

The ECO framework: advancing evidence-based science engagement within environmental research programs and organizations

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Abstract

Despite widespread interest in science communication, public engagement with science, and engaged research, a large gap exists between the theories behind science engagement and how it is practiced within the scientific community. The scholarship of science engagement is also fractured, with knowledge and insights fragmented across discourses related to science communication, informal science learning, participatory research, and sustainability science. In the present article, we share a planning tool for integrating evidence and theory from these discourses into effective programs and projects. The ECO framework promotes three distinct and interacting modes of science engagement practice: formative engagement (listening and relationship building), codesign and coproduction (action-oriented partnerships), and broader outreach (expanding networks and dissemination). By planning engagement activities with attention to these three modes of engagement, scientists and scientific research organizations will be better poised to address urgent needs for stronger connections between science and society and increased use of scientific research in decision-making.

Keywords: broader impacts, coproduction of knowledge, outreach, public engagement, science communication

The decades-long conversation about how to harness scientific research to address societal and environmental needs has taken on new urgency amid the ongoing climate crisis and COVID-19 pandemic. A common refrain, from scientific journals to Twitter, is for increased and more effective engagement among scientists, decision-makers, communities, and broader publics (Nature Medicine 2020, Chilvers 2021). But how effective engagement is defined, who participates, what its goals are, and how its practices are underpinned—or not—by scientific evidence can vary widely. As a result, much of the recent interest, participation, and investment in science engagement (box 1) remains siloed, and efficacy is hampered.

In the context of the biological and environmental sciences, scholarship relevant to science engagement is fragmented across at least four distinct discourses: a science communication discourse that is focused on public opinion about science and that emphasizes tactics such as message choice, framing, dialogue, and storytelling (NASEM 2017); an informal science learning discourse that is focused on how, why, and where people learn about science throughout their lives and that considers issues such as interest and identity along with science knowledge and skills (NRC 2009, Falk and Dierking 2010); a participatory research discourse that is focused on the process of biological and environmental research and the potential positive impacts, across both science and society, of opening that process to stakeholders and interested publics (Shirk et al. 2012, Bonney et al. 2016); and a sustainability science discourse that is focused on the integration and mobilization of scientific knowledge for natural resource management and environmental decision-making in various contexts (Cash et al. 2003, Arnott et al. 2020).

These discourses have developed in relative isolation, with research published across nonoverlapping research teams and journals (table 1). This fragmentation contributes to silos of research and blind spots and allows several longstanding barriers to effective science engagement practice to persist. These barriers, well documented across these literatures, include a lack of strategy (Besley et al. 2018); a narrow focus on knowledge acquisition as the sole objective of engagement (Bucchi and Trench 2008, NASEM 2017); passive, inefficient approaches to knowledge-sharing with decision-makers (Cash et al. 2006); and inequitable access and inclusion in science engagement opportunities (Dawson 2018, Canfield et al. 2020).

As practitioners who lead science engagement initiatives within environmental research programs and institutions, we see a critical need to better integrate existing knowledge across multiple discourses to forge stronger connections between science and society. Stronger connections, we and others argue, are vital for ensuring that research addresses the most pressing problems of the day, that diverse perspectives contribute to both the definition of these problems and their solutions, and that all people are empowered to contribute to a more sustainable and just world (Lubchenco 1998, Leshner 2003, McCallie et al. 2009, Groffman et al. 2010, Canfield et al. 2020, Chilvers 2021).

We build on the discourses outlined above to propose an actionable framework for planning science engagement programs in the biological and environmental sciences, called the ECO framework. In the following sections, we provide an overview of the ECO framework, describe its relationship to the discourses and barriers above, and illustrate how it could be applied by others who seek to use science engagement to strengthen the science–society interface.

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Box 1. What is science engagement?

We use the phrase *science engagement* to encapsulate the many intentional ways scientists and science professionals (i.e., science communicators, educators, policy experts, administrators, and other professionals who contribute to the scientific enterprise) choose to interact and communicate with people about science. The term *engagement* emphasizes meaningful interactions between scientists and publics that, over time, foster mutual understanding, knowledge exchange, and trust, which are essential for science to serve societal needs (McCallie et al. 2009, Groffman et al. 2010, AAAS 2016, Bell et al. 2017, NASEM 2017, Nadkarni et al. 2019, Canfield et al. 2020). These interactions may occur within programs variously described as outreach, broader impacts work, engaged scholarship, or translational research, and they may involve individuals and groups of people who might be categorized as stakeholders, decision-makers, community members, or members of the public, depending on context of the activities. We have found that from the perspective of a long-term research program or research institution, taking an integrated view of an overall science engagement portfolio can help make these efforts more synergistic, strategic, and effective.

The ECO framework

The ECO framework draws from our experiences gained through programs each of us has developed and led going back to the late 1990s, involving public and policymaker engagement with ecological science in the northeastern United States. Much of this program work has involved two US Long Term Ecological Research Network (LTER) sites: the Hubbard Brook Experimental Forest, in New Hampshire, and the Harvard Forest, in Massachusetts. These programs include the Hubbard Brook Research Foundation's Science Links (Driscoll et al. 2011) and Forest Science Dialogue programs (Bell et al. 2017), the Harvard Forest's Wildlands and Woodlands and New England Landscape Futures initiatives (Foster et al. 2010, Thompson et al. 2016, McBride et al. 2017), and the Science Policy Exchange (Driscoll et al. 2015). A recent project supported by the National Science Foundation called "Embedding Public Engagement with Science at Long Term Ecological Research Sites" has allowed us to integrate and apply insights from our prior work, together with a team of collaborators, to better understand and advance institutional cultures and organizational practices of science engagement within the long-term research programs at Hubbard Brook and Harvard Forest (Besley et al. 2021a, Peterman et al. 2021).

The ECO framework is structured around three categories of science engagement that we have found via our experiences at Hubbard Brook, Harvard Forest, and the Science Policy Exchange to be key to effective programs and that also reflect important ideas that have evolved in the engagement literature over time (table 1). These categories are formative engagement, codesign and coproduction, and broader outreach (figure 1). Formative engagement, the E in the ECO framework, describes practices focused on active listening and intentionally developing positive, ongoing relationships among scientists, community members, and decision-makers. Codesign and coproduction, the C in the ECO framework, describes action-oriented practices that bring scientists and public partners together to cocreate new ideas, data, products, and programs. And the O, broader outreach, describes the work of enhancing dissemination, increasing visibility, and expanding networks beyond those engaged in the other two modes. We conceptualize these categories as key modes of operation or modes of engagement practice, similar to the approach of other scholars, including Mach and colleagues (2020), who described modes of engagement based on types of relational interactions, and Scheufele and colleagues (2021), who distinguished engagement modalities on the basis of the level of influence of public participants on engagement activities and outcomes.

The overarching ideas of the ECO framework are that science engagement activities can be designed to operate intentionally

in one or more of these E, C, and O modes on the basis of one's goals, objectives, and desired impacts (figure 1) and that the engagement portfolios of research institutions can be developed to enhance these modes over time. The analogy to a set of gears highlights two important concepts embedded in the ECO framework: that effective science engagement should be viewed as an ongoing endeavor—gears turning—and that there are important interactive effects among these modes—gears turning other gears. For example, the connections that emerge from formative engagement and the exposure that occurs with broader outreach can lead to new, unanticipated opportunities for codesign and coproduction. A third insight, also illustrated by the analogy, is that science engagement requires inputs of energy: Gears have to be cranked. We discuss these key inputs of effective science engagement, people and funding, in a section below.

The main contribution we hope to make with the ECO framework is to provide scientists, outreach and engagement professionals, and other practitioners, with a simple, flexible planning tool that can support the adoption of more effective, evidence-based engagement practices within the environmental and biological sciences and also to provide a practical structure for integrating theory and evidence from siloed but complementary scholarly discourses (tables 1 and 2). As a process-based tool, the ECO framework is focused on the *how* of science engagement—on the big-picture, tactical approaches and core competencies that serve many of the long-term goals that relate to strengthening the connections between science and society, as was framed above, as well as the common shorter-term objectives that serve these goals, listed in table 2.

The ECO framework is part of a lineage of practitioner-oriented models, approaches, and tools in the environmental and biological sciences that draw both on theory and on-the-ground experiences. These include, for example, Varner's (2014) evaluative framework for scientific outreach, which promotes an iterative process of activity development, implementation, and evaluation, with a focus on goal setting, collaboration, and formative assessment. Also, Nadkarni and colleagues' (2019) STEM ambassador approach promotes a process of goal setting, immersion of scientists within target communities, informed program design, implementation, and reflection. And the practical guides in the knowledge coproduction literature (e.g., Djenontin and Meadow 2018) emphasize processes of relationship building, power sharing, and knowledge synthesis.

The ECO framework is complementary to these approaches, with a lens that is focused on the key capacities called for by many of these processes (i.e., the listening, relationship building, collaboration, and dissemination of the E, C, and O modes), and the

Table 1. Key ideas in the advancement of science engagement.

Year	Authors	Discourse	Key ideas
1998	Lubchenco	Sustainability science	Call to action for all scientists to devote their energies and talents to the most pressing problems of the day, in proportion to their importance, in exchange for funding.
2003	Leshner	Science communication	Call to action for scientists to move beyond what has been seen as a paternalistic stance in society and to embrace more open and honest dialogue that respects the public's perspectives and concerns, even when they are not shared.
2003	Cash et al.	Sustainability science	Systems that effectively harness science and technology for sustainability ensure the salience, credibility, and legitimacy of information across multiple interfaces.
2005	Rowe and Frewer	Science communication and participatory research	Three types of public engagement can be identified on the basis of the nature and flow of information: communication (one-way), consultation (two-way, asymmetrical), and participation (two-way, symmetrical).
2005	Lemos and Morehouse	Sustainability science	Successful coproduction involves stakeholders in multiple stages: problem definition, development of questions, research design, data collection, data analysis, meaning making, testing results, and dissemination of knowledge.
2009	National Research Council	Informal science education	Ample evidence demonstrates science learning occurs across informal environments, including in everyday experiences, designed settings, and programs.
2009	McCallie et al.	Informal science education	Public engagement with science in the context of informal science education emphasizes a shift from one-way transmission of knowledge from experts to publics to multidirectional dialogues that allow all participants to learn.
2010	Falk and Dierking	Informal science education	Most people learn about science not through schooling, but through informal settings and experiences, including museums, aquariums, and media.
2010	Groffman et al.	Science communication	Improving environmental problem-solving requires a rededication to the public responsibilities of ecologists. Ecologists need to adopt bidirectional models of engagement, frame results in ways that are more meaningful to audiences, and use new communication tools and strategies to reach larger and more diverse groups.
2011	Driscoll et al.	Sustainability science	Integrating ecosystem science for environmental policy and management requires key boundary-spanning functions, including relationship building, translation, and communication. Knowledge coproduction processes should be scaled to match decision contexts and available resources.
2012	Shirk et al.	Participatory research	Public participation in scientific research can enhance positive outcomes for research, individuals, and social-ecological systems. Effective projects consider the degree and quality of public participation. Quality relates to the extent to which project goals and activities align with and respond to participant needs and interests.
2013	Fischhoff and Scheufele	Science communication	Science communication should be informed by social and behavioral science rather than just intuition. Empirical research is essential to understand what people think about, know, and need to know about science, which will improve two-way communication.
2016	Bonney et al.	Participatory research	The democratization of science and improved wellbeing of people in society are possible deep outcomes of citizen science. To achieve these outcomes, project developers will need to increasingly place lay knowledge alongside scientific expertise and empower individuals to become active members of the scientific decision-making process. Issues of trust, fairness, equity, and risk are paramount.
2016	AAAS	Science communication	Public engagement with science is defined as intentional, meaningful interactions that provide opportunities for mutual learning between scientists and members of the public. A logic model links short-, medium-, and long-term outcomes of engagement activities to an aspirational vision of transformations in collective action, policy, research agendas, culture, and workforce.

Table 1. Continued

Year	Authors	Discourse	Key ideas
2017	National Academies (NASEM)	Science communication	Consensus report highlighting the importance and complexities of science communication, including rapidly changing communication environments and the challenges of public controversies.
2018	Besley et al.	Science communication	Proposes a theory of strategic science communication as planned behavior in the context of scientists' prioritization of communication objectives. Evidence suggest that scientists are more likely to say they will prioritize specific objectives if they think those objectives will make a difference.
2018	National Academies (NASEM)	Participatory research	Consensus report about how citizen science supports science learning, focused on the importance of designing for learning, including stakeholders in the design process, and allowing for iteration.
2020	Canfield et al.	Science communication	Defines inclusive science communication as a path for overcoming systemic inequities in access to and engagement with science, highlighting principles such as recognizing discrimination and oppression, adopting asset-based practices that uphold diverse perspectives, and cultivating belonging among participants.
2020	Mach et al.	Sustainability science	Reviews the concepts behind actionable knowledge and coproduction, recognizing diverse forms of engaged research that vary in terms of the origin of research questions, the types of relationships between researchers and societal partners, and the nature of interactions over time.
2022	Besley and Dudo	Science communication	Practitioner-oriented book that synthesizes available social science evidence related to the objectives of science communication, serves as a guide for evidence-based practice.

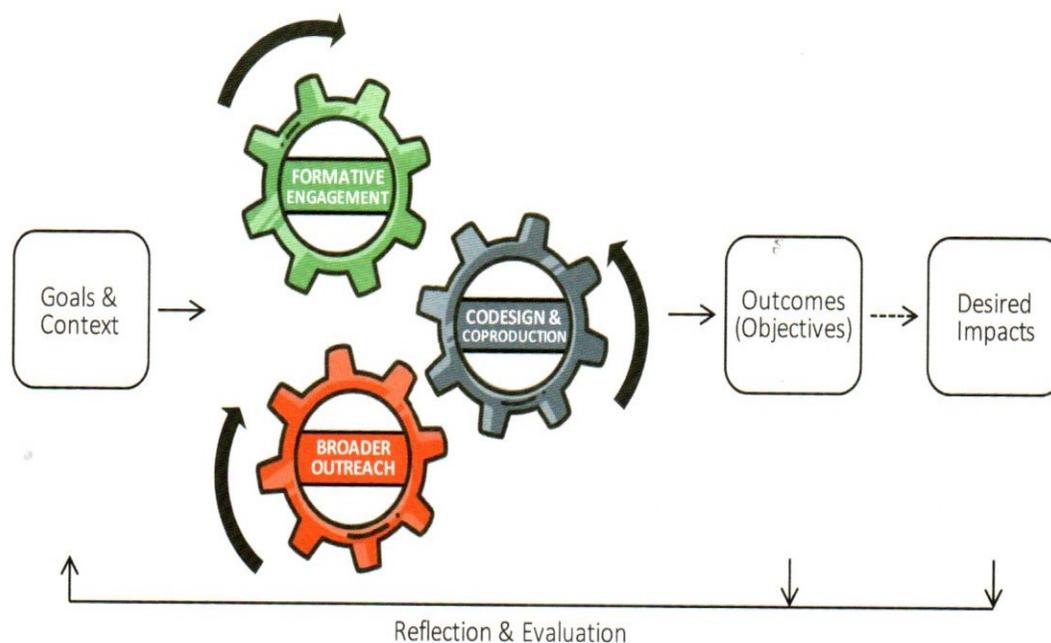


Figure 1. The ECO framework highlights three essential modes of science engagement practice as the process steps that lead from one’s engagement goals and external context to a set of direct outcomes, that over time, lead or contribute to desired impacts. Desired impacts are the long-term changes one wants to see in the world. These may be changes in society, in the environment, and in science. Outcomes are the shorter term, direct effects of engagement activities. These correspond to the objectives of table 2. Contextual factors include resources, geography, and social/political climate that influence one’s choice of engagement activities. Goals are the intended actions or behaviors that enable desired impacts over time. In practice, the ECO framework is designed to work in iterative loops, with intentional steps for reflection, evaluation (when possible), and adaptation based on the outcomes of engagement activities.

interactive effects across these modes of engagement. Below, we share descriptions of the E, C, and O modes of the ECO framework, along with examples of how we have operationalized these practices in our work at Hubbard Brook, Harvard Forest, and the Science Policy Exchange.

E: Formative engagement

Formative engagement is the term we use to describe intentional practices of listening to community members and decision-makers to understand a breadth of interests and perspectives and intentional work to initiate and foster positive relationships

Table 2. Science engagement objectives across different discourses: Four complementary frameworks.

Science communication	Informal STEM learning	Participatory research	Sustainability science
Besley and Dudo (2022) <i>Beliefs–Feelings–Frames</i>	NRC (2009) <i>Strands of Science Learning</i>	Phillips and colleagues (2018) <i>Individual Learning Outcomes from Participation in Citizen Science</i>	Cash and colleagues (2003) <i>Credibility–Salience–Legitimacy</i>
Science communication activities can affect a range of participant beliefs (e.g., beliefs about the world, oneself, one’s interlocutor), feelings, and frames (e.g., how one views an issue). Beliefs include those related to knowledge and awareness, risks and benefits, self-efficacy, integrity, caring and benevolence, willingness to listen, shared values, and competence.	Informal STEM learning activities support multiple learning outcomes, including: Sparking and developing interest and excitement, understanding science knowledge, engaging in scientific reasoning, reflecting on science, engaging in scientific practice, and identifying with the scientific enterprise.	Commonly desired and achievable learning outcomes of citizen science projects include: Interest in science and the environment, self-efficacy for science and the environment, motivation for science and the environment, knowledge of the nature of science, skills of science inquiry, behavior and stewardship	For scientific information to be effective in decision-making, information must be perceived by relevant stakeholders as credible (scientifically sound), salient (relevant to the needs of decision-makers), and legitimate (perceived as unbiased and fair in its treatment of opposing views and interests)

among scientists and these groups. This work takes time—relationships develop “at the speed of trust” (Convey 2006) is a common refrain—and scientists and science engagement professionals increasingly recognize the importance of having the capacity (i.e., time, funding, personnel) to do listening and relationship building work *before* new engagement programs are developed and proposed. We describe this mode of engagement as formative because it shapes the conditions and contexts of the deeper, collaborative mode of codesign and coproduction, and the broader, outward-facing mode of outreach.

In practice, formative engagement can occur in many different venues and activities—for example, during informal networking conversations at public events, via formal stakeholder advisory boards or community listening sessions, and through scientists’ participation in community-based organizations such as nonprofit boards. Drawing on the science communication literature, the key is to cultivate intentional, ongoing opportunities for scientists and community members to be able to listen to each other and feel heard, and for scientists, over time, to be able to demonstrate their benevolence, openness, integrity, and competence—key components of trust (Besley et al. 2021b, Besley and Dudo 2022).

Drawing on the informal science education literature, formative engagement provides a mechanism for mutual learning among scientists and publics (McCallie et al. 2009), which can illuminate the problems that communities view as worth solving and can clarify what people want, need, and expect from scientists (NASEM 2017). Formative engagement also allows scientists and science professionals to learn about and build on existing knowledge and community assets instead of allocating education and outreach resources to programs that are redundant or that reinvent the wheel. Put differently, formative engagement requires members of the scientific community to be open to changing their own minds and behaviors, not just gathering information for a predetermined goal.

In our work at Hubbard Brook, Harvard Forest, and the Science Policy Exchange, engagement practitioners have facilitated formative engagement via facilitated dialogue programs,

open-house events, advisory groups, and intentional networking conversations. These activities have served to build connections, surface multiple perspectives on socioenvironmental topics, identify knowledge gaps and blind spots of both scientists and nonscientists, and clarify specific science policy and management contexts. These outcomes, in turn, have sparked follow-up efforts, such as policy-relevant synthesis projects, the development and dissemination of research briefs for specific stakeholder audiences, and even new research endeavors.

One example of how we have employed formative engagement is with the Ice Storm Experiment at Hubbard Brook, a multiyear research project funded by the National Science Foundation that involved the creation of an artificial ice storm in the Hubbard Brook Experimental Forest (Rustad et al. 2020). The overall goal of the research project was to advance basic knowledge about the ecological impacts of ice storms on northern hardwood forests. Recognizing the importance of ice storms in multiple sectors of society, Garlick designed a roundtable dialogue event (Bell et al. 2017) to engage with professionals from different domains, early on in the project, to learn more about how people think about ice storms and ice storm impacts in forests, and to build connections with potential end users of the science. The event involved gathering project scientists and a group of invited professionals from the electric utilities, emergency response, land management, and weather observer communities for a facilitated discussion, followed by a field trip to the research plots. As a result of this meeting, the researchers learned that one of the measurements of the experiment—the amount of coarse woody debris produced by different thicknesses of ice—was valuable to multiple professional groups for understanding and predicting ice storm damage. This insight allowed the team to focus on those results in follow-up briefings with state agency personnel and in a final public report from the experiment.

One key lesson we have learned in our work over the years is that effective formative engagement requires reciprocity. Despite the importance of active listening and dialogue—and the focus on dialogue in the science communication and informal science education literatures (e.g., McCallie et al. 2009, Bell et al. 2017)—

listening sessions can feel extractive over time if people do not experience clear benefits from their participation. Similarly, dialogues for the sake of dialogue can feel unproductive if ideas and connections are not followed through to action. Effective formative engagement considers what the scientific community is sharing with participants, as well as what they are receiving, and it recognizes that meeting the participants' expectations and needs underlie mutual learning and relationship building.

C: Codesign and coproduction

The codesign and coproduction mode of the ECO framework is focused on scientists collaborating with stakeholder, community, and other public partners to cocreate new knowledge, products, and actions of direct interest and benefit to society. It is often used for goals related to the use of scientific knowledge in decision-making (Lemos and Morehouse 2005, Arnott et al. 2020) and when engagement objectives include enhancing the legitimacy of science in the eyes of user groups or affected communities and expanding the efficacy and capacity of partners and researchers (Cash et al. 2003, Driscoll et al. 2011). Codesign and coproduction might take the form of citizen science projects, research agendas codeveloped with managers and community partners, new community programs, or joint events. Outputs might include policy or management analyses, future scenarios, participatory modeling, online maps and tools, or even creative collaborations such as art installations.

This C in the ECO framework asks scientists and science professionals to push engagement beyond modes of listening and sharing into the space of cocreation. In our work, we distinguish the boundary between formative engagement and codesign and coproduction when engagement between scientists and partners becomes action oriented—when plans to *design* or *create* something together are hatched. Formative engagement often precedes codesign and coproduction because existing relationships and mutual understanding can be key inputs to these processes. There may be cases, however, where a codesign or coproduction process highlights a need for additional formative engagement to bring additional knowledge and perspectives into the process.

The underlying theory of codesign and coproduction carries both practical and transformative elements (Wyborn et al. 2019). In the sustainability science discourse, the coproduction of knowledge among scientists and decision-makers is understood as a key pathway for generating useful information for policy and management (Lemos and Morehouse 2005, Djenontin and Meadow 2018, Mach et al. 2020). This process often entails skilled facilitation of effective partnerships and productive exchanges among individuals and organizations with different perspectives, value systems, and power structures (Bednarek et al. 2018).

Although scholars commonly promote an idealized form of codesign and coproduction, in which all aspects are cocreated, from question generation to outputs (for a review, see Wyborn et al. 2019), in our experience, as well as in the literature, the practice of codesign and coproduction is much more variable. Participation can vary across a spectrum, from informing or consulting to involving, collaborating, and empowering (Shirk et al. 2012, IAP2 2018, Mach et al. 2020, Scheufele et al. 2021). Codesign and coproduction initiatives can be initiated and led by stakeholders and community members (e.g., the American Geophysical Union's Thriving Earth Exchange), by scientists (Shirk et al. 2012, Mach et al. 2020), and by other groups (e.g., government entities).

We have facilitated, participated in, and observed a number of different forms of codesign and coproduction, from emerging

research–practice partnerships between scientists and natural resource managers at Hubbard Brook, to community-engaged scenario development and analysis at Harvard Forest (McBride et al. 2017). Driscoll and colleagues (2011) introduced the idea that the form and practices of coproduction should be scaled to the context and resources of a given program or project, rather than assuming that more is necessarily better. In some cases, community partners may prefer a consulting model of participation over a collaborating model depending on their priorities.

In the Ice Storm Experiment example introduced above, the research team did not initially intend to work in the codesign and coproduction mode, but an opportunity arose during the course of the project. Following widespread media coverage of the experiment, professionals from the National Weather Service and a national network of backyard weather observers contacted the project investigators to inquire about their methods of measuring ice accretion. The challenge of measuring ice accretion was also a topic of discussion that arose during the formative engagement roundtable dialogue and field trip described above. In response to this emergent issue, Garlick convened a series of collaborative meetings with the project investigators and a group of external researchers and practitioners from these professional groups. These meetings led to the formation of a new team of partners who codesigned a spin-off experiment at the Hubbard Brook Experimental Forest to test several different methods of ice accretion. This work, in turn, led to the coproduction of a new low-cost protocol for backyard weather observers that is now being implemented nationwide (Campbell et al. 2020).

Another example of the codesign and coproduction mode in action is in the policy-relevant synthesis projects led by Fallon at Harvard Forest and the Science Policy Exchange (e.g., Driscoll et al. 2015, Lovett et al. 2016, Thompson et al. 2016). These projects involved convening partners from multiple perspectives (e.g., research, policy, management, affected communities) to codefine key policy-relevant science questions and develop data synthesis approaches to address those questions. The approaches included data compilation and analysis, scenario development and modeling, and interpretation. One key lesson of this work was the importance of project leaders maintaining appropriate boundaries between research and advocate interests to protect the credibility of final research results and products (Cash et al. 2003).

O: Broader outreach

The term outreach has long been used in scientific communities to describe efforts aimed at sharing knowledge with community members and broader publics. Drawing on this traditional usage, the O in the ECO framework describes practices aimed at expanding networks, increasing visibility, and broadly disseminating relevant scientific ideas, knowledge, and products beyond the groups engaged through the other modes. Broader outreach activities tend to be more unidirectional than other forms of science engagement, but they can play an important role in supporting multidirectional exchanges and relationship building with community members and decision-makers, particularly when intentionally linked with formative engagement and codesign and coproduction. Commonly used practices in the broader outreach mode include message definition (which can include focus groups), careful choice of messengers and channels, media outreach, social media campaigns, webinars or policy briefings, and the development and dissemination of science communication products such as videos, fact sheets, research briefs, and infographics.

As science engagement practitioners and scholars, we encounter two divergent perspectives on broader outreach. One view places a high priority on broader outreach activities and products, underpinned with a tacit assumption that increasing awareness of science and high audience numbers are key metrics of success. In contrast, another view is starkly dismissive of the concepts and practices of outreach as limited and outdated (Leshner 2003), emphasizing instead the turn in the science communication, education, and policy literatures toward more participatory and dialogue-based forms of engagement. In our work, we have experienced the value of both of these perspectives, with participatory engagement being enhanced by outreach efforts and vice versa. The ECO framework integrates these approaches as a complementary set of tools.

Broader outreach practices can promote the uptake and use of science by others (i.e., within organizations, policy decisions, management actions, and individual choices) and can generate feedback on research to inform new approaches, questions, and data needs. In the context of engagement with policymakers about science related to an upcoming decision, widespread media coverage generated by outreach efforts can provide important validation regarding public interest and the importance of the issue. Also, broader outreach plays an important role in inclusivity and the democratization of knowledge. Although formative engagement and codesign and coproduction operate within relatively small groups of individuals, broader outreach harnesses the power of existing, widely used platforms to ensure that knowledge is not exclusive to known—and often privileged—actors.

In the example of the Hubbard Brook Ice Storm Experiment described above, the broader outreach practices used by the team included message development, working with professional photographers to capture high-quality images and video of the experiment, and direct outreach to media outlets. These efforts facilitated worldwide media coverage of the research, which in turn led to new partnerships and connections. For example, professionals from the National Weather Service became engaged with a new coproduction experiment described above, and the project scientists were invited to give briefings to decision-makers with New Hampshire Homeland Security and Emergency Management who had learned about the research in the news.

In Fallon's work at Harvard Forest and the Science Policy Exchange, the development of written outreach strategies was a key element of successful policy-relevant synthesis projects. These strategies guided the development of communication products and activities tailored to specific goals and target audiences. For example, to increase the uptake of research products that emerged from formative engagement and coproduction processes, Fallon's team employed press events timed with the publication of research results for the media, in-person briefings for state and federal legislatures, and online webinars for interest groups.

Overcoming common barriers to effective engagement

The ECO framework's modes of engagement offer a structured way of incorporating evidence-based engagement practices into scientific research programs. These modes also provide a structure that can help address several longstanding barriers to effective science engagement: a lack of strategy, a narrow focus on knowledge acquisition, passive approaches to knowledge sharing for decision-making, and a lack of inclusivity. We discuss each of these barriers in relation to the ECO framework below, followed

by a consideration of the inputs needed to drive effective science engagement within research organizations.

Barrier 1: A lack of strategy

Scientists face what seems like an ever-expanding menu of options for communicating and engaging with communities, decision-makers, and broader publics. Should we start a citizen science program? How should we use social media? What about podcasts or video? In our experience, many of these tactical decisions, whether designing activities with broader impacts for a research project or designing core education and outreach programs of a research institution, are based more on intuition and individual interest than clearly defined strategy. Such ad hoc and opportunistic approaches can lead to inefficient use of time and resources, staff and participant burnout, missed opportunities for connecting with local communities and key stakeholders, and missed opportunities for collective impact across activities. To address these issues, science engagement scholars are calling for more strategic efforts that are grounded in evidence and theory, as well as community interest (Besley et al. 2018, Jensen and Gerber 2020).

Strategic science engagement begins with asking why one wants to engage. What are the desired societal impacts one seeks to contribute to, and what specific behaviors by stakeholders, decision-makers, scientists, and others, are needed to achieve those impacts? These engagement goals can then be broken down into a set of priority, near-term effects that can be tracked or measured (labeled *objectives* in table 2, following the terminology of Besley et al. 2018), and activities can then be designed to suit (Kellogg Foundation 2004, Besley et al. 2018). Table 2 lists some of the key objectives that practitioners might prioritize in their science engagement strategies, drawing on the literature from the four discourses.

The process of strategy development is often iterative: Goals and objectives can evolve as engagement activities progress and as scientists develop a deeper understanding of the perspectives of community members and decision-makers. Also, scientists within research institutions are often navigating multiple goals for engagement (e.g., ensuring ongoing community and funder support, enhancing organizational diversity) alongside portfolios of existing education and outreach programs that have variable funding streams and staffing patterns. As a process-based tool, the ECO framework can provide a structure for working within this shifting terrain, emphasizing the importance of beginning with goals, including pathways via formative engagement for incorporating community and stakeholder perspectives into strategy design, and considering the tactical approaches inherent to the E, C, and O modes. In these ways, the ECO framework can serve as an initial support for developing more strategic engagement programs. Effective strategy development also requires deeper processes for choosing the right objectives to prioritize, on the basis of one's goals, and aligning specific tactics to those objectives (Besley and Dudo 2022).

Barrier 2: Narrow focus on knowledge acquisition

Another long-standing barrier to effective science engagement is a tendency for scientists and science professionals to focus on the acquisition of knowledge by members of the public as the sole objective of science engagement (Besley et al. 2018). Sometimes called the *knowledge deficit* approach or the *deficit model*, it assumes that greater awareness and knowledge about science will lead to informed decision-making and support for science (Allum et al.

2008). Or put another way, ill-informed decisions and a lack of support for science stem from members of the public not understanding scientific concepts or being aware of scientific progress. However, decades of social science research have shown that other factors, beyond knowledge and awareness, are more important to influencing individual behaviors and willingness to trust and support science (Bauer et al. 2007). These include risk-benefit beliefs, normative beliefs, and efficacy beliefs; beliefs about scientists' values and identities, benevolence, integrity, abilities, and willingness to listen; and also beliefs about how people feel about and frame issues (Hendriks et al. 2015, Montano and Kasprzyk 2015, Besley et al. 2018, Besley et al. 2021b).

The three modes of the ECO framework are focused on the importance of listening, relationship building, and collaborating, in addition to sharing scientific information and insights. This integrated approach can help overcome knowledge-deficit thinking and provides a heuristic for incorporating other kinds of objectives (table 2), particularly relational objectives, into the design of science engagement programs. Also, it is important to note that overcoming the knowledge-deficit approach does not mean that sharing scientific knowledge and increasing awareness are unimportant. It simply means that other objectives should also be considered and potentially prioritized, including ethical efforts to shape beliefs about how scientists and scientific knowledge are perceived—for example, that scientists share values with community members. It also means ensuring that scientists involved in outreach are considering how their own knowledge, beliefs, and behaviors might change as well.

Barrier 3: Passive approaches to knowledge sharing for decision-making

A related barrier to knowledge-deficit thinking is the reliance on passive, inefficient approaches to sharing scientific knowledge for use in decision-making. This is the traditional case of scientists sharing research findings in scientific journals and other outlets, hoping that decision-makers and other stakeholders will eventually become aware of the work and be able to apply the information to their own contexts (Cash et al. 2006, Hall et al. 2012, Rogga 2021). In this approach, scientists are positioned as external experts, isolated from decision-makers, and there is little or no support for the necessary and often complex processes of assembling, synthesizing, and reevaluating information so that it can be used to inform specific decisions. As a result, many scientific insights sit unused rather than being mobilized for the benefit of society. This is sometimes described as the *loading dock model*, using the analogy of scientific knowledge as a helpful product that languishes on a loading dock rather than being packaged and delivered to users (Cash et al. 2006, Meadow and Owen 2021, Rogga 2021).

One antidote, following the sustainability science discourse, is to apply a coproduction approach, in which end users are involved as partners in the knowledge generation process, thereby enhancing both the relevance of the results and the pathways for its use (Lemos and Morehouse 2005, Arnott et al. 2020, Mach et al. 2020). Another approach is to adopt intentional outreach practices to share scientific results with potential knowledge users and larger spheres of publics, using multiple formats and channels where audiences look for and receive information already. The ECO framework can help facilitate these approaches by promoting intentional partnerships among scientists and stakeholders, and the use of collaborative and participatory processes with broader outreach strategies that reach beyond known actors and networks.

Barrier 4: A lack of inclusive practices

Despite growing platforms for science communication and increasing interest and support for science engagement activities, these opportunities continue to leave out many groups, including people of color, Indigenous communities, people with low income or education attainment, people with seen and unseen disabilities, and religious communities (Feinstein and Meshoulam 2014, Medin and Bang 2014, Dawson 2018, Canfield et al. 2020). This lack of inclusion plays a role in sustaining systems of injustice in society (Dawson 2018), and also reduces the potential for science engagement to contribute to societal and environmental solutions for all, and hinders the formulation of questions and hypotheses that enrich science by limiting the perspectives and lived experiences involved. Finally, the lack of inclusive practices limits the efficacy of science engagement by undermining the legitimacy of any associated research or science communication products as perceived by people who live in communities implicated by the research.

In Canfield and colleagues (2020), a group of science communication scholars defined inclusive science communication as a path forward for addressing this barrier, grounded in a number of important approaches, including recognizing historical oppressions and centering the voices and knowledge of marginalized peoples in science engagement activities, intentionally cultivating participant belonging, and adopting practices that are flexible and build on the assets and interests of participants. Canfield and colleagues (2020) summarized three key traits of inclusive science communication: intentionality, reciprocity, and reflexivity. That is, intentional consideration of audiences and partners and how marginalized identities have been represented and reinforced in science communication; reciprocal partnership development that values multiple forms of expertise and facilitates authentic cocreation; and continuous reflection on identities, approaches, and outcomes in science engagement, followed by adaptive practices (Canfield et al. 2020).

The ECO framework can support inclusive science engagement by providing a broad, initial structure for setting intentions, considering audiences and partners, facilitating partnership development, and establishing iterative loops of reflection and adaptation (figures 1 and 2). As a planning tool, the ECO framework explicitly prompts practitioners via a series of reflective equity checks to pause and consider biases and inclusive practices as they plan activities and programs (figure 2). And the modes of the ECO framework, emphasizing the importance of formative engagement and codesign and coproduction, can support multiple, lasting pathways for community inclusion and leadership in science engagement. Applied in these ways, the ECO framework can serve as an initial support for developing more inclusive engagement programs. Inclusivity also requires deeper processes of personal reflection, skill building, and structural changes within scientific programs and organizations that consider power dynamics, cultural norms, and asset-based approaches (Bevan et al. 2020).

Key inputs of effective science engagement

We developed the ECO framework as a planning tool to advance the design of effective science engagement programs within environmental research institutions. The framework operates at a strategic level to promote three interacting modes of engagement practice, each of which necessitates its own set of competencies. For example, formative engagement and codesign and coproduction require facilitation skills, knowledge and relationship

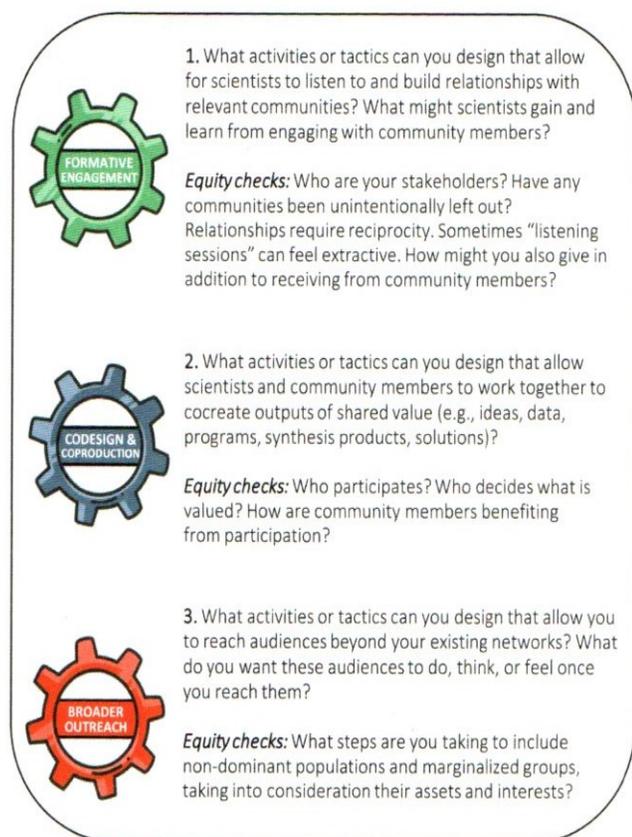


Figure 2. Prompts for using the ECO framework as a strategic planning tool for science engagement programs based on one’s goals and long-term desired impacts.

brokering, and mediation. Broader outreach draws on networking skills, written and oral communication, and event production. Who carries these capacities within scientific organizations?

In our experiences at Hubbard Brook, Harvard Forest, and the Science Policy Exchange, team-based approaches have been essential (Besley et al. 2021a). As science engagement professionals, we have worked in leadership positions within these organizations to design and lead engagement strategies and programs. These efforts have also involved leadership and participation from individual scientists, as well as other professionals—often consultants—with particular skillsets, such as science writers, external facilitators, media producers, and program evaluators. Community members and decision-makers have also played key leadership roles, especially in the practices of codesign and coproduction.

We recognize that many effective science engagement projects are led by scientists and that not all research organizations have the capacity to support science engagement staff. However, considering the broad array of skills required, more attention and support is needed across the scientific community for team-based approaches to engagement that recognize the expertise of professionals (Besley 2020). The scientific community, particularly those interested in engagement and impact, also need to recognize and support the time and financial resources required for effective science engagement so that project work and staffing are sustainable and not entirely reliant on soft funding. These resources may come from better integrating broader impacts into the intellectual merit of federal research grants or grants from private foundations, but it is also important to expand support from the core operating budgets of research institutions. As science engagement becomes increasingly essential to the core missions and practices of research institutions and as the activities and practices of engagement become more sophisticated, we expect demand for this

work to rise, the roles and skills of professionals to expand, and the dedication of core resources to increase to help ensure the work is sustainable and, in that way, more able to align with the evidence bases shared in the present article.

Conclusions

Amid growing interest in and scholarship related to science engagement, scientists and science professionals face the complex task of deciding what engagement activities and communication channels to prioritize. This includes individual decisions made by scientists about their own engagement efforts, as well as organization-level decisions about engagement projects and programs, typically made by the leaders of research groups and institutions, as well as professionals who serve in science communication, outreach, and science policy roles. These decision points are key opportunities for advancing science engagement practices that are more strategic, grounded in evidence, and effectively positioned to overcome barriers to impact. By highlighting three essential, interacting modes of engagement, the ECO framework promotes synergistic efforts designed to strengthen the connections between science and society over time. These connections are the pathways for fulfilling an expanded social contract for science that advances both new discoveries and needed solutions.

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References cited

- [AAAS] American Association for the Advancement of Science. 2016. Theory of Change for Public Engagement with Science. Center for Public Engagement with Science and Technology. www.aaas.org/programs/public-engagement/theory-change-public-engagement-science.
- Allum N, Sturgis P, Tabourazi D, Brunton-Smith I. 2008. Science knowledge and attitudes across cultures: A Meta-analysis. *Public Understanding of Science* 17: 35–54.
- Arnott JC, Mach KJ, Wong-Parodi G. 2020. Editorial overview: The science of actionable knowledge. *Current Opinion in Environmental Sustainability* 42: A1–A5.
- Bauer MW, Allum N, Miller S. 2007. What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public Understanding of Science* 16: 79–95.
- Bednarek AT et al. 2018. Boundary spanning at the science–policy interface: The practitioners’ perspectives. *Sustainability Science* 13: 1175–1183.
- Bell L, Lowenthal C, Sittenfeld D, Todd K, Pfeifle S, Kollmann EK. 2017. Public Engagement with Science: A Guide to Creating Conversations among Publics and Scientists for Mutual Learning and Societal Decision-Making. *Museum of Science*. www.mos.org/pes/guide.