Scientific Outreach: Toward Effective Public Engagement with Biological Science

JOHANNA VARNER

Most scientists agree that interacting with the public is a worthwhile endeavor, but participation in science outreach remains fairly low among biologists. Furthermore, current practices in science outreach remain largely based on ineffective communication models that may undermine public trust and interest. I argue that, in trying to improve both participation rates and the effectiveness of science outreach, we must take a more scientific approach, and we must practice outreach with the same rigor as the science that we share with the public. Here, I describe common misconceptions that can undermine the value of science communication with the public at many scales. I then describe an evidence-based, iterative, evaluative framework for biologists at all career stages to pursue public engagement in the biological sciences. These guidelines can also inform formal outreach training for scientists, specifically in promoting dialogue and engagement.

Keywords: science communication, public engagement in science, science outreach, nontraditional public, dialogue

In the last decade, numerous calls for increased dialogue between scientists and the public have come from professional societies (Royal Society 2006, Agre and Leshner 2010), funding agencies (e.g., the National Science Foundation's Broader Impacts Criterion), and fellow scientists (e.g., Nisbet and Scheufele 2009). Indeed, effective interaction between life scientists and the public could not be more timely. In an era of declining funding rates, most science remains publicly financed and, therefore, demands the public's support. Biology is also central to many of today's societal grand challenges, including climate change, economic productivity, health, and sustainability. By sharing their extensive knowledge of Earth's natural systems, life scientists can help the public make sound choices about complicated issues (Fischhoff 2013). Conversely, public input can enrich biology discourse by offering new perspectives, refining the relevance of current research, and stimulating new inquiries (Pace et al. 2010).

Although most scientists agree that interacting with the public is a worthwhile endeavor (Davies 2008), overall participation rates remain lower among life scientists than among those in other science disciplines (Jensen et al. 2008, Jensen 2011). Within life science, ecological and behavioral biologists are twice as likely to be active in outreach than are cellular and molecular biologists (Jensen 2011). Across disciplines, scientists report not participating in outreach because they feel unprepared to effectively interact with the public (Royal Society 2006, Jensen et al. 2008, Besley and Nisbet 2011). Indeed, it is difficult to learn about effective outreach from the literature, because the data are scattered across the education, communication, psychology, and public health literature (Carleton-Hug and Hug 2010), and these studies are rarely targeted at biologists. Furthermore, scant infrastructure currently exists for scientists to receive formal training in public communication.

In trying to improve both participation rates and the effectiveness of science outreach, we must take a more scientific approach. For centuries, the social sciences have assembled a vast body of empirical evidence about how information and trust flow through human social networks and affect beliefs, values, and behaviors (Fischhoff and Scheufele 2013). Like scientific teaching (Handelsman et al. 2004), scientific outreach must be practiced with the same rigor as the science that is to be shared with the public. In this Forum article, I describe common misconceptions that can undermine the value of science communication with the public at all scales. I then describe a concrete model for scientific outreach, which is based on knowledge of how people learn and on empirical tests of various approaches. Evidence from the literature supports each step of the model, which serves as an evidence-based, iterative, evaluative framework for biologists at all career stages to pursue public engagement in the biological sciences. Finally, I discuss how this model reveals specific needs in outreach training for

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scientists and highlight the numerous benefits to scientists of participating in outreach.

What is effective outreach?

Sound science begins with clear terminology. In this article, I take a broad definition of *outreach* as "any scientific communication that [directly] engages an audience outside of academia" (Poliakoff and Webb 2007, p. 244); however, I largely exclude interactions with the mass media, which have been recently reviewed elsewhere (Peters 2013 and the references therein). Outreach can therefore scale in time commitment from online communications requiring an hour of effort to large-scale conservation or citizen science initiatives that define a career (supplementary table S1). Outreach can also include a range of approaches and activities (*sensu* Rowe and Frewer 2005) in which information flows from scientists to the public (e.g., educational resource development and dissemination), from the public to scientists (e.g., citizen panels, surveys), or between scientists and the public (e.g., online discussions, science cafes, citizen science).

Effectiveness inherently depends on an explicit definition of goals and an assessment of how well the exercise achieves its intended purpose (Rowe and Frewer 2005), both of which are lacking in the majority of science outreach (Carleton-Hug and Hug 2010). In considering the *effectiveness* of outreach, I suggest that we adopt a recent definition from Fischhoff (2013):

> Effective science communications inform people about the benefits, risks, and other costs of their decisions, thereby allowing them to make sound choices.… The goal of science communication is not agreement, but fewer, better disagreements. If that communication affords [scientists and the public] a shared understanding of the facts, then they can focus on value issues. (p. 14033)

Although objectives and envisioned outcomes will inevitably vary widely among scientists and institutions, I argue that effective outreach should be less about building consensus on controversies and more about building capacity, fostering mutual trust, and achieving a shared understanding of the relevant science.

Evidence from the social sciences: From well-intentioned misconceptions to sound science

As life scientists, we are well versed in scientific discourse and dissemination, but rarely do we receive formal training about how to communicate with a diverse public. As a result, science outreach is often modeled on scientific communication and intuition instead of on an empirical understanding of how nonscientists assimilate information into their mental frameworks. Several misconceptions about science communication pervade current outreach practices. These misconceptions stem from erroneous assumptions about who *the public* is, how they learn, and how information is assimilated into their beliefs and behaviors.

When asked about their motivations for participating in outreach activities, the overwhelming majority of scientists reported that they felt a duty or desire to educate the public, whom they believe are inadequately informed about science (Royal Society 2006, Davies 2008, Jensen et al. 2008, Besley and Nisbet 2011). This belief exemplifies deficit-model thinking: The underlying assumption is that a knowledge deficit is the primary source of negative public attitudes toward science and the environment and of perceived inaction on social or political issues. The logical extension of this assumption is that providing information or educational materials will reverse negative attitudes and catalyze the favored social or political action. Although this belief is intuitively appealing and extremely widespread, it has very little empirical support: A large body of evidence demonstrates that gaining knowledge does not change attitudes or behavior (Lehr et al. 2007, Heimlich and Ardoin 2008, Ho et al. 2008, Nisbet and Scheufele 2009, Groffman et al. 2010, Bain et al. 2012, Kahan et al. 2012). In fact, even an intention to act is a poor empirical predictor of behavior, which depends instead on a complicated network of interacting factors, including social context, self-confidence, and emotion (Ajzen 1991, Heimlich and Ardoin 2008).

In addition to perceiving a knowledge gap, many scientists also believe that the public is homogenous and not intrinsically interested in learning about science (Besley and Nisbet 2011). However, sociological research suggests that "the public" is actually a diverse collection of many publics, each with its own knowledge, values, beliefs, mental models, and worldviews (Maibach et al. 2009, Fischhoff 2013). These predispositions act as mental filters that crucially influence the response to new scientific information (Scheufele 2013). Americans tend to learn about science through informal, free-choice experiences, such as surfing the Internet, watching television, and visiting places with educational materials (e.g., zoos or museums; NSB 2012). However, not all sources of new information are equally trusted. Instead, the reliability of a source is often judged by how well it complements preconceptions, and new information tends to be interpreted in such a way that it supports these existing mental frameworks (Schultz and Zelezny 2003). For example, rather than fostering agreement, a better understanding of the science underlying controversies appears to strengthen preexisting beliefs originating in political or religious ideologies, thereby increasing polarization (e.g., Ho et al. 2008, Kahan et al. 2012). Thus, opposite interpretations of the same information may emerge in different publics because information is sifted through different mental filters.

As a result of the deficit model and the myth of the homogenous public, outreach is frequently conceived as a one-way communication from scientists to the public, which must be simplified, sensationalized, and strategically constructed to avoid uninterest, misinterpretation, or hostile

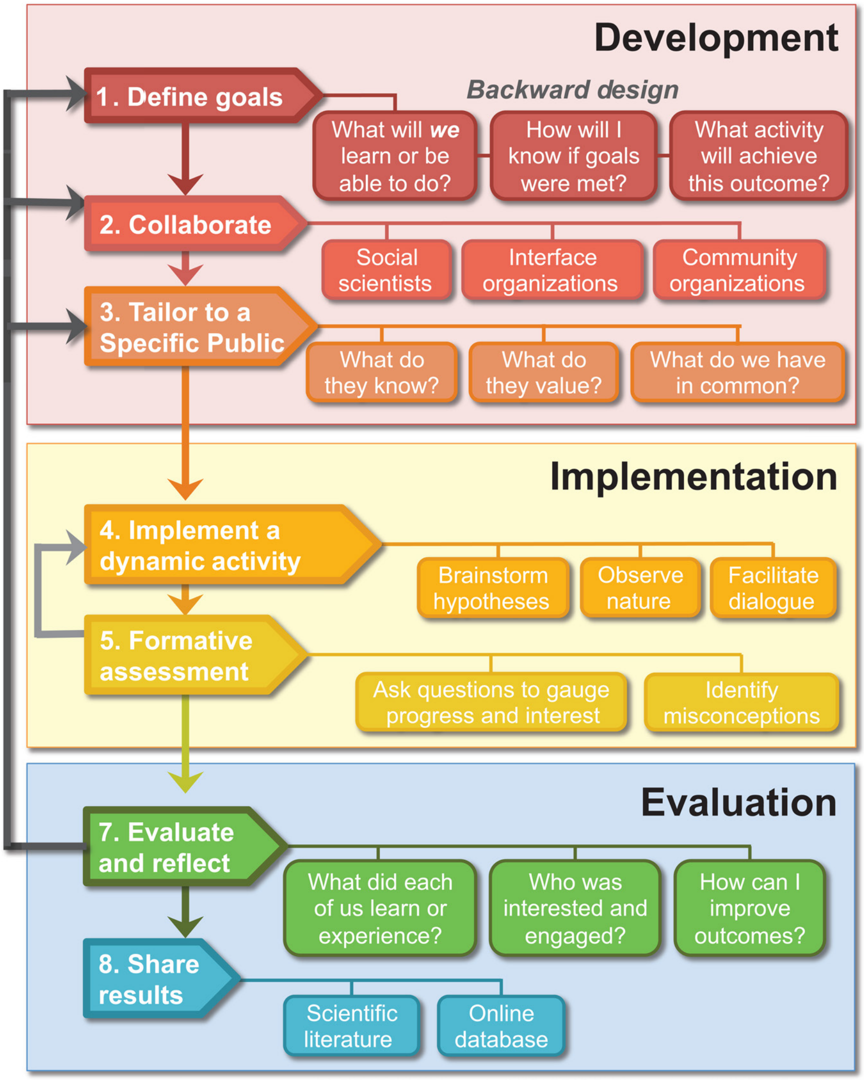

Figure 1. A concrete, evidence-based, iterative model for scientific outreach. Outreach activities can be conceptualized in three phases: development, implementation, and evaluation. Evaluations do not necessarily need to be formal or controlled experiments; rather, they should provide feedback for the researcher about whether goals were reached and how the activity or presentation was received. Details for each step in the model are covered in the text.

reactions (Davies 2008). Indeed, only 12% of scientists in a large survey indicated that *engagement* meant listening or attempting to understand the views of the public (Royal Society 2006). Trust in scientists is undermined when outreach is perceived as a top-down persuasion campaign (Monroe 2011), and a unidirectional flow of information creates boundaries between scientists (who have authority over a body of knowledge) and the public (who do not understand this knowledge). These boundaries are further reinforced when scientific knowledge is branded as *specialized* (i.e., not a necessary part of one's general education) and the public is not allowed to participate in knowledge creation (Peters 2013).

Conversely, constructivist theory, which guides the most current and effective education reforms, acknowledges that publics create meaning and contribute to knowledge production in various ways (Berkowitz et al. 2005). The educational psychology literature has also clearly demonstrated the power of active engagement in knowledge retention, enthusiasm, and higher-level cognitive capacity such as that gained by honing analytical skills (e.g., Handelsman et al. 2004, Michael 2006). Finally, recent evidence suggests that public trust in scientists is enhanced when scientists extend trust to the public, empower the public to assess the data, and display their own vulnerabilities, particularly for potentially contentious issues (Goodwin and Dahlstrom 2013).

Scientific outreach: A new framework for effective science communication

Despite the large body of evidence that they are not effective, the deficit model and one-way communication continue to pervade science outreach (Davies 2008). As scientists, we would never conduct an experiment without careful planning or data collection, but most outreach about science lacks a description of goals (Phipps 2010) and an evaluation (Carleton-Hug and Hug 2010). These problems render the collection of evidence and the assessment of effectiveness impossible. Here, I propose a new framework for scientific outreach that is based on knowledge of how people learn and empirical tests of various approaches, that captures elements of science itself by generating a dialogue whenever possible, that uses assessment to iteratively improve effectiveness, and that is about science, itself.

Like a process-based logic model (e.g., Dwyer and Makin 1997), scientific outreach has goals and activities that are carefully planned and evaluations that permit specific shortcomings to be identified. It is not my intention to propose a magic-bullet solution to understanding the complexities of science communication (e.g., if we just tell better stories or use the right language…). Instead, I hope to provide tools for interested life scientists at any stage of their career to improve their outreach through a concrete framework that is evidence based, iterative, and evaluative (figure 1) and that can be applied to multiple levels of outreach (e.g., supplementary table S1). Compared with the current practice of

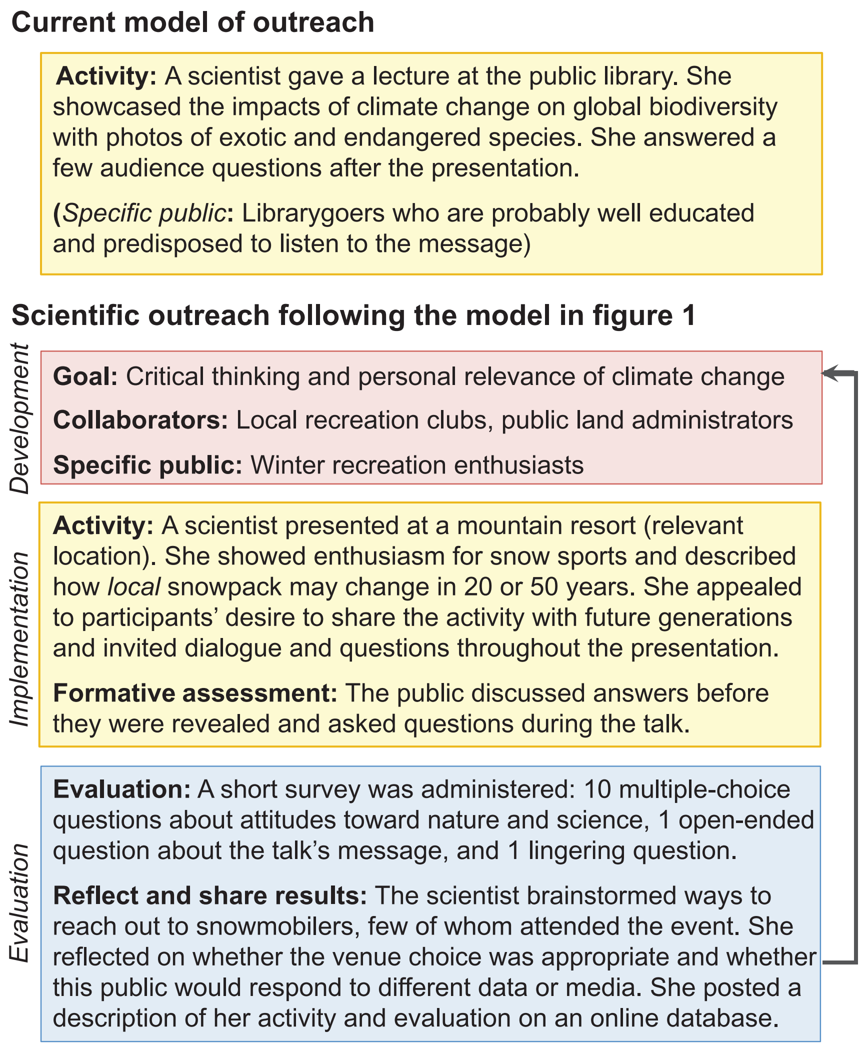

Figure 2. Adapting the current paradigm to the new model. The top panel shows how many scientists currently conceptualize outreach: Little time is spent in development, and there is no evaluation. The specific public is not explicitly considered in development, although it is likely to be well educated and predisposed to the message. Nontraditional publics are largely overlooked. In contrast, the lower panels show how the same goal could be structured according to the scientific outreach model, with appropriate development and evaluation. The scientist establishes common ground and personal relevance with a public that is often overlooked for scientific engagement.

outreach, more time should be spent formally developing and evaluating outreach rather than simply implementing sporadic and unconnected activities (figure 2).

Development

Strategies such as backward design (Wiggins and McTighe 2005) can help organize practical goals and determine measurable milestones of success (figure 1). In backward design, the desired results are first identified (i.e., *What should I and the public know, understand, and be able to do?*). Scientists might also explicitly consider some learning goals for themselves (i.e., *What can I learn from the public during our interaction?*). Next, acceptable evidence of results is determined (i.e., *How will I know whether these goals were reached?*). Activities and experiences are planned last (i.e., *What activities will help me reach this measurable outcome?*; Wiggins and McTighe 2005). In scientific outreach, evaluation is always a part of the initial outreach plan, although it does not have to be formal. Most publics will gladly offer feedback and reflect on their experience, especially if it is presented as an opportunity to teach the "experts" what those publics value (Monroe 2011).

In addition, much can be gained by working across different fields of expertise. Social scientists have vast experience articulating communication objectives and designing evaluations, both formal and informal. Interface organizations (Osmond et al. 2010) are also trained to work with diverse publics. For example, zoos, museums, and aquariums have been promoting conservation education for decades. Trusted resources in a community, such as churches (Hitzhusen and Tucker 2013) or artists (Buckland 2012), can also act as interface organizations and may help broaden participation with diverse publics.

Existing attitudes, beliefs, and values create mental filters, which crucially affect the way that new information is processed (Groffman et al. 2010, Kahan et al. 2012). Therefore, being sensitive to the values of the public with which one interacts is essential to promoting trust and dialogue (Lehr et al. 2007). Connecting science to the personal domain of everyday life decreases the metaphorical distance from the research questions and emerging technologies (Havens et al. 2012). Personal relevance can be conveyed through appropriate analogies, examples, and frames. The same information can be interpreted in different ways, depending on how it was presented (Scheufele 2013), and frames are essentially interpretive storylines that suggest an interpretation; they can be triggered by words, imagery, and nonverbal cues. Although framing is frequently presented in the life science literature as a powerful magic bullet for strategic communication about environmental issues (e.g., Schultz and Zelezny 2003, Groffman et al. 2010), it is also "an integral part of our day-to-day communication… that makes [information] accessible to nonexpert publics" (Scheufele 2013, p. 14045). Therefore, rather than placing a spin on an issue (i.e., creating a false but advantageous narrative), the responsible use of framing can be an effective tool to communicate personal relevance.

Finally the character of the messenger is also important for public buy in. Messages are more likely to be accepted if common ground is established immediately and people are approached with patience and respect (Braus 2009). Using appropriate language is also crucial to becoming a likable messenger: The authoritative tone of scientific communication is inherently alienating, and many common words have different meanings in academic papers than they do in public settings (Snow 2010).

Implementation

In some cases, the background of the public may be extremely diverse or difficult to research, but several common strategies can make a Web site, exhibit, presentation, demonstration, or conversation interesting and accessible to most publics.

Although it is the norm for scientific communications, most publics will lose interest if they are drowned in lengthy introductions or methods before reaching exciting results or a chance to actively participate. A vivid hook, such as a video or photo, will help capture attention at the outset of the interaction (Reynolds 2009). Another way to engage the public in the process of science is to present research questions or data as a puzzle to solve and brainstorm hypotheses or interpretations together (Reynolds 2009). This discussion can also serve as an informal assessment and familiarizes the scientist with the preconceptions and attitudes of a specific public (figure 2).

There is strong empirical evidence that, in most publics, experiential learning and personal experience affect attitudes and beliefs more strongly than do logical arguments or reasoning (e.g., Myers TA et al. 2013). Specifically, direct encounters with nature are more powerful in fostering learning and personal relevance than are images (Berkowitz et al. 2005). Observing live animals, in particular, fosters strong personal connections with science and nature in many publics (Myers OE et al. 2009).

The scientific-teaching literature has long demonstrated the power of active engagement in fostering learning (Handelsman et al. 2004, Michael 2006). Similarly, two-way dialogue has more-profound effects on interest and mutual social understanding than one-way presentations do (Lehr et al. 2007). Even in a traditional presenter-and-audience setting, such as a lecture, an exhibit, or the development of Web content, dialogue can be facilitated by explicitly inviting questions and feedback (throughout the presentation, if there is one; figure 2), listening attentively, responding warmly and respectfully, and offering to follow up by e-mail (Monroe 2011).

Emotion is a powerful motivational force that promotes personal relevance, aids in long-term memory, and can mobilize a person to respond (Ballantyne and Packer 2005), but it must be managed carefully. Fear appeals, in particular, can have unintended effects and can engender feelings of helplessness that develop into denial, apathy, or resignation and that, ultimately, prevent engagement with the material (Bain et al. 2012). Emphasizing the positive benefits of taking action appears to be more effective in this respect than does emphasizing the risk of disaster associated with inaction, especially with skeptical publics (Bain et al. 2012).

Although factual knowledge may persist, enthusiasm and active engagement fade in the absence of reinforcement after an informal science interaction (Adelman et al. 2000). Providing *action resources*, such as an online resource list, people to contact, a public event schedule, or take-home activities, helps maintain enthusiasm and provides accessible avenues for continued engagement (Ballantyne and Packer 2005).

There is strong evidence that *formative assessments* (i.e., midstream evaluations) are significantly more instructive than are single endpoint evaluations (Morris et al. 2007, Carleton-Hug and Hug 2010). Many of the techniques above (e.g., asking questions to gauge interest, brainstorming hypotheses or interpretations) can also serve as formative assessments. Because it allows progress and the interest level to be gauged and misconceptions to be identified, this type of instant feedback allows immediate improvements to a message, presentation, or activity (figure 1; Keeley 2008).

Evaluation

Evaluation is essential to improving outreach effectiveness. A formal evaluation involving the use of control groups or an external evaluator may be desirable for large, multiyear programs, such as citizen science or conservation efforts (Margoluis et al. 2009). However, informal science outreach may be informally evaluated with surveys, pre- and posttests for content knowledge or attitudes, or a discussion with participants (Keeley 2008). One simple informal evaluation is to provide index cards and ask participants to anonymously write a few sentences about the message of the activity or any lingering questions that they have, which would reveal the most salient take-home points and the participants' general attitudes toward the subject matter (e.g., motivated versus apathetic). This feedback can be used to refine goals and activities or identify new collaborators (figure 1). Finally, encouraging reflection for all parties (i.e., both scientists and the public) allows all of the participants to forge connections among their experience, actions, and the concepts learned (Hatcher and Bringle 1997). Reflection activities could include critical discussions, presentations to peers, or writing in a journal.

Finally, many outreach evaluations are stored in private databases or are reported only to funding agencies; these reports rarely become publicly available (Carleton-Hug and Hug 2010), although they could be extremely informative. Several Web sites accept informal reports of science education and outreach, such as *http://informalscience.org* and *http://informalcommons.org*. Browsing the suggestions posted on these sites can help refine goals, activities, and evaluations.

A challenge: Reaching nontraditional publics

Most outreach efforts rely on voluntary participation (e.g., attending events, contributing to research, reading online materials), but volunteers tend to be well educated and predisposed to participate; they also tend to already value science and the environment (figure 2; Nisbet and Scheufele 2009). For example, Americans who already have more formal education are more likely to visit informal science institutions, such as zoos or natural history museums, than are those with less formal education (NSB 2012). It is more challenging to encourage dialogue with other publics, particularly for outreach that requires a physical presence and participation rather than the consumption of online media. Instead, we should strive to interact with diverse publics that are often overlooked, including urban or at-risk youth (Pandya 2012), religious or cultural organizations (Hitzhusen and Tucker 2013), motorized recreation enthusiasts (e.g., boaters, snowmobilers, all-terrain vehicle riders; Morris et al. 2007), incarcerated men and women (Nadkarni 2004), and legislators and public officials (Meyer et al. 2010). Sensitivity to values is crucial for engaging diverse publics in dialogue (figure 2), and collaborations with interface organizations (Osmond et al. 2010) or trusted resources in a community (Bain et al. 2012) can help establish common ground and personal relevance with frequently overlooked publics.

Implications for communications training

Communication training can significantly improve outcomes of scientist–public interactions for both parties (Webb et al. 2012), and many online resources are available for the public communication of science (supplementary table S2). Some organizations have also offered workshops for scientists who wish communicate with the public (e.g., the National Science Foundation's "Science: Becoming the messenger" workshop); however, the language that permeates many of these resources, such as *audience* and *presenter* or *crafting a message*, is entrenched in the deficit model and reinforces one-way communication.

Given the empirical effectiveness of strategies such as dialogue and active learning, future outreach training for scientists should move beyond the concept of crafting a better message for public consumption. Specifically, training should help scientists recognize that they, too, can learn from outreach and develop the skills and confidence to engage diverse publics in dialogue. Because many scientists perceive face-to-face conversations with the public as "difficult" or "dangerous" (Davies 2008, Webb et al. 2012), developing interactive online resources could be an easy and safe first step in dialogue training. Social networking, online discussion boards, and the ability to upload dynamic media content make the Internet a democratic and dialogic form of communication relative to media such as television or newspapers (Peters 2013). Furthermore, the Internet has become the public's favored source of scientific news and information (NSB 2012, Peters 2013); therefore, online communication could allow scientists to easily engage a large and diverse public. Other aspects of training should be focused on forming partnerships with appropriate agencies (e.g., social scientists or interface organizations) and building capacity for incorporating evaluation (formal and informal) into current outreach practices.

Benefits of participating in outreach

Unfortunately, current institutional practices are not conducive to many scientists' having active public outreach lives. Outreach is often seen as something that must be done on one's own time, outside of "real" research (Royal Society 2006, Salguero-Gomez et al. 2009). Furthermore, institutions lack an incentive structure in hiring, promotion, and tenure decisions that would reward outreach activities. Older, senior scientists are typically more likely to participate in outreach (Royal Society 2006), whereas younger scientists (e.g., undergraduate and graduate students or postdoctoral researchers) value outreach activities but do not feel that they have the time or support from their mentors or institutions to participate widely (Salguero-Gomez et al. 2009).

Despite these barriers, social science research has demonstrated that interacting with the public can have strong positive impacts on scientists themselves. Contrary to the expectation of hostile reactions or misinterpretations, many scientists who have participated in outreach described the public as friendly, fairly well informed, and keen to engage (Pearson et al. 1997). Similarly, the National Science Board (NSB 2012) reported that 91% of the Americans surveyed expressed strong or moderate interest in new scientific discoveries. Furthermore, participation in outreach does not negatively affect scientific productivity or prestige (Jensen et al. 2008). In fact, many scientists report that interacting with the public enhanced their communication skills (Pearson et al. 1997, Davies 2008, Laursen et al. 2012) or even their own research (Salguero-Gomez et al. 2009, Pace et al. 2010). Ultimately, to increase participation in outreach, we must increase institutional and cultural support for outreach activities as a valued form of service for scientists at all career stages, from undergraduate students to senior faculty members.

Conclusions

Outreach can have positive effects both on public engagement with science and on scientists themselves (e.g., enhancing communication skills). However, many scientists and professional societies still conceptualize outreach as one-way communication with little development or evaluation. I advocate that we can and should take a more scientific approach to outreach, one based on an empirical understanding of how people make sense of scientific information and participate in public discourse. Personal relevance is essential for engagement, and factors that increase personal relevance depend on the knowledge, attitudes, and values of a specific public. Furthermore, empirical evidence overwhelmingly demonstrates that active engagement, dialogue, and discussion are crucial factors in promoting knowledge retention, enthusiasm, and analytical capacity.

Therefore, future training for scientists in public communication should be focused more on the skills and confidence to promote dialogue with the public than on the strategic crafting of messages. By conceptualizing outreach as an iterative process, like scientific teaching or science itself, we can meaningfully bring about mutual trust and understanding between scientists and the public.

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Johanna Varner (johanna.varner@utah.edu) is a PhD candidate in the Department of Biology at the University of Utah, in Salt Lake City.