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Bridging Science with Society: Defining Pathways for Engagement

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Science communication that fosters shared understanding, co-creation of meaning, and prompts large-scale change, is far from a one-way transmission of information. Rather, it is a multifaceted *system* that integrates different forms of knowledge and ways of knowing, attends to the complexity of social and environmental challenges, and conveys strong verbal and nonverbal skills (Brown et al., 2010). In 2019, Brooke Smith compared science communication to the Washington D.C. Metro transit system. Considering the efficiency of the Metro to move people where they need to go, Smith reflects on what it would take to put in place a highly functioning infrastructure to help scientists who want to communicate and engage effectively get where they need to be (Smith, 2019). Communication centers that offer science communication training opportunities are uniquely positioned to empower scientists to navigate this complex system. Training opportunities could include courses, workshops, seminars, and/or opportunities for scientists to practice their communication skills. The goal is to prepare scientists to interact with different publics and share scientific information clearly and efficiently. The scientists who enroll in these training opportunities seek to improve how science informs decision-making processes at the individual, organizational, and community levels. But prompting such change requires more than just the mastery of foundational communication skills. Scientists must also learn how to *engage* with these publics, something they can only do once they recognize the complete social and cultural systems wherein communication occurs. Communication centers that address science communication training in this way, mediate between knowledge and action across social domains, and challenge the boundary between science and society (McGreavy et al., 2013). In this paper, we argue that effective science communication requires *engagement* rather than traditional knowledge transfer, and we highlight the relevance of social considerations to accomplish effective engagement. We offer primary pathways for engagement that are key to spanning the boundary between science and society, and specify concrete suggestions for communication centers to implement these pathways. We conclude by discussing examples wherein social factors played a role in successful engagement.

Science Communication and Engagement

Engagement involves a process of paying attention, caring about, and participating intellectually, emotionally, and/or physically with a set of ideas, practices, people, and/or questions

(Fredricks et al., 2016; Linnenbrink-Garcia et al., 2011). Successful engagement depends on effective communication. Often, people reduce communication to a one-way process of conveying information and contrast it against the term engagement, which winds up being defined as a two-way exchange. In this paper, we move deliberately toward a different understanding of these terms that views them as mutually interdependent parts of the same process. Rather than viewing communication simply as the transactional exchange of information, we see communication as constitutive. By this, we mean that communication itself shapes our sense of the world rather than simply reflecting some fundamental, objective reality that can be accessed directly through language. From this vantage point, communication is not a thing we convey (i.e. information to be transmitted), but rather a process that forms our experiences of and relationships with each other and the material world in which we live (Craig, 1999). As a result, all engagement is shaped through communication and our daily practices of living.

Following this line of thought, scientists are much more than "senders" of information, but rather active participants in a series of diverse, complex interactions that can foster greater collaborative capacity. This emphasis moves us closer to an understanding of sharing science as engagement rather than simply as knowledge transfer. Effective engagement is critical to addressing the vast challenges faced in creating greater societal contributions to, support for, and use of science. There is solid evidence that the "information deficit model" fails to bridge knowledge with action (Kahan, 2010; Sturgis & Allum, 2004). Placing science on a "loading dock," as Cash et al. have described it, and waiting for society to come and pick it up and use it has failed to create the powerful kinds of societal integration of science needed to address complex societal problems (Cash et al., 2003). Instead, there is great need for a framework that recognizes the importance of transdisciplinary engagement that integrates different forms of knowledge and ways of knowing, attends to the complexity of challenges, and prioritizes boundary spanning and strong communication as essential factors (Brown et al., 2010). Preparing scientists to be effective communicators and boundary-spanners is key to accomplishing this goal.

Working Across Social and Cultural Boundaries

The point of engagement is to foster stronger societal connections with science. Training scientists to engage in ways that improve science-society relationships, can help create a better understanding of individual and institutional barriers to, and opportunities for, engagement. Such boundary work requires careful consideration of the different histories, practices, and structures associated with the culture of groups involved in engagement. Broad consensus exists around the idea that scientists themselves must play a greater role in communicating science to diverse audiences as a means of advancing effective engagement and boundary spanning. But scientists are not equipped to do this on their own, and training programs that target knowledge transfer skills to fill the information deficit, do not help scientists achieve this broader goal. Communication centers that adopt a systems perspective to science communication – that recognize the different social settings and opportunities for boundary crossing – are better equipped to provide training and preparation that support productive engagement across social communities and within the boundary spaces that operate to separate them.

Different models exist for boundary work. Much of the scholarly literature has emphasized the critical role of boundary organizations, which have been defined as sitting at the interface of science and policy and supporting information exchange and collaboration across science and policy communities (Guston, 2001). Guston introduced the concept of the boundary organization as a way to manage the relationship between science and policy in the context of developing a US technology transfer policy. Boundary organizations seek to ensure better boundary management and improve how science enters into decision making contexts (Berkes, 2009; Crona & Parker, 2011; Guston, 2001). Research on learning uses boundary crossing as a way of understanding the role of perspective making and perspective taking in processes of dialogue, communication, and meaning-making. These processes of encountering ideas in relationship to one's own experiences and histories as well as those of another support identity development; in the case of science communication, the development of identities as science engaged learners or as socially engaged scientists (Akkerman & Bakker, 2011; Bakhtin, 1981).

More recently, the conversation has shifted toward considering roles for scientists themselves as boundary spanners (Parker & Crona, 2012; Smith et al., 2016). Some researchers have called on scientists to join forces with social science communication specialists, to promote audience-centered communication as the pathway toward greater public understanding of, engagement with, and support for science (MacArthur et al., 2019). Others have extended the concept of the science-policy boundary to consider broader science-society boundary spanning and management (Bednarek et al., 2018; McGreavy et al., 2013). We adopt this latter approach here to highlight the importance of scientists themselves in spanning the science-society boundary.

To accomplish this goal, there is a critical need for (1) scientists to engage more effectively within a range of societal contexts, and (2) a comprehensive understanding of the different engagement pathways for scientists to span the science-society boundary. Certainly, boundary organizations have a central role to play in helping bring science to society, but scientists themselves must be involved, whether as direct representatives of science or as key informants to boundary organizations to ensure the saliency, credibility, and legitimacy of the science being shared beyond the walls of academe (Cash et al., 2006). Communication centers that offer training in this area are in a unique position to help scientists bridge the gap between academe and the larger society.

Pathways to Support Effective Communication for Productive Engagement

Because compelling communication enables impactful engagement, scientists must develop and practice core communication skills to become effective boundary-spanners regardless of the specific contexts in which they chose to engage. These competencies include skills to develop structural or organizational elements, such as targeting a communication effort for a given audience and context, developing a focused message, and constructing a logical and compelling narrative. Basic competency training should also cover skills that are more visible, including using accessible or plain language, practicing effective nonverbal communication and/or writing style, and applying principles of design to develop effective visual aids. Additionally, scientists need opportunities to develop dispositions that allow them to effectively empathize and connect with public audiences and to notice and respond to the cues that audiences express in real time. Preparing scientists for this work involves creating opportunities for them to learn about, test, and refine these ideas, dispositions, and skills through performance and feedback cycles conducted in safe spaces (AAAS, 2020; Aurbach et al., 2019).

In addition to the development of foundational communication competencies, scientists pursuing different pathways for public engagement require sector-specific skills and content knowledge. For example, engagement with policymakers requires significantly different types of preparation, networks of connectivity, resources, and capacity than engagement with teachers or with students. As the field of science communication expands, there is a growing need to consider how different training programs are designed to address particular needs. Additionally, the difference between structured training for STEM professionals who have already advanced in their careers, compared to communication training delivered as coursework during STEM graduate or undergraduate programs must be recognized (Kuchel, 2019). Productive engagement activities involve boundary crossing into communities with existing social histories, structures, practices, and routines. Some communities have long histories of engagement with science. Others may have had strikingly different experiences with science, receiving broad cultural messages that science is "not for them," fortified by a lack of role models in the sciences, or by weak experiences with science in school. Social routines vary across communities. For example, public engagement is often undertaken by social groupings such as families, couples, or friends who support one another's participation. In policy circles, participants are typically representing the interests and needs of larger groups not visible in the room. By viewing this work as a system, scientists will be prepared to draw on foundational communication skills that will enable them to match their language with social and cultural norms and expectations, for enhanced engagement with various audiences.

Table 1 begins to separate the different possible pathways communication centers could take, depending on the contexts and audiences for engagement. We differentiate between the goals, sites, and audiences for engagement, and the forms of knowledge or preparation needed for productive engagement. The content in the table is meant to be illustrative, not exhaustive.

Social Histories. Different social communities have different histories with science, which leads to varying levels of expectations, preparation, and readiness to engage. For example, policymakers may have been trained to look to science for hard, clear data that can clarify policy choices. On this basis, productive communication with policymakers requires modes of communication that clarify rather than reveal complexity. Many members of the general public may have experienced science as an elitist or exclusionary field of practice, which has often led to perceptions of science as difficult to comprehend, or irrelevant to their daily lives. Effective communication with these communities may require firmly rooting science in meaningful issues that are familiar to the public audience, where they may have ideas or experiences to contribute to the discussion.

Social Structures. Different social communities are organized around different types of structures. For example, educators in K-12 classrooms or afterschool programs typically have a structured sequenced curriculum, that makes room for particular ideas at particular years in the K-12 span, and weeks or even days in a given year. Effective communication requires relating science to that sequence: the ideas that came before and the ideas that will follow. Similarly, the science engagement opportunity offered to the general public occurs within a larger science learning ecosystem; People have an array of opportunities to experience science, from everyday activities in the kitchen or backyard, to mainstream media, the web, formal experiences, and others. Effective communication helps people make connections between these experiences, building on prior experiences and creating the incentive to seek out future experiences.

Social Practices and Norms. Social communities differ in their social practices. For example, some cultural groups position adults as experts whose authority and standing must be deferred to. Other social groups position young people as budding authorities. Understanding these types of cultural variation is essential to effective communication. Similarly, the social practices of many K-12 schools position teachers as the authorities in their classrooms. Typically, in classrooms there is only one teacher, and one authority; others are meant to follow instruction. Students, as well as teachers, are accustomed to taking on these specific roles. Effective communication in the classroom needs to either follow or explicitly negotiate alternative practices of who has or is the authority in the classroom, in cases where scientists wish to co-teach or otherwise involve the teacher in the activities.

Social Routines. Routines represent the formats, platforms, and/or patterns of interactions that characterize different social engagements. For example, public/lifelong learning activities typically involve branding and marketing efforts that can attract notice and participation. Coordinating science concepts will vary depending on whether the platform for engagement is a curated exhibition, live interactive discussion, or testimony at a policy panel. K-12 settings typically have tightly constrained time-periods (50 minutes) for any given lesson. Understanding the skills required to be effective in each setting and developing training appropriate to meet those needs is critical to support scientists in these spaces. Navigating cultural boundaries around "what constitutes reliable evidence, convincing arguments, procedural fairness, and appropriate characterization of uncertainty" is essential for scientists who want their work to make a difference in the context of policy (Cash et al., 2003). Serving as an expert witness in a criminal case or providing testimony in front of a legislative body requires knowledge and experience with the process of how decisions are made in these respective theaters. Social routines span a wide range, from knowledge about language use, appropriate dress, and body language.

Implementing Pathways to Support Productive Engagement

Communication centers who seek to support science engagement can implement these pathways to reimagine their training programs, resources, and/or outreach activities to address these issues. In many instances, communication centers already have access to the resources necessary to accomplish these goals but they are either unrecognized or underutilized. We offer some suggestions that centers can use to capitalize on the pathways listed above. First, many communication centers are staffed with individuals representing a variety of education levels, content area expertise, and hands-on experience. It is not uncommon for people to discover a career in science communication after years of a successful career in another field such as corporate communications, education, law, policy, journalism, or public health. Some may even be scientists themselves. Communication centers can draw on these individuals' experiences to facilitate engagement in a number of ways. For example, considering the communication cultures and strategies that exist in other fields could signify key concepts to include in training and preparation for scientists. Additionally, these faculty and staff likely have existing professional networks of experts on which they could call to review materials for content accuracy, offer case study examples drawn from actual experiences, or consult as a trainer on a particular program. Communication centers' faculty and staff should not operate solely in the sphere of science communication. They must remember how they got to their careers in science communication, and utilize the unique knowledge they bring to the table.

Second, while many science communication training programs are evidence-based, communication centers must ensure that this evidence-base is drawn from multiple fields such as intercultural communication, science of science communication, public health, medicine, and education, to name a few. If communication centers are advocating for science engagement, they must also practice it, by offering programs that integrate knowledge across fields. This integration could emerge through the breadth of content covered, the examples highlighted, or the methods borrowed. Such integration creates the most realistic experiences for scientists that will ultimately prepare them for success.

Third, communication centers must design programs that acknowledge the cultures in which scientists are most likely to communicate and engage. Geographic location, socioeconomic status, and political climate will influence how their audiences will react to and interpret scientific information. Educating scientists about how people tend to think about science based on these factors is essential. Social science research into various audiences can be utilized to facilitate understanding. One resource for this research is S*cienceCounts,* a nonprofit organization that conducts empirical research on various publics and their attitudes toward science, willingness to engage in science communication, and trust in scientists. They make their findings publicly available on their website as a way to increase resources that promote science in society. Integrating this information in existing training and preparation, or offering outlets for scientists to obtain such information is crucial.

Fourth, in addition to science communication training, communication centers can offer scientists opportunities that allow them to fully learn about, understand, and in some ways assimilate themselves into the contexts in which they are most likely to engage in science communication. Opportunities for scientists to go out into the community and simply observe, learn about people, their cultures, and the contexts wherein science communication takes place is an experience that cannot be attained through didactic training or consuming research. The mere experience will lay the foundation for all communication competencies that scientists can learn. Social science researchers engage in a similar process when they are conducting ethnographic research on particular groups. They immerse themselves in cultures that are unfamiliar to them so that they can learn and describe that culture accurately. Similarly, actors who are cast as characters that are based on actual people often spend weeks to months observing them in their natural environment so that they can accurately portray that person, and fully understand what drives their mannerisms and rituals. As part of this discovery process, scientists also have the opportunity to meet and network with key gatekeepers and opinion leaders in the community, that could help them establish credibility with particular groups. For scientists, there is no better lesson in understanding an audience than to observe that audience in their natural habitat. When actual observation is not possible, video examples can also be useful in helping scientists visualize the context and contemplate the communication challenges they may face with a particular group. Communication centers that can provide opportunities for scientists to engage with audiences and fully understand surrounding environments before diving into communication skills training will provide a more comprehensive approach to training.

We present these suggestions to communication centers as a starting point to reimagine their training and preparation for scientists, to foster science engagement and empower scientists to span the science society boundary. We encourage communication centers to draw on their existing strengths, resources, and networks to evolve new ideas and create opportunities for engagement. It is unrealistic to think that any one communication center could incorporate all aspects of this process into their missions, so centers should capitalize on their strengths and the strengths of others to connect scientists with the most influential opportunities available.

Three Examples: Communication and Engagement Training

Below we provide examples of leading programs that specialize in science communication and engagement within each of the three pathways – Public/Lifelong Learning, Decision Making, and Education. Although each of the programs outlined below also supports scientists' general learning and provide foundational skills training, we note them in this context as models for how communication centers could support sector-specific learning within each of the three primary pathways outlined above.

Public/Lifelong Learning: The STEM Ambassadors Program

A successful training program focused on public/lifelong learning is the NSF-funded STEM Ambassador Program (STEMAP) hosted at the University of Utah (www.stemap.org). Their program **goal** is to facilitate two-way exchange between scientists and the public. After admission into the competitive program, scientists, referred to as "STEM Ambassadors," brainstorm opportunities to engage with communities outside of traditional science education settings (e.g., schools, museums). Ambassadors identify specific "focal groups" or communities unaffiliated with STEM whose interests and values overlap with the Ambassador's STEM discipline and/or personal characteristics (e.g., ethnicity, hobbies, family role).

With regard to **settings,** Ambassadors engage in the venues where the focal group naturally gathers. They receive training in building community contacts, designing engagement activities, and communicating science through a series of workshops. Prior to initiating their engagement activity, Ambassadors visit the engagement venue to develop a deeper understanding of the focal group (i.e., "immersion visit") and **social histories**. During the immersion visit, Ambassadors note the customs and norms of the focal group and venue layout. They incorporate this information into an engagement activity that fits seamlessly into the group's activities and venue. Ambassadors develop and prototype the engagement activity with feedback from STEMAP staff, peers, and members of the focal group. They facilitate one or more engagement activity and solicit feedback from the group. STEMAP engagement activities emphasize the exchange of information between scientist and members of the focal group and often highlight common ground between the scientist and participants.

Although the goal of all STEM Ambassadors aligns with the goals of public/lifelong engagement, the program places emphasis on creating a dialogue between scientists and other facets of society. Communicating scientific knowledge is secondary. To achieve this dialogue, Ambassadors must develop specific skills that align with community **practices and norms**. These skills include identifying shared interests and values with a focal group, developing a relationship with group members, collaboratively designing an engagement activity, and evaluating whether that activity accomplished STEMAP goals and objectives. Although some of these skills cut across the various pathways, the full constellation of these skills fits most squarely within the public/lifelong learning pathway. **Social routines** within this program vary greatly given the diversity of participants.

For example, a STEM Ambassador and microbiologist identified fermentation cooking enthusiasts as a focal group she sought to engage. The Ambassador enjoys making sauerkraut, kimchi, and kombucha in her spare time. Her training in microbiology is closely related to this hobby, giving her an understanding of the microbial processes at work in fermentation cooking. The Ambassador reasoned that she could facilitate a mutually beneficial exchange with cooking enthusiasts where she shares the science behind the fermentation cooking and learns new recipes and techniques from members of the focal group.

The Ambassador identified a cooking school offering a fermentation cooking class as a venue where members of this group might gather. She approached the cooking school about partnering on an engagement activity with the objective of demonstrating that scientists and cooking enthusiasts have mutual interests and can learn from each other. She conducted an immersion visit to the school and spoke to the class chef to understand the structure and routines of the class. She became familiar with the recipes, the age and experience of the participants, and the class format. The Ambassador collaborated with the chef to provide microbiology content that complemented the fermentation class curriculum. She presented this information alongside the chef during two fermentation classes. In turn, she learned new recipes and tips to improve her own preparation of fermented foods.

This "ambassador" approach integrates practices from public relations, design thinking, and science communication. Evidence from scientists trained in this approach revealed that scientists became more proficient and effective in engaging diverse public groups. Challenges addressed in current work include quantitatively assessing impacts on the public and scientists and reducing time investment of program staff. This is one example of a public engagement program that embraces contemporary science communication models that advocate for open-ended exchanges between scientists and society.

Decision Making: COMPASS

COMPASS is a leader in science communication training in the U.S. Its mission is to help scientists engage effectively in public discourse about the environment. COMPASS' non-partisan approach has led to unique opportunities for scientists to be involved in conversations with "unlikely bedfellows," catalyzing new thinking and possibilities for more robust, science-informed policy solutions. Through research-based communication trainings, coaching, and real-world connections, COMPASS supports scientists to build the communication skills, networks, and relationships they need to be successful in their communication efforts. One of COMPASS' core tools, the Message Box, is designed to help scientists distill their message and focus it on the needs of particular audiences, such as policy makers or journalists. Hand-in-hand with its trainings, COMPASS empowers environmental scientists to connect with the individuals and organizations in decision-making contexts where their research is relevant. Advanced COMPASS training and coaching includes the setting of goals for stronger societal engagement and assistance with navigating engagement across a science career. Given their specific expertise in environmental policy issues and position as a boundary-spanning organization, COMPASS is able to bridge fundamental skills training with networking and advanced topical training opportunities that help scientists navigate the complex world of policy. COMPASS' focus on helping scientists expand their networks also creates greater connectivity among scientists, leading to peer learning and engagement opportunities. COMPASS has numerous success stories of scientists whose work has impacted decision making at federal, regional, state, and local levels.

The focus on environmental policy allows COMPASS participants to do more in-depth investigations of the **social histories** of the policymakers they will be engaging with. For example, whether or not they are already engaged in environmental legislation, and if and how they support or oppose using scientific testimony to inform policy. The social histories of the communities being affected, or the places under discussion, are also critical. COMPASS prepares participants to address the key **structures** that policy makers consider, such as economic and political implications associated with the science under discussion. The **social practices and routines** of policymakers are closely considered, as presentations are honed to address language, time constraints, uses of visuals, and compelling narratives that policymakers can draw upon.

In 2004, Dr. Scott Doney, a marine biogeochemist, brought the issue of ocean acidification to the public eye due to a connection made at a Leopold Leadership Fellows training led by COMPASS. Doney decided to focus on one aspect of his research, ocean acidification, for his Message Box. One of the journalist experts that COMPASS brought to the training was intrigued by the issues Doney raised and persuaded him to write an article about it for

Scientific American, which caught the attention of then-Representative Jay Inslee (now Governor of the state of Washington). Rep. Inslee reached out to COMPASS to organize a briefing with Doney and other scientists studying ocean acidification. COMPASS went on to host a series of briefings and meetings on Capitol Hill involving leading ocean acidification scientists. This work catalyzed the development and passage of the Federal Ocean Acidification Research and Monitoring (FOARAM) Act in 2009, which provided funding for NOAA, NSF, and NASA to conduct a coordinated research and monitoring program. COMPASS also trained scientists in the ocean acidification community so that they could effectively convey what they knew, both individually and as a field, and connected them with journalists and policy makers. COMPASS organized field trips for local policymakers with scientists in Oregon to discuss the local impacts of ocean acidification. Many of the scientists involved in these events went on to become trusted resources for policy makers and have been involved in regional and state efforts such as the Washington State Blue Ribbon Panel on Ocean Acidification and the West Coast Ocean Acidification and Hypoxia Science Panel. This work laid the foundations for ongoing policy impact, including the passage in 2017 of Oregon Senate Bill 1039, which created the Oregon Coordinating Council on Ocean Acidification and Hypoxia.

From that initial conversation between a journalist and a scientist at a training, COMPASS knew that the issue of ocean acidification was one to pay attention to and needed the intervention of a boundary organization like COMPASS, given the large gap between science and policy. Sustained efforts to build a network of effective science communicators, strengthening relationships with key decision-makers, journalists, and influencers, and continued engagement over time has helped close that gap between science and policy.

Education: Ciencia Puerto Rico

Ciencia Puerto Rico (CienciaPR) is a dynamic non-profit organization democratizing science and transforming science education in Puerto Rico and training young scientific leaders from underrepresented backgrounds. Their work revolves around developing strategies and resources that make science more engaging and culturally relevant to Puerto Rican and Latinx audiences. The organization brings together a global community of 8,600+ scientists, students, educators, and allies, who are the key ingredient to more than a dozen programs in three main areas: engaging scientists in science communication and outreach, training and advancing the career development of scientists, and developing culturally relevant science education resources and experiences for K-12 students and teachers.

Since 2006, CienciaPR has successfully engaged and trained scientists in science communication and outreach, which has led to the publication of 610 popular science stories in media outlets in Puerto Rico, the U.S. and Spain, over 270 podcast episodes, and a book called "¡Ciencia Boricua!" among other initiatives. Since 2011, CienciaPR has successfully completed 3 projects (impacting 220 students from 120 schools and 51 municipalities) to make science relevant to Puerto Rican students and improve their attitudes, interests, and self-confidence. The organization has also trained 430 teachers in Puerto Rico on how to use resources, like science articles and the "¡Ciencia Boricua!" book, to make science pertinent to the culture and context of their students in the classroom.

CienciaPR's work draws from a deep understanding of Puerto Rico's **social histories**, which include a decade-long economic recession and a centuries-old history of colonization, and the **social structures** of the local education system in which science is mainly taught passively, without engaging students in the process of inquiry and discovery, and in ways that are often disconnected from the social and cultural context of the students. Recently, CienciaPR reoriented its strategic direction to engage scientists, educators, and students in "transforming science education to promote a culture of science, critical-thinking, and problem-solving." Following Hurricanes Irma and Maria, which devastated the Caribbean in September 2017, CienciaPR shifted the implementation of this strategic direction to create science lesson plans that use project-based learning (PBL) that frame topics through grand challenges that Puerto Rico faces in the aftermath of the natural disasters. The lessons developed by CienciaPR are aligned with **social structures and routines** of Puerto Rico's curricular middle school standards and Next Generation Science Standards (NGSS). They incorporate real life stories about Puerto Rican scientific role models; pose reflexive questions related to the scientific concepts in the context of the current situation in Puerto Rico; and prompt students to observe, research, and find solutions to problems in their environment using low-cost approaches. These contextualized PBL science lessons challenge Puerto Rico's traditional K-12 **social practices and routines**, to support new forms of students' engagement with learning, attitudes towards science, and content knowledge. The long-term goal is to shift **social practices and norms,** across the island's classrooms, from teacher-centered to student-centered.

Discussion and Limitations

The examples provided above demonstrate the ways in which the social histories, structures, practices, and routines of public audiences are attended to in targeted ways by training programs preparing scientists to engage with particular audiences. For example, understanding the constraints on K-12 teachers is critical to engagement between scientists and schools. Recognizing that students may come to engagement with social classroom practices that hinder their agency in engaging with science, or that teachers seldom have sufficient time to prepare and plan for lessons in ways that might be optimal, is critical to successful engagement with schools. If these constraints are acknowledged, scientists can work with them rather than against them, and increase their chances of productive collaborations across the boundary spaces of school and science.

In the boundary spaces, scientists and public audiences can both engage in and recognize one another's social practices and norms, and, at the same time, develop new, hybrid forms of engagement that draw on the respective social practices of each. For example, scientists can use language and images that are familiar to public audiences or policymakers. Members of the public can be supported to try on and use sense-making practices of scientists, for example grappling with competing explanations by examining data more closely in classrooms or museum-type engagement activities. Adopting a systems perspective that recognizes the different social settings and opportunities for boundary crossing, helps us to map out the landscape of engagement opportunities and training and preparation programs that can support productive engagement across social communities and within the boundary spaces that operate to separate them.

This paper presents a structural framework to think through the key pathways we have conceptualized as arenas of public engagement. Beyond the three identified here, there are others that lay outside of this paper's scope that are worthy of discussion in future analyses. For example, bench scientists interact with treating physicians who help patients make decisions about their health based on science. Teams that collaborate across disciplines and different types of institutions (for example, university-industry collaborations) represent a central site where science crosses institutional and disciplinary boundaries. Engagement with different media sources and platforms itself presents an interesting case which is not fully captured in our preliminary framework. These areas need further discussion about the types of training required to enable more effective collaboration and support systems. This paper has not focused on programs whose exclusive purpose is to network and connect scientists with engagement opportunities, for example the Thriving Earth Exchange through the American Geophysical Union or SciLine, which links scientists with journalists. Our focus here is specifically on organizations that provide science communication training, even if they also support networking and engagement opportunities.

Furthermore, we have limited ourselves to presenting a structural framework with selected examples from the respective arenas we discuss. There are opportunities to expand this framework, and characterize each of these arenas more specifically in terms of the competencies required to participate, and the training available to achieve these competencies. Likewise, we have not attempted to map onto this framework all of the existing training opportunities in the U.S., nor have we addressed the science communication training programs outside of the U.S. Future work should explore how the current offerings reflect the need, with an eye toward balancing supply with demand. Our framework presents a high-level conceptual overview that can help us consider where particular gaps in the system lie. This presents a structured way to assess and grow science communication training and support systems more strategically. Future efforts might survey current providers to assess in greater detail the areas of greatest strengths and the most significant gaps.

Conclusion

Approaching these challenges from a systems perspective creates a number of opportunities for communication centers to stand in service to science in society. Systems thinking invites scientists to consider critical science-society points of intersection where engagement is needed. It helps identify what kinds of skills, expertise, networks, and support these intersections require for effective engagement to take place. It also highlights the broader landscape of current approaches and how different training programs approach meeting the range of needs at different stages in the training and engagement processes. In short, communication centers can achieve greater alignment of their efforts, investments, and outcomes by taking a 50,000-foot view of science communication and engagement, planning strategically, and operating together to support and draw on one another's strengths.

Engagement is an ever-changing, dynamic landscape that invites communication centers to reimagine their training approaches and operate adeptly and collaboratively as the contexts shift. Viewing this challenge through the lens of systems thinking maintains the focus on the scientists who require support to be most effective in their engagement, and it compels communication centers to build the support systems they need to create greater integration of science into society. Mapping the system lets trainers identify assets and gaps and can help inform action to ensure the best possible alignment of all variables.

This analysis focuses specifically on training pathways for critical areas of engagement. We present this social framework as undergirding other efforts already underway to build and support a growing community of science communication trainers and researchers. Far from a one-way approach that attempts to equip scientists and send them off into different engagement pathways, we view this as a dynamic model that can help communication centers design strategies for bringing the knowledge, experience, and networks that engaged scientists build outside academe, back into the culture of science. This systemic approach can help communication centers map out potential career pathways outside of academe for scientists, and develop a deeper understanding of how they can grow and sustain stronger integration across the different areas in which scientists pursue their careers. Ultimately, our aim is to lay a framework that can advance a stronger infrastructure across all communication centers' efforts.

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Table 1

Spheres of Engagement			
	Public/Lifelong Learning	**Decision Making**	**Education**
Goals	To support awareness, interest, and understanding of science.	To inform, influence, or advocate for decisions and policies that affect society at large.	To enrich how science is presented in formal and informal (K-12) settings.
Settings	Interactive events (Science Festivals, Science Cafes/Pubs, Science Museums, Non-Science Public Places) Static content (Blogs/Web, Radio/TV, Social Media) Citizen Science	Government settings Courtrooms Councils/Advisory Boards	K-12 classrooms K-12 afterschool K-12 teacher development IHE (non-science depts)
Social Histories	Histories of access and inclusion/exclusion (e.g., by race, gender, socio-economic) Relevance of subjects of scientific research to local histories, industries, social settings	How policy is made Existing relevant policies and statutes	Current STEM education policies and standards Teacher preparation
Social Structures	Local STEM learning ecosystem Local communities and populations (regardless of science connection)	Economic implications Political implications Influencers & gatekeepers	Competing curricular priorities

Social Practices and Norms	Dynamics of multi-generational or cultural groups Cultural variation in learning	Dynamics of formal decision-making culture (e.g. language, hierarchy) Providing information sharing (e.g., testimony, depositions, one-pagers)	Lesson planning Alignment with state, local, and federal standards and best practices
Social Routines	Marketing and branding Content or event coordination	Legislative or judicial timelines (sessions, court dates) Formalized provisions for information sharing	Yearlong and daylong scheduling constraints Planning time and norms