Crafting and evaluating Broader Impact activities: a theory-based guide for scientists

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To secure research funding from grant-awarding agencies such as the US National Science Foundation, scientists – despite not typically being trained in non-technical communication or public engagement – must competitively formulate so-called Broader Impacts activities. Dissemination activities are often proposed as Broader Impacts of research, but what characteristics of these activities truly indicate their potential to be "broad" or "impactful"? How can the "impacts" of very different activities be fairly compared during peer review? Combining the experiences of successful practitioners with communication theory, I have synthesized a five-point framework that could help both proposers and reviewers craft and compare Broader Impacts dissemination activities. This "Broader Impacts Impact Framework" summarizes best practices in communication and outreach, and can be easily used by scientists during proposal writing and review. This framework focuses on five main factors: who, why, what, how, and with whom.

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Scientists and those who evaluate proposed research requiring funding (hereafter "reviewers") have expressed the view that – during the US National Science Foundation (NSF) proposal process – fulfilling the Broader Impacts (BI) criterion is more challenging than addressing the Intellectual Merit (IM) criterion (NSB 2011). True, scientists' expertise generally lies predominantly in the subject matter addressed by IM, but perhaps the greatest problem is that, in contrast to the IM criterion, no standardized framework exists for evaluating BI activities. BI spans a wide spectrum of potential outcomes (top of Figure 1), with "dissemination of research findings to increase scientific literacy" being the third most proposed category across all NSF directorates (after "teaching/training" and "broadening participation of underrepresented groups"; NSB 2011). How can these very different dissemination efforts be fairly compared?

Reviewers look for particular characteristics in the IM section of a proposal, regardless of the subject of the research project, and all competitive IM descriptions display certain qualities: for instance, appropriate and rigorous research design with suitable sample size and controls, a solid theoretical foundation for the work, the potential to substantially advance understanding, and evidence that the proposer is knowledgeable and has the resources to carry out the study. The latter two characteristics are even listed in the NSF Proposal and Award Policies and Procedures Guide (NSF 2013). Essentially, principal investigators (PIs) know that the IM sections of their proposals must demonstrate particular qualities, and reviewers are aware that they must look for them.

Yet what should PIs demonstrate or emphasize in their BI descriptions to convince the reviewer that their proposed activity will be truly "broad" or "impactful"? Guidance from NSF remains sparse regarding best practices in the crafting and judging of BI activities (NSF 2007, 2013). A common goal of many BI activities, however, is skill-building or wide dissemination of knowledge, with the intention that research-generated information or new skills will be used outside of the original research group; for convenience, I will hereafter call these varied efforts "outreach", because they typically extend beyond the PI's research program (bottom of Figure 1). My goal has been to answer the following question: what qualities characterize broad and impactful outreach activities, making them more effective in practice and potentially more competitive in peer review? Although I focus on NSF and the BI criterion, the principles I describe here can be applied to any effort intended to disseminate or use scientific research outside the research group where it was generated. By examining examples of successful information-dissemination programs, cautionary tales, and theoretical work, I have created a standardized framework of characteristics that may help proposers and reviewers craft and compare BI activities that focus on bringing research-generated

In a nutshell:

- Scientists often struggle to formulate effective Broader Impacts activities for their funding proposals
- Communication theory may offer helpful strategies
- All successful dissemination activities share common characteristics
- Highlighting just five of these characteristics in proposal descriptions could help peer reviewers to judge and compare the potential for impact among a range of proposed Broader Impacts activities

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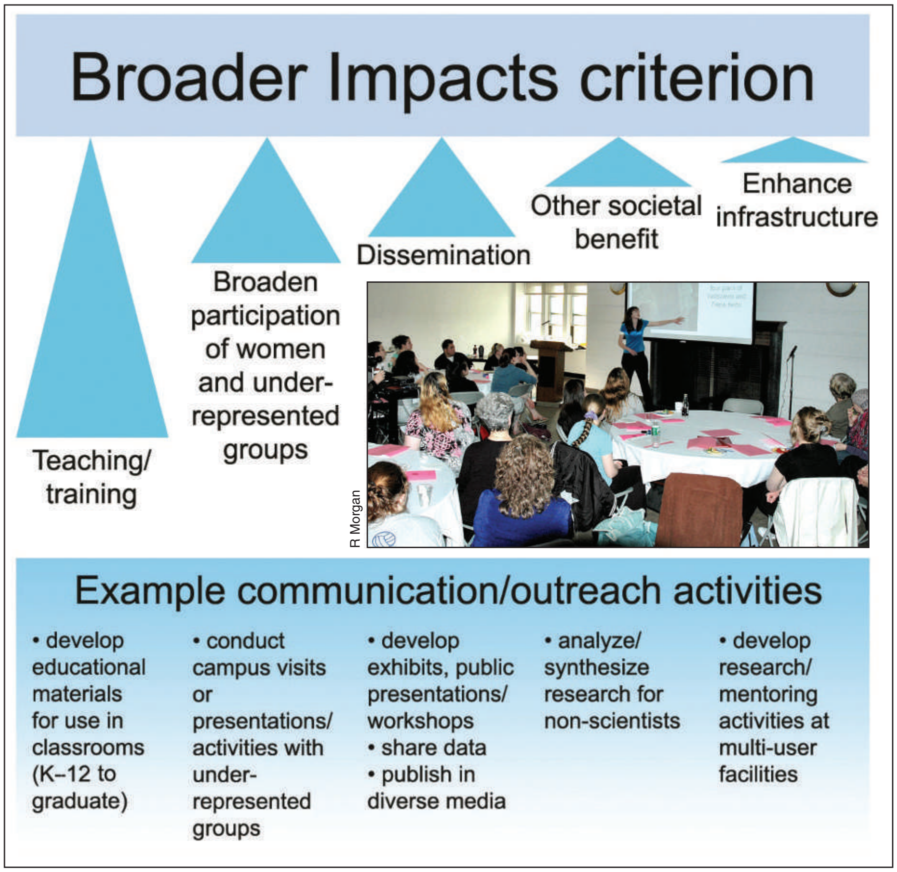

Figure 1. *The NSF Broader Impacts criterion spans a range of activities and outcomes, typically arranged in five categories. (top) The length of each triangle corresponds to the relative popularity of each category among NSF proposals (NSB 2011). (bottom) Despite the categories' apparent differences, NSF (2007) provided examples, paraphrased here, for each category that relate to the guidance offered in this paper. Inset photograph: the author explains an ecological concept at a local conference.*

information to various audiences. I call this a Broader Impacts Impact Framework (formerly "Factor"; Skrip in press), or BIIF for short.

The BIIF

The BIIF (Table 1) consists of five straightforward categories of characteristics that scientists should carefully consider when evaluating the potential for success of their BI outreach activities. For example, supposing someone in my research subdiscipline – songbird migration, nutrition, and physiology – proposes BI outreach activities that will (1) engage citizen scientists in data collection, (2) bring their science to public lectures or workshops, or (3) detail the results of their work online or in non-scientific publications (Figure 2). Imagine that a reviewer encounters three competing proposals, with equally competitive IM, each of which suggests one of these types of activities. How might that reviewer judge which among them is best, or determine whether any of the activities are likely to be "impactful"? The BIIF synthesizes theory and best practices to help answer these questions by calling attention to the following straightforward considerations: who, why, what, how, and with whom.

Who is the audience?

Descriptions of BI activities in proposals should define a target audience and be as specific as possible. When it comes to potential for "impact", all audiences are not equal. Proposers should be prepared to defend their choice of audience and state why that audience is the most important one to reach because they are the most likely to use and spread the science-generated information.

Evidence suggests that, to have the greatest effect regardless of activity type, PIs should focus their outreach efforts on so-called "gatekeepers" or "opinion leaders", individuals or institutions that exert the most influence and therefore have the greatest potential to affect policies and practices, spread a scientific message, or serve as a trusted conduit for some call to action (Heberlein 2012; Clayton *et al.* 2013). Gatekeeping/opinion-leading audiences – including policy makers, community program administrators, educators at informal learning centers, religious leaders, teachers, and wildlife managers – are perhaps in the best position to make use of information that is disseminated by scientists, and can serve as trusted, familiar conduits for a message (Khalil and Ardoin 2011; Purcell *et al.* 2012; Trautmann *et al.* 2012; Jordan *et al.* 2013). After all, how people receive and use information depends on how much they trust the source, and personal communication among individuals in social networks remains a primary vehicle for messages and for recruiting people into activities or ways of thinking (Besley *et al.* 2008; Cronje *et al.* 2011; Chu *et al.* 2012).

How could this idea be used during proposal preparation and peer review? Returning to the hypothetical example of the three competing BI activities (Table 2a), we must first keep in mind that the "best" audience for a dissemination activity depends on what that activity is trying to accomplish. So if, for example, the proposers' aim is to promote conservation of bird habitats and the planting of fruiting shrubs that many songbirds use during migration, in the context of a BIIF, a very strong BI section will identify a specific audience of gatekeepers or opinion leaders to whom the dissemination activity will be initially directed, while a weak BI section will not (Table 2a).

Why propose a particular activity?

The widespread notion among scientists that simply providing scientific information will change public opinions or help the public solve environmental problems remains a fallacy that undermines the very mission of the BI criterion. Communication professionals and social psychologists have long understood that the "deficit model" approach to science outreach (wherein the public is seen to have an "information deficit", fixable by provision of data) is ineffective in accomplishing educational goals or achieving lasting attitudinal/behavioral changes (Gross 1994; Besley and Tanner 2011; Heberlein 2012). Yet scientists have been slow to espouse this view, mainly because they are not trained to consider different models of knowledge-building, the values and roles of non-scientific expertise, and the competing factors and filters that affect how scientific information is assimilated and used by non-scientists. The "public" is not an empty vessel waiting for scientific knowledge; rather, the varied and complex social needs of different audiences must drive the outreach efforts of scientists.

Returning to the hypothetical example (Table 2b), if a PI's proposal claims that s/he intends to "educate the public" through BI activities, reviewers should be wary. To what end is the PI trying to "educate the public"? Who is "the public"? Is this "education" meant to bring about a behavioral change through one-way provision of scientific information? If so, the chances are high that it will not work. Pro-environmental change does not depend on ecological understanding alone; it also depends on the non-ecological (aesthetic, economic, etc) values that an audience holds, irrespective of their comprehension of the science (Hager *et al.* 2013). Rather than focusing on "knowledge gaps", BI activities should propose solutions and actions in which audience members can be engaged, to improve their own lives and environment, in accordance with their existing values. Aims that are highly specific are more likely to come to fruition (eg Roberts 2009) and should be more highly valued in proposal ranking.

If a proposer intends to increase knowledge, without any unrealistic expectation that a behavior change will follow, s/he should be able to identify specific knowledge gains that are planned. Defining and measuring changes in scientific literacy can be problematic, especially if the audience is already relatively scientifically literate; thus, if a proposer seeks to increase scientific (including ecological) literacy, reviewers should be suspicious unless literacy in a particular topic area is specified (Cronje *et al.* 2011; Phillips *et al.* 2012). Essentially, means of knowledge dissemination should be appropriate for the type of knowledge they are meant to improve and suited to the "why" behind the effort (Table 2b).

What should a BI activity involve?

Ideally, proposers should be able to demonstrate that they will consider the needs of their audience. Several "key themes" emerge from the literature: (1) promoting self-empowerment, (2) exchange of ideas, (3) value of non-scientist opinions, (4) interactivity, (5) personal contact, and (6) performing a service (see below). Essentially, when hoping to successfully deliver a message to a specific audience, scientists must strive to understand that audience and what its members want.

When presenting the public with a description of an environmental problem, self-empowerment and agency – the notion that an audience member can do something relevant and that her/his actions will matter – should be stressed (key theme 1) (Koepfler *et al.* 2010; Jordan *et al.* 2012a; Clayton *et al.* 2013). Additionally, the recipients of outreach efforts must have the opportunity to contribute feedback at all stages of project development (key themes 2, 3, and 4) (Dickinson and Bonney 2012; Druschke and Seltzer 2012). To promote retention and audience satisfaction, for example, the Cornell Lab of Ornithology's citizen-science programs treat their participants as customers, and attempt to provide the best "service" to keep those participants engaged (key themes 5 and 6) (Chu *et al.* 2012; Trautmann *et al.* 2012). To have the greatest effect, BI activities should strive to do the same, by identifying the unique needs, attitudes, and

Table 1. The Broader Impacts Impact Framework (BIIF)

(1)	**Who** is the audience for the activity? How was the audience chosen? Does the audience include "gatekeepers" and/or "opinion leaders"?
(2)	**Why** was this particular activity chosen? Does the activity perpetuate the myth of information deficit (ie that information is enough to promote behavior or policy changes)? Does the proposal specify a particular objective to be met?
(3)	**What** does the activity involve? Does the activity incorporate the following: Audience self-empowerment? Exchange of ideas/interactivity/personal contact? Value of non-scientist opinions/contributions? Serving a public need?
(4)	**How** will the activity accommodate human nature? Does the activity incorporate the following: Direct experience? Audience's sense of identity? Specificity of action?
(5)	**With whom** is the activity to be designed or performed? Does the proposal demonstrate prior experience in successful outreach? Does the activity involve collaboration with social scientists, professional communicators, or other intra- or extra-institutional staff?

Notes: The BIIF consists of five categories of qualities that characterize "impactful" outreach activities; this framework can help proposers to craft, and reviewers to compare and rate, Broader Impacts outreach activities.

Figure 2. *In a hypothetical example, three scientists studying the ecophysiology of songbirds propose different Broader Impacts activities in their funding applications: (1) engage citizen scientists in data collection, (2) bring their science to public lectures or workshops, or (3) detail the results of their work online or in non-scientific publications. The Broader Impacts Impact Framework helps distinguish the strengths and weaknesses of such proposed activities, regardless of their different forms.*

motivations of their audience and by aiming to supplement that audience's knowledge and skill set with research-generated information and skills (Gross 1994). Of course, this requires that PIs recognize how much their audience already knows and can do (Petts and Brooks 2006). To my knowledge, no how-to document currently exists that advises scientists on how best to complement their expertise with target audience expertise (eg how best to mesh the knowledge base and skill sets of researchers and non-scientists). However, Frechtling (2010) offered strategies for identifying audience attitudes before projects begin and for evaluating project outcomes. Ideally, any proposal would reflect a clear understanding of the audience's motivations, as well as plans to modify the suggested approach based on audience feedback.

Any of the three BI activities that were previously introduced in the hypothetical bird nutrition example – citizen-science outreach, public workshops and lectures, or non-scientific publications – can display the key themes discussed earlier if their proposers are sufficiently creative (Table 2c). According to the BIIF, a very strong proposal description would indicate that the BI project will seek feedback from the audience, promote personal two-way communication, and identify what the audience can do about a particular science-based problem.

Table 2. Three hypothetical competing proposals with different proposed Broader Impacts outreach activities

	High potential for "impact"	*Low potential for "impact"*
(a) **Who**	Proposal identifies specific audience that can further spread the message (eg "Our audience includes leaders and members of specific bird or garden clubs, such as…").	No description is given of the best conduit audience for the activity (ie gatekeepers or opinion leaders who could more likely influence others).
(b) **Why**	Proposal demonstrates that the PI is well acquainted with the needs and attitudes of the audience, and the scope of the activity is realistic (eg "We will draw on the pro-wildlife values of local landowners to encourage pro-bird gardening habits..."). The PI does not expect to bring about behavioral change in a wide, heterogeneous audience by provisioning general science facts.	Proposal displays vague, information-deficit thinking; eg "We will educate the public…", "We will increase general scientific literacy…", or "We will raise awareness…". Educational goals are not specific.
(c) **What**	Proposal indicates that the project will seek feedback from the audience, promote personal two-way communication, and identify "what you can do".	The project's communication will be solely one-way, with no knowledge-building among the audience or promotion of self-empowerment.
(d) **How**	The project will provide direct experience, appeal to a sense of "ownership" or "place" (eg "my" garden, "my" town, "my" backyard birds), and/or identify the means to achieve a specific behavior (eg "We will highlight where landowners can buy the kinds of shrubs that birds use during migration, to plant at home...").	The proposal makes no mention of direct experience, consideration of audience identity, or specific educational or behavioral targets.
(e) **With whom**	The PI has an intra-institutional (eg communication department) or extra-institutional (eg museum, school) partner. A social scientist will study the activity's outcomes.	A PI without communication expertise makes no effort to collaborate with a communication specialist.

Notes: In this hypothetical example, a reviewer considers three proposals from different principal investigators (PIs) with equally competitive Intellectual Merit, but proposing three different Broader Impacts activities (citizen participation in data collection, lectures/workshops, and online or print articles); use of the Broader Impacts Impact Framework helps distinguish competitive activities with high potential for "impact" from less competitive activities, regardless of the form that activity takes.

How does an activity truly affect an audience?

BI activities with the highest potential for impact are those that accommodate human nature. Scientists may be tempted to claim that an audience "should" do, know, think, or value a certain "something" related to their work; but rather than tell people what they should care about, truly effective programs describe how science is relevant to what people already value, believe, or do (Bonter 2012; Chu *et al.* 2012; Heberlein 2012; Purcell *et al.* 2012). Outreach efforts that adopt this approach tend to follow the three guiding principles discussed by social psychologist Thomas Heberlein (Heberlein 2012) in the context of pro-environmental campaigns: the "direct experience principle", the "identity principle", and the "specificity principle". They could easily – and should – be integrated into the way proposals are prepared and compared.

First, an audience is more likely to learn a particular skill or adopt a particular attitude or behavior if they have had direct experience with the phenomenon in question and can relate to it on a personal level (Bonney and Dickinson 2012; Heberlein 2012; Jordan *et al.* 2012b; Oberhauser 2012; Reynolds and Lowman 2013). As much as possible, outreach efforts must therefore provide direct experience (eg encourage or facilitate data collection or other observations, solicit artwork or other participatory creative works, or offer opportunities to contribute to a specific outcome), or remind the audience of a relevant direct experience they themselves have had (eg visiting, making, or observing something in their own lives).

Second, the most ingrained attitudes and behaviors are those most closely tied to an individual's own sense of personal identity or ownership; deeply emotional values can reframe how an individual interprets a science-based message (Laslo *et al.* 2011; Heberlein 2012). Consequently, an audience's established worldview must be taken into account before a scientist begins an outreach effort, as that worldview is unlikely to change in the face of new information. Fortunately, identity-based attitudes can be powerful allies when efforts are crafted to draw on the pride that audiences take in themselves and their communities (eg Purcell *et al.* 2012; Hager *et al.* 2013).

Finally, the specificity principle suggests that audiences do not necessarily behave in ways consistent with their own attitudes, given the myriad factors that determine their day-to-day actions and decisions. If a scientist wants to increase the popularity of a particular pro-environment or pro-science behavior (eg using energy-saving technologies or reporting bird sightings) among a particular audience, it is important to target and facilitate that behavior. Facts alone do not solve problems; people act when provided with a sense of self-empowerment and agency (as mentioned above) and a sense of free choice, which helps to prevent them from resenting an expert's directions or advice (Heberlein 2012).

So, according to the BIIF (Table 2d), a very strong BI section will describe activities that provide an audience with a direct experience, induce them to recall one, or give them the sense of a personal stake in the science. Ideally, it also will appeal to the audience's sense of place or ownership, will focus on a particular behavior, and will provide or suggest the means by which the audience can achieve it.

With whom is the activity to be designed or performed?

Scientists need not be skilled in outreach to have an impact; indeed, it is arguably an extra burden on them to obtain those skills. Instead, partnering with social scientists (including social psychologists), professional communicators, artists, filmmakers, museum staff, and/or educators can help to promote synergy among different professionals already equipped with the necessary skills to design impactful outreach efforts. All of these individuals are experts in message formulation and delivery and can be valuable resources and collaborators. Scientists should avoid "reinventing the wheel" by working with pre-existing infrastructure – ie pre-established staff, community groups, institutions, or partnerships – to achieve dissemination goals.

This idea of partnership is not new, but it should be stressed during proposal preparation and review. As Burggren (2009) pointed out, if the ultimate goal of the BI criterion is to pair effective outreach with high-quality science, rather than transform the abilities or philosophies of scientists, individuals who are trained in outreach and public education should be the ones actually doing the outreach and education. For instance, museums and other educational institutions provide pre-existing infrastructure for grant-funded scientists, so as to satisfy the BI criterion and also to maximize the acceptance of their message, given that these institutions are typically considered as trusted and politically neutral venues for free-choice learning (Alpert 2009; Khalil and Ardoin 2011). Intra-institutional bodies can also offer professional outlets for academics to gain the most impact from their BI activities; boundary organizations such as extension services, university communications offices, and supporting resources for faculty within academic institutions specialize in the outreach skills that PIs may lack or simply do not have time to exercise (Roberts 2009; Dickinson and Bonney 2012).

Furthermore, when social scientists can study the success or progress of BI activities as they are carried out, changes to the activities' format or approach can be made mid-project and future activities can be improved based on their findings (Burggren 2009; Frodeman and Parker 2009; Druschke and Seltzer 2012). Many methods and criteria exist for evaluating these activities, and should be chosen to suit the project at hand (Rowe and Frewer 2004; Frechtling 2010). Such an iterative evaluation approach parallels the "adaptive management" strategies already familiar to ecologists; much can be gained from studying how a project is working while it is still ongoing.

According to the BIIF (Table 2e), therefore, a very strong proposal description will demonstrate that the PI either has proven experience in successful outreach project design/execution or has partnered with an individual or group who does. In particular, collaborations with social scientists who will study the BI activity, and with institutions or offices that already have strong relationships with non-scientist communities, should be of great value.

Conclusion

At the heart of the BIIF is the idea that, regardless of the BI outreach activity, a strong proposal will display certain elements that indicate a high potential for impact. If the five categories of qualities described above (Table 1) are addressed in a funding proposal, scientists and reviewers can compare a wide range of activities. This is not intended to promote certain BI dissemination activities over others, as long as they accomplish the desired outcome – that is, the impact they are meant to have.

BI activities should aim to:

- target a specific audience that can make practical use of the proffered, research-generated information and include the potential for ongoing effects through non-target audiences (eg if the target audiences are educators, policy makers, or wildlife managers);
- achieve an outcome with a contextual rather than an "information-deficit" approach;
- communicate self-empowerment and encourage personal contact and feedback;
- accommodate human nature by considering Heberlein's (2012) direct experience, identity, and specificity principles; and
- integrate with existing outreach programs that offer a diverse range of additional skills.

Any dissemination activity – ranging from citizen data collection, to public lectures and workshops, to popular online and print publications, and more – could be effective if their proposers explicitly addressed these points. In this way, disparate BI activities can be compared, not by making value judgments about the different media and techniques they use or by tallying audience numbers, but by carefully examining whether they fulfill the basic criteria that communication professionals and social psychologists have described in their varied discussions of successful impact.

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References

Alpert CL. 2009. Broadening and deepening the impact: a theoretical framework for partnerships between science museums and STEM research centres. *Soc Epistemol* **23**: 267–81.

Besley JC and Tanner AH. 2011. What science communication scholars think about training scientists to communicate. *Sci Commun* **33**: 239–63.

Besley JC, Kramer VL, Yao Q, *et al.* 2008. Interpersonal discussion following citizen engagement about nanotechnology. What, if anything, do they say? *Sci Commun* **30**: 209–35.

Bonney R and Dickinson JL. 2012. Overview of citizen science. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Bonter DN. 2012. From backyard observations to continent-wide trends: lessons from the first twenty-two years of Project FeederWatch. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Burggren WW. 2009. Implementation of the National Science Foundation's "Broader Impacts": efficiency considerations and alternative approaches. *Soc Epistemol* **23**: 221–37.

Chu M, Leonard P, and Stevenson F. 2012. Growing the base for citizen science: recruiting and engaging participants. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Clayton S, Litchfield C, and Geller ES. 2013. Psychological science, conservation, and environmental sustainability. *Front Ecol Environ* **11**: 377–82.

Cronje R, Rohlinger S, Crall A, *et al.* 2011. Does participation in citizen science improve scientific literacy? A study to compare assessment methods. *Appl Environ Educ Commun* **10**: 135–45.

Dickinson JL and Bonney R (Eds). 2012. Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Druschke CG and Seltzer CE. 2012. Failures of engagement: lessons learned from a citizen science pilot study. *Appl Environ Educ Commun* **11**: 178–88.

Frechtling J. 2010. The 2010 user-friendly handbook of project evaluation. Revision to NSF 02-057. Arlington, VA: National Science Foundation, Directorate for Education and Human Resources, Division of Research and Learning in Formal and Informal Settings.

Frodeman R and Parker J. 2009. Intellectual Merit and Broader Impact: the National Science Foundation's Broader Impacts criterion and the question of peer review. *Soc Epistemol* **23**: 337–45.

Gross AG. 1994. The roles of rhetoric in the public understanding of science. *Public Underst Sci* **3**: 3–23.

Hager GW, Belt KT, Stack W, *et al.* 2013. Socioecological revitalization of an urban watershed. *Front Ecol Environ* **11**: 28–36.

Heberlein TA. 2012. Navigating environmental attitudes. New York, NY: Oxford University Press.

Jordan RC, Ehrenfeld JG, Gray SA, *et al.* 2012a. Cognitive considerations in the development of citizen science projects. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Jordan RC, Ballard HL, and Phillips TB. 2012b. Key issues and new approaches for evaluating citizen-science learning outcomes. *Front Ecol Environ* **10**: 307–09.

Jordan RC, Brooks WR, Gray SA, *et al.* 2013. Rising to the "broader impacts" challenge. *Front Ecol Environ* **11**: 234–35.

Khalil K and Ardoin N. 2011. Programmatic evaluation in Association of Zoos and Aquariums–accredited zoos and aquariums: a literature review. *Appl Environ Educ Commun* **10**: 168–77.

Koepfler JA, Heimlich JE, and Yocco VS. 2010. Communicating climate change to visitors of informal science environments. *Appl Environ Educ Commun* **9**: 233–42.

Laslo E, Baram-Tsabari A, and Lewenstein BV. 2011. A growth medium for the message: online science journalism affordances for exploring public discourse of science and ethics. *Journalism* **12**: 847–70.

NSB (National Science Board). 2011. National Science Foundation's Merit Review criteria: review and revisions. Arlington, VA: NSF. NSB/MR-11-22.

NSF (National Science Foundation). 2007. Merit review Broader Impacts criterion: representative activities. Arlington, VA: NSF. www.nsf.gov/pubs/2002/nsf022/bicexamples.pdf. Viewed 30 Sep 2014.

NSF (National Science Foundation). 2013. Proposal and award policies and procedures guide (PAPPG). Arlington, VA: NSF. NSF 14-1, OMB Control Number 3145-0058.

Oberhauser KS. 2012. Monitoring monarchs: citizen science and a charismatic insect. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Petts J and Brooks C. 2006. Expert conceptualisations of the role of lay knowledge in environmental decisionmaking: challenges for deliberative democracy. *Environ Plann A* **38**: 1045–59.

Phillips T, Bonney R, and Shirk JL. 2012. What is our impact? Towards a unified framework for evaluating outcomes of citizen science participation. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Purcell K, Garibay C, and Dickinson JL. 2012. A gateway to science for all: celebrate urban birds. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

Reynolds JA and Lowman MD. 2013. Promoting ecoliteracy through research service-learning and citizen science. *Front Ecol Environ* **11**: 565–66.

Roberts MR. 2009. Realizing societal benefit from academic research: analysis of the National Science Foundation's Broader Impacts criterion. *Soc Epistemol* **23**: 199–219.

Rowe G and Frewer LJ. 2004. Evaluating public-participation exercises: a research agenda. *Sci Technol Hum Val* **29**: 512–56.

Skrip MM. Assessing the Broader Impacts of ecological research: towards a "Broader Impacts Impact Factor". Proceedings of the Fourth Summer Symposium on Science Communication; 5–7 May 2014; Ames, IA. Ames, IA: Iowa State University. In press.

Trautmann NM, Shirk JL, Fee J, *et al*. 2012. Who poses the question? Using citizen science to help K–12 teachers meet the mandate for inquiry. In: Dickinson JL and Bonney R (Eds). Citizen science: public participation in environmental research. Ithaca, NY: Comstock Publishing Associates.

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