant funds, the challenge will be to secure future funds to continue offering the opportunity and perhaps expand to other conferences (such as AHCJ and SEJ) and to other activities (internships, layoff bridge funds, pandemic relief funds, alumni network, independent events, etc.).

However, the precarious nature of the journalism industry with its declining employment security [including traditional science reporting jobs (Tenore, 2009)] makes the prospect of a workforce recruiting intervention difficult. Why would a person want to become a reporter much less one covering a topic area that does not draw the same attention as say entertainment, sports, or politics? The response is that while the profession is changing (Carr, 2019), science journalism as a need and opportunity is growing (Hayden and Hayden, 2018). Combining that reporting opportunity with the U.S.'s diversifying population underscores the need for minorities to enter the profession. Thus, we remain motivated to continue our work.

The SciCommDiversity Travel Fellowship was strategically designed to be complementary and synergistic to the non-profit DiverseScholar's main project of doctoral STEM workforce diversity (Roca, 2013). As shown in **Figure 1**, all of the doctoral-level services could be replicated for the growing SciCommDiversity fellows community that we are building. For example, an independent SciCommDiversity conference could have its own sponsorships. Perhaps the revenue generated from such SciCommDiversity assets would fund future cohorts of the fellowship. However, currently, the DiverseScholar revenue is subsidizing the SciCommDiversity project since the Idea Grant funding has ended.

The MinorityPostdoc and SciCommDiversity projects are synergistic for three reasons. First, the travel fellow's reporting assignments create content for the *DiverseScholar* magazine (**Table 2**). In some cases, the fellows are reporting about the non-profit's own activities such that they then serve as an internal communications staff. Second, travel fellows who decide to pursue doctoral graduate studies in the social sciences could become future professors of science communication. Thus, during their PhD education, such SciCommDiversity "alumni" would benefit from the DiverseScholar/MinorityPostdoc resources and activities. Third, science journalism will improve when there is more diversity in reporting sources (Kleyman, 2013; Crowell, 2019). Under the DiverseScholar umbrella, the SciCommDiversity fellows can network with an emerging group of diverse PhD professionals. For example, if the SciCommDiversity fellows witness the science talks at the DiverseScholar Postdoctoral Conference, then this networking mimics their experience at the ScienceWriters New Horizons in Science seminars but with more presenter diversity.

A future direction that would inform our understanding of the science communication workforce climate would be to study the experience of minority communicators and reporters. A thorough study of the fellows was beyond the scope of the current work. However, the SciCommDiversity fellowship applicant pool is the desired research population for future rigorous social science inquiry since this population is much more diverse than the general NASW membership (**Figure 2**) or of the respondents to an informal survey of minority science writers (Diep, 2014). Capacity limitations also prevented a thorough analysis of the impact of the travel fellowship experience on the NASW community and the larger science communication workforce.

Future research could assess the SciComm skills preparation, media career knowledge, and STEM-topic interest among minority journalists/scientists. For example, previously published survey instruments (Schmidt, 2017) could be applied to our diverse study population. This could probe their interest in reporting about basic vs. applied SciComm news topics such as the environment vs. environmental justice as well as health vs. health disparities.

Much research needs to be done with respect to understanding our conference travel intervention itself and the psychological/sociological dimensions of the fellowship experience. Future work can draw from the studies about interventions that encourage minorities to pursue STEM careers (Fagen and Labov, 2007; DePass and Chubin, 2009; Segarra et al., 2020). Research has been conducted about conferences as interventions specifically examining the SACNAS (Chemers et al., 2011) and ABRCMS events (Casad et al., 2016). We propose that the fellowship creates informal learning opportunities improving a fellow's social/cultural capital, identity as a communicator, science writing self-efficacy, and career skills. The fellowship may also facilitate peer-to-peer and mentor-to-fellow individual relationships and networks that provide psychosocial support (**Table 1**).

In closing, the SciCommDiversity Travel Fellowship with its financial support and associated mentoring could have an important role in diversifying a profession entrusted with stewarding science awareness for the demographically changing United States. As has been noted, "public understanding [of science] cannot be divorced ultimately from issues of cultural identification..." (Wynne, 1992).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AR, DL, TH, and C-LC collaborated on this article. All authors contributed to the article and approved the submitted version.

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Broadening Perspectives on Broadening Participation: Professional Learning Tools for More Expansive and Equitable Science Communication

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Many professionals in the field of science communication have argued that our work too often tends to be designed for people like ourselves—those already interested in, comfortable with, and engaged with science. Thus, our work, ostensibly intended to broaden who engages with STEM, may in fact be exacerbating rather than reducing disparities with regard to who has access to and makes use of designed (vs. everyday) opportunities for science engagement. In this conceptual analysis, we posit that inclusive science communication must be conceptualized as a process of cultural exchange, rather than as a process of translation. Thus, the goal is not to speak more simply or more loudly, but rather with more understanding and mutualism. We share the results of an exploratory project that developed a suite of research briefs designed to support science communication professionals in reflecting on key structural barriers that operate to institutionalize science as an non-inclusive domain of activity. We conclude that more dialogic ways of professional learning among science communicators can reveal biases, gaps between goals and reality, and other underlying practices that must be addressed if we are to advance inclusive forms of science communication.

Keywords: equity, inclusion, professional learning, boundary object, boundary crossing, science communication, broadening participation

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INTRODUCTION

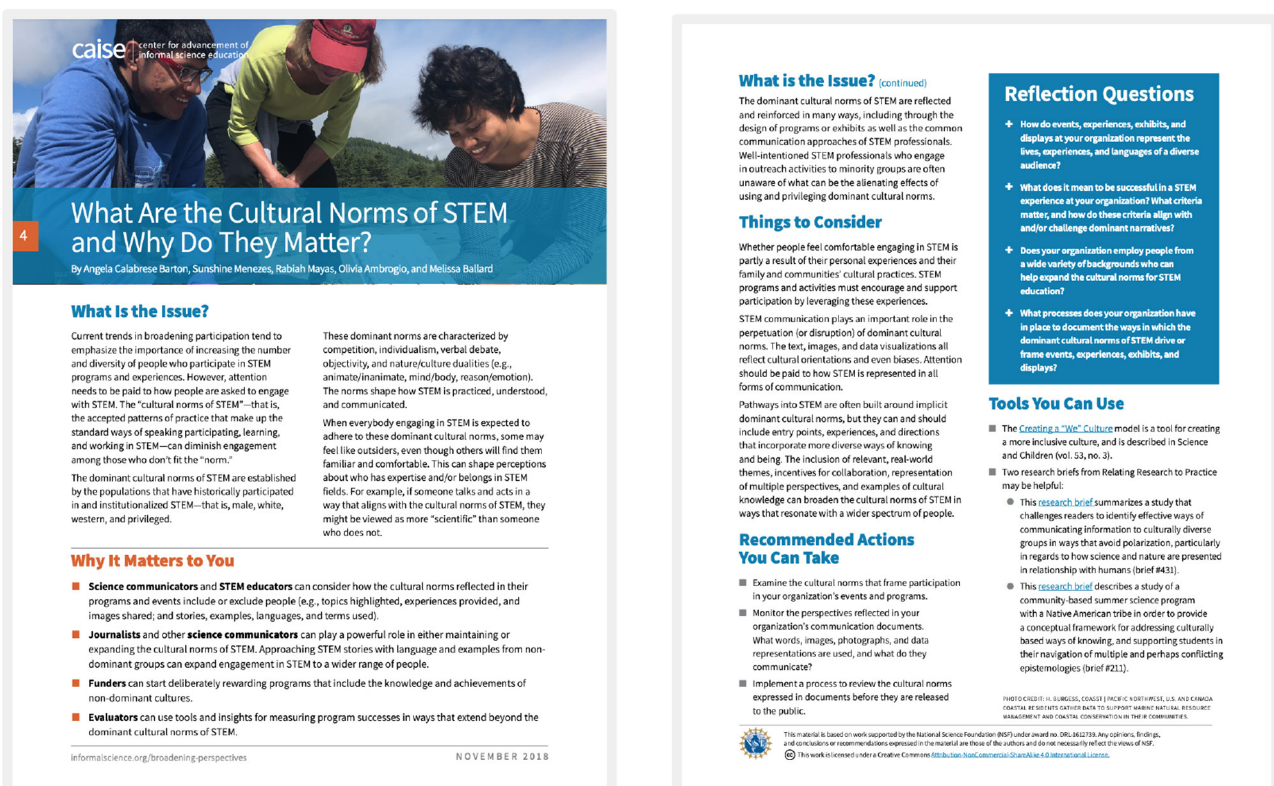
The Matthew Effect describes the phenomenon whereby systems of reward and recognition lead to the rich getting richer while the poor get poorer (Merton, 1968). For example, in science the more well-established you are, the more often your studies are cited, even if they are not much different than the work of newer scientists or scholars. Fame attracts fame, wealth attracts wealth. Feinstein and Meshoulam (2014) have argued that the work of science communication often triggers the Matthew Effect: We primarily engage those who seek engagement on our terms, on our turfs, in our language, and in ways that we ourselves find appealing or salient. Thus, the already science-engaged become even more science engaged. Through such approaches, the authors note, we may, in fact, be exacerbating rather than ameliorating disparities with regard to who has access to and makes use of designed (vs. everyday) opportunities for science engagement.

There are notable exceptions to this scenario in the many promising efforts that deeply engage socially, racially, and economically diverse communities [see Dawson (2014), Canfield et al. (2020), Polk and Diver (2020)]. These communication efforts move beyond the walls of universities and museums to adopt culturally relevant and responsive "asset-based" modes of interaction or pedagogy, and they seek to co-design and collaborate with communities. But such programs remain the exception to the rule; they are often led by particular and passionate individuals, or supported by specific, often short-term, funding streams. Their celebrity status, as distinct from the pack, suggests the existence of more deep-seated structural, institutional, and cultural factors that limit such notable programs from becoming more widespread and sustainable.

It is that challenge—to identify structural issues that seem to hold back the field in its efforts to expand diversity, equity, inclusion, and access—that the Center for the Advancement of Informal Science Education (CAISE) sought to address in the fall of 2017 by forming a task force to review current practices in the field and make recommendations for how we might move the field forward. The task force consisted of 15 professionals from a wide range of science communication organizations, including community-based organizations, science museums and universities, and representing both research and practice. In this paper we describe how we theorize the process of changing attitudes, commitments, and strategies for broadening participation in science communication as work at the boundaries of multiple professional perspectives—of scientists, science communicators, informal science practitioners, and others. As such we explore how "boundary objects" co-developed by professionals from across a range of perspectives, can be used to foster productive conversations about equity and inclusion in science communication, and to negotiate tensions that will inevitably arise as individuals, teams, and organizations seek to make change (see **Figure 1** for example). The case that this project describes is intended to lay the groundwork for further research and development, including future empirical studies related to the efficacy of adopting "boundary-crossing" approaches to inclusive science communication.

A TASK FORCE ON BROADENING PARTICIPATION

Broadening participation in STEM has generally referred to increasing participation of people from historically underrepresented communities in the pursuit of STEM studies, professions, and civic decision-making (Fealing et al., 2015). These communities include people of color, people with disabilities, women and girls, people living in poverty, people who were formerly incarcerated, others, and include the ways in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What Are the Cultural Norms of STEM and Why Do They Matter?

By Angela Calabrese Barton, Sunshine Menezes, Rabiah Mayas, Olivia Ambrogio, and Melissa Ballard

What Is the Issue?

Current trends in broadening participation tend to emphasize the importance of increasing the number and diversity of people who participate in STEM programs and experiences. However, attention needs to be paid to how people are asked to engage with STEM. The "cultural norms of STEM"—that is, the accepted patterns of practice that make up the standard ways of speaking participating, learning, and working in STEM—can diminish engagement among those who don't fit the "norm."

The dominant cultural norms of STEM are established by the populations that have historically participated in and institutionalized STEM—that is, male, white, western, and privileged.

These dominant norms are characterized by competition, individualism, verbal debate, objectivity, and nature/culture dualities (e.g., animate/inanimate, mind/body, reason/emotion). The norms shape how STEM is practiced, understood, and communicated.

When everybody engaging in STEM is expected to adhere to these dominant cultural norms, some may feel like outsiders, even though others will find them familiar and comfortable. This can shape perceptions about who has expertise and/or belongs in STEM fields. For example, if someone talks and acts in a way that aligns with the cultural norms of STEM, they might be viewed as more "scientific" than someone who does not.

Why It Matters to You

- **Science communicators** and **STEM educators** can consider how the cultural norms reflected in their programs and events include or exclude people (e.g., topics highlighted, experiences provided, and images shared; and stories, examples, languages, and terms used).
- **Journalists** and other **science communicators** can play a powerful role in either maintaining or expanding the cultural norms of STEM. Approaching STEM stories with language and examples from non-dominant groups can expand engagement in STEM to a wider range of people.
- **Funders** can start deliberately rewarding programs that include the knowledge and achievements of non-dominant cultures.
- **Evaluators** can use tools and insights for measuring program successes in ways that extend beyond the dominant cultural norms of STEM.

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What is the Issue? (continued)

The dominant cultural norms of STEM are reflected and reinforced in many ways, including through the design of programs or exhibits as well as the common communication approaches of STEM professionals. Well-intentioned STEM professionals who engage in outreach activities to minority groups are often unaware of what can be the alienating effects of using and privileging dominant cultural norms.

Things to Consider

Whether people feel comfortable engaging in STEM is partly a result of their personal experiences and their family and communities' cultural practices. STEM programs and activities must encourage and support participation by leveraging these experiences.

STEM communication plays an important role in the perpetuation (or disruption) of dominant cultural norms. The text, images, and data visualizations all reflect cultural orientations and even biases. Attention should be paid to how STEM is represented in all forms of communication.

Pathways into STEM are often built around implicit dominant cultural norms, but they can and should include entry points, experiences, and directions that incorporate more diverse ways of knowing and being. The inclusion of relevant, real-world themes, incentives for collaboration, representation of multiple perspectives, and examples of cultural knowledge can broaden the cultural norms of STEM in ways that resonate with a wider spectrum of people.

Recommended Actions You Can Take

- Examine the cultural norms that frame participation in your organization's events and programs.
- Monitor the perspectives reflected in your organization's communication documents. What words, images, photographs, and data representations are used, and what do they communicate?
- Implement a process to review the cultural norms expressed in documents before they are released to the public.

Reflection Questions

- How do events, experiences, exhibits, and displays at your organization represent the lives, experiences, and languages of a diverse audience?
- What does it mean to be successful in a STEM experience at your organization? What criteria matter, and how do these criteria align with and/or challenge dominant narratives?
- Does your organization employ people from a wide variety of backgrounds who can help expand the cultural norms for STEM education?
- What processes does your organization have in place to document the ways in which the dominant cultural norms of STEM drive or frame events, experiences, exhibits, and displays?

Tools You Can Use

- The Creating a "We" Culture model is a tool for creating a more inclusive culture, and is described in Science and Children (vol. 53, no. 3).
- Two research briefs from Relating Research to Practice may be helpful:
  - This research brief summarizes a study that challenges readers to identify effective ways of communicating information to culturally diverse groups in ways that avoid polarization, particularly in regards to how science and nature are presented in relationship with humans (brief #431).
  - This research brief describes a study of a community-based summer science program with a Native American tribe in order to provide a conceptual framework for addressing culturally based ways of knowing, and supporting students in their navigation of multiple and perhaps conflicting epistemologies (brief #211).

PHOTO CREDIT: H. BURGESS, COASST | PACIFIC NORTHWEST, U.S. AND CANADA COASTAL RESIDENTS GATHER DATA TO SUPPORT MARINE NATURAL RESOURCE MANAGEMENT AND COASTAL CONSERVATION IN THEIR COMMUNITIES.

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FIGURE 1 | Sample practice brief on cultural norms of STEM. ©Center for the Advancement of Informal Science Education.

which multiple identities may intersect. In this view, both the broadening participation challenge and solution focus primarily on creating access to existing pathways into STEM and on increasing the number of those pathways. The assumption underlying this approach is that when points of access are increased, more diverse and more representative populations will have more opportunities to participate in STEM and will opt to pursue those opportunities.

The CAISE task force began its work by seeking to broaden definitions of what broadening participation means and looks like. Using purposive sampling (Babbie, 2014), we interviewed 30 experts in the field recognized for their work in informal STEM learning and science communication to surface critical issues and challenges regarding broadening participation and needs in the field. We then assembled the task force, and through both virtual and face-to-face monthly meetings, the group challenged definitions that were focused on "access" alone, and shared examples of efforts that adopted inclusive, culturally relevant pedagogies, to change the places, reasons, and strategies for science communication. Over the course of the year, task force members identified many committed individuals, promising practices, and generative ideas in the field. It also identified four underlying systemic factors that appeared to be constraining the field's overall progress in broadening participation:

1. Science communication programs commonly adopt narrow definitions of "what counts as STEM" which constrains our ability to recognize the STEM learning experiences and assets that people bring to science engagement opportunities.
2. Representations and instantiations of science are typically informed by the dominant cultural norms of STEM, which are mostly white, western, and male. Reinforcing these norms can further alienate or marginalize publics from non-dominant communities.
3. Science communication programs seldom are designed with learning ecosystems perspectives in mind, which means that they miss building on existing or prior STEM experiences and linking to future and ongoing experiences beyond the science communication event itself.
4. Science communication programs are often housed in larger organizational or institutional settings that do not place equity on the same footing as science itself in terms of organizational mission and focus. This imbalance often leads to the marginalization of staff heading up equity initiatives and ultimately a lack of budget and staff support, frequently limited by time-constrained grant funding.

More detail on these barriers can be found in the CAISE report: https://www.informalscience.org/sites/default/files/BPreport.pdf.

The task force began to investigate models for supporting individuals committed to change to begin to develop conversations and allies within their programs or organizations. Responding to research that questions the value of traditional "translational" approaches of simply "telling" people what research says (Biesta, 2010; Weiser, 2015), we instead chose to pursue a more dialogic approach that recognized the cultural fields and boundaries that often separate the scientific community from more marginalized communities historically excluded from science. While no one set of tools will definitively move the entire field forward, research suggests that through reflective and critical discussion, science communicators can become aware of ways to work with, in, and/or around such structural barriers, and over time begin to make change in their practices and priorities [e.g., Bevan and Xanthoudaki (2008), Martin et al. (2019)]. This is where change can start: Building movements at the staff level that transition to organizational levels and ultimately to a field level where they can no longer be marginalized.

Boundary Objects

The CAISE task force thus set out to create a set of boundary objects that could support professional groups in developing shared understandings of what broadening participation in science is/could be, the practices that support broadening participation in science, and the challenges institutions may face in working toward broadening participation in science.

A boundary object is any object that facilitates communication across different social worlds (Star and Griesemer, 1989). Boundary objects gain meaning when people from different communities need to collaborate, but do not always bring a shared history of perspective to that collaboration. Yet the objects themselves are familiar to different stakeholders even if their purpose, value and/or meaning may be taken up differentially because of the social worlds they inhabit (Akkerman and Bakker, 2011). Boundary objects are both adaptable to local needs and constraints while stable enough to build a common identity across different worlds (Star, 1989).

For example, in their landmark study of boundary objects in museum contexts, Star and Griesemer (1989) describe how various artifacts of the Berkeley Museum for Vertebrate Zoology, such as specimens and maps, supported amateur collectors and museum professionals to come together to develop the museum. These differences in position and perspective matter in working toward something new and different that could not be achieved without that difference. Boundary objects mediate across difference while centering commonality (Wenger, 2010). As strategy tools they allow for coordinated discourse and activity toward advancing individual and collective understanding and linking communities toward a common task (Spee and Jarzabkowski, 2009). They are referred to as "boundary" because they literally help to bring people together from differently bounded worlds, reshaping relationalities among people, and how such objects are used and understood (Fleischmann, 2006).

Boundary objects not only bridge understanding across people from different positions and locations, they also challenge boundaries, expanding upon who belongs, how and why. This last point is particularly important when considering the practices of broadening participation and their impacts. We see these tools as not only coordinating activity that allows for knowledge integration across positions/perspectives, but also allowing for the transformation of the participating communities or of the nature of the boundary itself.

TABLE 1 | Barriers and briefs.

Systemic barrier	Sub-topics for practice briefs
Narrow definitions of broadening participation in STEM	• Why broaden perspectives on broadening participation in STEM? • What does learning have to do with science communication? • What does asset-based STEM learning look like?
Dominant cultural norms of STEM	• What are the cultural norms of STEM and why do they matter? • What counts as STEM? • How can we help scientists adopt equity approaches to science communication?
Learning ecosystems framing	• What is a STEM learning ecosystem? • How can we re-think assumptions about parent engagement? • How can we build on existing assets within a community?
Institutional prioritization	• How can institutions model inclusion in the workplace? • What does working "with" (not "for") our communities look like?

To develop a set of broadening participation boundary objects for the science communication field, the CAISE task force explored a strategy, developed by the NSF-funded Research+Practice Collaboratory, to work with mixed teams of researchers and practitioners to identify key topics they felt the field was struggling with and produce double-sided, one page "practice briefs" summarizing the evidence base from both research and practice. Practice briefs—unlike most research briefs—are designed to start with the questions and daily decisions of practitioners, and draw on research to address these questions on a single, pithy, double-sided document. Practice briefs are meant to be easy to use, quick to read, and concrete in their implications (Bell and Rhinehart, 2015). They are used to foster professional learning conversations as well as to guide practice. An external evaluation found the Collaboratory practice briefs to be productive boundary crossing tools because they were research-based but reflected practitioner perspectives, came from a trusted source, were at the right "grain-size," were succinct and well-organized, and provided links to additional resources (Anderson et al., 2019). This model seemed well-suited to the goals of the CAISE task force and the needs of the science communication field.

To foster productive conversations about the four systemic barriers, we expanded the task force to include 15 additional collaborators. This group collectively explored specific aspects of the four barriers, identifying 11 practical questions that could serve as generative ways into the larger conversation (See **Table 1** for the list). Each brief drew on the evidence base, from both research and practice, to describe the salience of the issue, ideas to consider for practice, recommendations for action, and reflection questions. Links to other tools and resources were included for those who wanted to read further.

To support the use of the briefs, the task force produced additional mediating tools that science communication professionals could use to prepare for engaging in the conversations with their staff, colleagues, and boards, including:

- **Structural Analysis:** A report that summarizes four structural barriers to broadening participation efforts at scale. The report discusses each issue in depth and also provides examples of efforts that exemplify positive inclusive public engagement in STEM.
- **Summary for Stakeholders**: An overview to be shared with organizational boards, CEOs, funders, or other stakeholders to develop support for internal discussions. It explores how engaging in broadening participation can enhance the relevance and impact of the organization in its community.
- **Conversation Guide:** To help those championing equity efforts, a guide for facilitating discussions centered on the briefs. It summarizes key issues and provides tips for leading reflective conversations with staff and team members.

These tools, constituting a Broadening Participation Toolkit, can be downloaded for free from https://www.informalscience.org/broadening-perspectives.

REFLECTION ON PRACTICE IN PRACTICE

We piloted the practice briefs at four different informal science centers, one STEM-focused community-based organization, and a large national conference attended by 250 science communication and engagement leaders who had grants from the National Science Foundation's Advancing Informal STEM Learning (AISL) program. The piloting organizations used the briefs in small reflective discussions with small staff teams (4), board and executive teams (3), and a youth group. Individuals at the conference discussed briefs with colleagues both new and known to them.

In all cases, participants read one or more briefs selected as relevant to the focus of their work. For example, several of the staff groups read briefs related to pedagogy, such as *How Can We Build on Existing Assets Within A Community?* Whereas, a board of directors read briefs addressing institutional positioning issues, such as *What is a STEM Learning Ecosystem?* Participants at the national conference read *What Does Learning Have to Do with Science Communication?, What Are the Cultural Norms of STEM And Why Do They Matter?,* and *What Counts as STEM?*

When asked if their project teams would benefit from reading briefs together, individuals attending the AISL PI conference commented that the briefs could help their teams be more strategic in their program design (36%), more impactful in their Diversity, Equity, Inclusion, and Access [DEIA] efforts (35%), and better equipped to support their own/their staff's professional learning (21%). *What Are the Cultural Norms of STEM and Why Do They Matter?* was assessed as potentially the most beneficial brief for supporting professional learning and developing more strategic DEIA programs. Addressing the open-ended question: "My project team could benefit from reading this brief together because…" responses included:

> *Our work involves co-creation with community partners; [but it] could be compromised by well-intentioned but biased cultural norms impacting the partnership and communication.*

> *We are working with communities that are culturally diverse and different from culture of [the project principal investigator].*

> *It would help us become more effective in engaging communities outside traditional ISE learning venues.*

> *We currently miss opportunities or don't have the full impact that we could if we addressed/thought about cultural norms in STEM.*

> *Culture is one of the most resilient barriers but also a powerful and under-leveraged solution space for inclusion.*

Results of the pilot testing suggest that the boundary objects may be helpful in three different ways: advancing shared understanding and thinking about DEIA, strengthening program design or approaches to advance DEIA, and building staff capacity to engage in productive reflective practice. In the next sections we discuss each one.

Advancing Shared Understanding and Thinking About DEIA

Importantly, the five pilot test organizations were already engaged in conversations about broadening participation in STEM, and there was awareness about the importance of this work. Further, at the national convening of 250 science communication and engagement leaders, by virtue of their success at securing NSF funding, it can be assumed that most individuals—because they would have read the NSF solicitations and their proposals would have been reviewed with the foundation's broadening participation goals in mind—would have been at a minimum aware of the need to deepen our understanding of how to broaden participation in STEM and in some cases might be field leaders in such efforts.

> *The briefs are super helpful because they get everybody on the same page. The conversation about diversity, about who you are serving, can be so complicated. There are people who have committed a lifetime of research to it—to assume any one of us would be an expert in this would be difficult. So, having a resource that gives us a shared view and shared things to consider is a huge help.*

One piloter described how the briefs generated discussions among her education team about the terms "equitable" and "equal" and their use throughout the science center. Another described how the "pathways" vs. "pipeline" metaphor described in the brief *Why Broaden Perspectives on Broadening Participation in STEM?* started a "great conversation about different metaphors for broadening participation." Another commented that the briefs helped her team identify not only areas they needed to work on, but things they were already doing that they hadn't realized were helping to broaden participation in their contexts.

Several participants at the AISL conference noted how the briefs, as boundary objects, could help to bridge conversations between scientists and science communicators and educators. For example, the brief *What Does Learning Have to Do With Science Communication?* was seen as potentially helping scientists, who already focused on teaching in their professional practice, see themselves as communicators. Another noted that thinking about the connection would help scientists realize the need for more careful pedagogical reflection:

> *Having our scientists understand more about how learning happens and the sociocultural context of learning will make their science communication more effective and meaningful.*

Others commented on how discussion of *What Are the Cultural Norms of STEM and Why Do They Matter?* could be helpful:

> *Dominant norms are so prevalent in physics outreach. Being able to identify them will help to push back /challenge/ constructively create new, more inclusive norms for programs and activities.*

> *We help natural scientists become more effective communicators. Often these science researchers have not thought about their cultural assumptions.*

In sum, the briefs helped respondents negotiate complex topics, opening up a space and time for reflection on assumptions, definitions, and intentions that could help to clarify whether and how science communication efforts were strongly aligned to support broadening participation in STEM or not.

Strengthening DEIA Practices in Programs and Engagement Activities

The pilot sites reported impacts on their programs and practices in three areas: public engagement, museum exhibits, and evaluation. For example, after discussing the brief *What Are the Cultural Norms of STEM and Why Do They Matter?*, a museum staff person reported that their team realized that although they organized their public programs to involve collaborative team work, their exhibit floor had a large number of images of individual scientists, inadvertently reinforcing common perceptions of science as the work of the "lone genius." They began to explore how they might illustrate the collaborative nature of science on their exhibit floor. Reading the brief *How Can We Re-Think Assumptions About Parent Engagement?* led another informal educator to reconsider the kinds of prompts they gave parents to engage their children in the programs and to include activities and ideas that parents could pursue with their children when they returned home. Another museum educator noted that the brief *What Does Learning Have to Do With Science Communication?* led her staff team to explore how they could extend participant sharing and reflection that already happened in their summer programs to the field trip programs that occurred during the school year. A museum leader said that his brief led their staff to consider how they might better evaluate their programs on an expanded set of learning outcomes. In all cases, the pilot users noted that the questions and recommended actions to take on the briefs helped to focus their conversations and thinking toward action steps.

A museum director at a Midwestern science museum noted that staff reflection on the full suite of briefs had led to two specific changes at her museum. In the first instance, the museum was in the process of renovating its classrooms, which had been named after figures such as Galileo and Newton. Through discussing the specific actions they could take to signal more inclusion on their museum floor, the group began to consider other scientists whose names could be used for the classrooms. For the first classroom they selected African-American astronaut Mae Jemison. Because the classrooms were used not only for programs but for birthday parties for museum member families, her team is currently considering how they can develop background material to familiarize classroom users with the work of Jemison and of other scientists, representing more diverse experiences and backgrounds, whose names will be attached to future classrooms.

Second, the director noted that discussing if and how their summer programs were accessible to the broad community led them to look into the files to see how many of the 90 young people who had attended summer camp the prior year had attended on one of the scholarships offered by the museum. They found to their surprise that they had only issued one scholarship. This discovery led them to reflect on the strategies they had used to ensure that families who did not already come to the museum were aware of the programs and the financial support. The museum took two concrete actions: first, it set aside a number of camp spots only for scholarships, which placed a financial onus on the staff to make sure that they found students to fill the scholarship spots. Second they began an intensive effort to engage a range of community educators, teachers, parents, and youth at the school programs, the afterschool community programs, and the local refugee support agencies to inform parents of the programs, the financial support, and what to expect in terms of transportation, food, and the science focus. These efforts led to a significant uptick in the number of scholarships offered, going from one to 20 in the first few months.

Several participants at the AISL conference noted how using *What Are the Cultural Norms of STEM and Why Do They Matter?* could help scientists be more effective in their work:

> *It would better prepare students and scientists from my campus to communicate their science message more effectively to diverse audiences.*

Overall, participants discussed how the briefs could lead to more intentional program design decisions and implementation efforts.

Building Staff Capacity for Reflection and Discussion About DEIA

One of the pilot users noted that she had had an ongoing research-practice partnership with an informal science education researcher that had productively evolved both of their thinking about equity and learning. The briefs gave her a concrete tool to begin to extend these conversations about equity to her staff. In particular, she noted that in addition to establishing shared knowledge, the briefs' questions for reflection helped to launch and focus discussions, connecting the big ideas to their specific context and work.

> *We have everybody from exhibits to finance to education on the management team. They all have a different view of things. The reflection questions on the brief forced us to talk together in a specific direction. We would read them all out loud, and then one of us would call out one question. We made some initial changes to programs based on those conversations. Now, we are building our 5 year strategic plan, and the pillar of DEIA and how we can achieve mission has been at the forefront of our strategic planning. Thinking about our practices across the organization and what they have been and what they could be, and what that looks like.*

Several piloters noted that discussing the briefs led to reflections on the kinds of partnerships the organizations had. For example, the *What is a STEM Learning Ecosystem?* brief posed the question "Who is missing from your STEM ecosystem and why?" This prompted the group to think deeply about who they were not working with, which led them to begin to explore working with libraries more deeply. Partnerships discussions included thinking about who they were serving as well as who they were collaborating with. The Executive Director at one of the piloting organizations became enthusiastic about how he could use these specific ideas emerging from the discussions to talk to donors about new possibilities.

Above all, piloters noted that using the briefs gave gravity and specificity to discussions about equity in their workplaces. As one person described, "Once you raise that level of conversation in any setting and continue to build awareness of it, you let people know that it is an important thing to talk about." Another piloter noted that reflective discussions then circled back to concrete issues: "We were talking about our team, our organization, what is the next step and how we serve another community we want to serve and how is it that we continue to seek out support for the things we don't know. And hiring practices came up over and over again... That was so exciting to the team because they lead a lot of our people and are passionate about that. So a lot of discussion about how do we recruit folks, where do we put out postings, what is the language we use? It generated so much exciting conversation."

Participants at the AISL conference noted the professional capacity building benefits for scientists. For example, *What Does Learning Have to Do With Science Communication?* was described as being useful for helping "scientists (university faculty) to consider pedagogical practices." Another noted that the brief's reflection questions could be prompts in science communication trainings. Yet another noted that it could serve as a useful tool for science communication training programs:

> *...it will support public engagement with science professional development workshops for scientists... because scientists often do not realize the connection between teaching (in classroom) and*

> *communicating research to a broader audience. [And] it would give us a chance to all get on the same page about what we think learning is, and this encapsulates a lot of the learning lit that they need to know.*

Several also noted also how the briefs could help science communication trainers to reflect on their own professional practices as trainers, considering what ideas and resources were most important to include in their work with scientists.

> *Because we train scientists and engineers in a variety of disciplines from a variety of places—[it will be] useful for us as we develop our programs and in how we provide resources to those we train.*

DISCUSSION

In this section we discuss how the practice briefs hold possibilities as boundary objects. Importantly, briefs focus attention, raise questions, and seed dialogue around broadening participation and its intersection with inequality. They do not propose solutions, which will vary widely by local context. As boundary objects, they create the conditions in which solutions can be identified, considered, and tried out in good faith with full support of relevant stakeholders. Our project raised many questions about both why and how these tools can engage diverse stakeholders in dialogue about structural and institutional barriers to broadening participation in science communication.

The briefs and other boundary objects create space for dialogue that may allow for differences in views to surface, allowing people and organizations to work toward deeper, more critical shared understandings. But as people in organizations come together to reflect forward on broadening participation participants will necessarily come from different positions, locations, and perspectives.

First, the practice briefs, as boundary objects, support developing understandings on what broadening participation is and may be. As boundary objects, the practice briefs present users with commonplace scenarios and reflection questions that open up shared questions on what participation in science communication could be. These are meant to spark dialogue on the assumptions that different individuals bring to broadening participation, as well as to provide information and resources for digging deeper into issues salient to groups. Consider, for example, how organizations may currently address access and opportunity: The undergirding assumption often held by science communicators and informal science educators is that increasing access and opportunity alone will increase broadening participation. Without reflection on undergirding assumptions about why people do or do not participate (addressing issues such as the cultural norms of STEM, asset-based vs. deficit-based approaches, etc.) such assumptions built into organizational and institutional practices may actually work against broadening participation.

Information and reflection questions around why and how the "access-alone" approach places the burden of participation on non-dominant populations can yield powerful dialogue on how the lack of participation may not simply be an issue of individuals' lack of awareness, availability, cost, or physical barriers such as transportation (i.e., access), but rather to histories of systemic exclusion. As boundary objects, these briefs and documents, may support take up of if, how, and why an organization's engagement programs and opportunities may be designed, intentionally or not, to reproduce existing patterns of STEM participation.

Second, the practice briefs, as boundary objects to engage professionals with varied and disparate experiences, may promote deepening awareness of current practices and their impacts, as well as developing ideas/plans for new practices. For example, across the suite of tools, four questions are posed that expose differing perspectives while centering on the commonalities of STEM engagement: (1) Why do people choose to engage in STEM? (2) How are people asked to engage with STEM? (3) When do critical approaches to broadening participation need to happen? and (4) Where do critical approaches to broadening participation need to happen? By working through these questions, these tools support people and organizations in articulating a vision of what broadening participation means and how that vision directly impacts the *how, when,* and *where* of programs, approaches and practices. The briefs then dive into specific critical areas of broadening participation, providing brief snapshots of how these strategies and approaches work in context with the possibilities for seeding dialogue on how these practices, and variations of them, may work—or not—in one's own local context.

Tensions

The positive results reported by pilot users are highly encouraging. But there are also tensions in the use of briefs that may be relevant to other efforts to engage practitioners with research-based evidence on equity and inclusion.

First, reflection and sharing requires time as well as trust. Providing the time and cultivating the trust requires organizational leadership.

Second, several pilot users noted the need for concrete examples or illustrations of the points being made in the briefs. People noted the need for specificity, and even for examples relevant to the many different roles and responsibilities entailed in science communication and engagement. Research suggests that practitioners are more likely to embrace research findings when the contexts are the same (Nelson et al., 2009). But this creates a significant challenge to science communication, where contexts, settings, and content, and audience vary so widely. The single sheet practice briefs are necessarily limited in what they can include, and there are limited examples in the field that they can point to. This remains an ongoing tension.

Third, several pilot users noted that language could sometimes be a barrier. One person commented that when terms needed to be defined (in sidebars) she wondered if they needed to be used at all. We posit that oftentimes engaging research and practice in science communication requires people to move outside of their comfort zones and to try on new language with specific meanings. If attention is paid to definitional work, this process can strengthen conversations and collaborations (Ryoo and Shea, 2015).

Fourth, and more challenging, a few of the piloters noted their sensitivity to difficult conversations about dominant cultural norms in science and society. For example, one person noted that all of the people in her discussion group reading *What Are the Cultural Norms of STEM and Why Do They Matter?* were women. She wondered how a white male might have felt if he were in the group, and/or if that would have affected the conversation. Another pilot user said that she tested it with a group whose supervisor she supervised—being higher up in the hierarchy, with less direct contact with this group may have been responsible, she felt, for a lack of engagement with the ideas in this particular group. They may have felt uncomfortable sharing their thoughts. Another pilot user noted that not all staff are ready for the conversation at the same time.

These comments remind us that there are strong power dynamics in the workplace that must be considered, and may sometimes dissuade people from taking initial steps to be reflective about organizational practices. It is well-documented in the literature that discomfort in talking about race is a symptom of whiteness. These tools are meant to provide supports that allow movement into uncomfortableness (Swanson and Welton, 2019) because we hold the stance that white professionals in science communication must confront their own complicity and their white fragility in racial inequality that is often reproduced in their own organizations (DiAngelo, 2011). As described, these power dynamics may include race and culture, age/tenure, organizational hierarchies, and tenuousness of some professional relationships. While these structures are real and create challenges, they may also be at the heart of institutional inertia or even resistance to seriously addressing organizational histories of bias or exclusion.

Fifth, because boundary objects work at the boundaries of communities, they necessarily surface tensions as differences in language, meaning and practice inevitably emerge (Oswick and Robertson, 2009). We suggest that it is important to view working with boundary objects in efforts to broaden participation as an emerging and continual process, such that arising tensions can be considered important fodder, and collective critical insight, for next steps.

Finally, because participation in this project was voluntary, we believe that most users had achieved a particular level of "readiness" to lead and have these conversations. While this issue needs to be explored more thoroughly, it begs the question of how to generate readiness.

The CAISE task force produced the overview for organizational leaders and the conversation tips for the toolkit users as a way to begin to address and bridge these power dynamics. We posit that organizational leadership buy-in is crucial. Further research and evaluation are needed to understand whether and how conversations might want to start with those committed to addressing organizational histories and then slowly expand to include others in the organization. Further, more research is needed on whether such cultural, dialogic, and boundary crossing approaches can lead to more inclusive and productive science communication in the long run. What is clear from the organizational change literature is that any change process needs a champion(s), and that the champion needs support, which the tools are intended to provide. Ideally these conversations would take place among multiple organizations, with the leaders of the conversations participating together in a community of practice that could offer each other support and opportunities for reflection on the process. Collectively, this could create greater levels of "uptake" and changes to practice at the field level.

As flexible and open-ended tools, boundary objects are meant to offer directional guidance for issues to consider rather than a concrete roadmap for exactly what to do. Organizations, audiences, and providers all live and work in unique sociocultural, and geopolitical contexts that shape needs and practices in particular ways. The challenges of working toward broadening participation can be thorny. The Informal Science/Science Communication sector can draw on these resources as it seeks to transform its contributions to broadening participation.

CONCLUSION

Research indicates that the challenge of broadening participation is more complex than simply providing greater access and opportunity (Philip and Azevedo, 2017). Inequalities persist for individuals from non-dominant communities, leading to limited access, encouragement, and opportunity to pursue STEM futures, whether it be STEM professions or civic decision-making (Canfield et al., 2020). The CAISE task force set out to identify key structural barriers in the field regarding more systematic and systemic adoption of DEIA practices in broadening participation. One of these structural barriers involved recognizing the cultural dimensions of science and science communication, and thus the need to approach inclusion as a process of cultural boundary crossing and exchange. Based on its analysis, it then focused on creating tools—boundary objects—for professionals in the field who were committed to making change through starting or deepening reflective dialogues among their staff or peers in the workplace. To create these tools, we leveraged perspectives from both SciComm/ISE researchers and practitioners, and from across a broad range of SciComm/ISE organizations and settings. This means that not all of the practice briefs are relevant to all SciComm/ISE practitioners, but several are relevant to most.

This approach represents a potentially important tool in the toolkit for change. As one of the field testers said: "If you already think you are doing it, the briefs will help you challenge your assumption. If you are trying to move toward more DEIA, the briefs will help you start. Are you really aligned? The best thing about them is that they force a dialogue, but the hardest thing is 'what's next?' It does not take you the next step. That has to come from the organizations' desire to achieve the goal. The briefs represent one tool in the arsenal that is needed for long term change." As this pilot tester noted, the briefs put the onus on the organization: How do we keep it going, what do we do to next, why is this important? This allows each organization, different in size and pace and resources, to determine what makes sense for its specific context.

Change starts with small steps. As interest and buy-in grows, change can spread across an organization and ultimately across a field. These conversations represent a start. This is a long-term process, and toolkit users cannot expect structural field-wide changes to occur overnight. The toolkit needs to be taken up with patience and generosity toward colleagues and even the institutions we work in, understanding that even getting people in a room prepared to be reflective and discuss difficult issues can represent a significant change and opportunity.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Following 45 CFR 46.101(b)2, Ethical and Independent Review Services, an external ethical review board, reviewed the proposed data collection plan, and has deemed the activities exempt (#16014-04). The review allows CAISE project coPIs and external evaluation partners Inverness Research, to interview and solicit views of pilot testers and participants at the NSF AISL meeting (reported in this paper). All responses reported here were voluntarily provided by project participants.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the conceptualization, implementation, and analysis of the process reported here. They collaborated fully on the creation of the MS and are listed in alphabetical order.

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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