Achieving Broader Impacts in the National Science Foundation, Division of Environmental Biology

SEAN M. WATTS, MELISSA D. GEORGE, AND DOUGLAS J. LEVEY

Since 1997, the National Science Foundation's (NSF) efforts to promote the Broader Impacts Criterion (BIC) have yielded mixed results. Here, we evaluate proposals to the Division of Environmental Biology (DEB) from submission through the reporting stage to assess DEB's implementation of the BIC. Our results suggest that within DEB, past principal investigators have tended to underreport broader impact activities, and past reviewers have paid them less attention than intellectual merit activities. Activities targeting broadening participation of underrepresented groups were particularly rare in all of the document types that we examined (i.e., proposals, panel summaries, and reports). In 2013, the NSF overhauled the review and reporting processes and recommended institutional links to promote the BIC. By examining both the mechanics of the Broader Impacts Criterion and the policy setting within which it has been implemented we hope to contribute to efforts to clarify the broader impacts concept and improve its effectiveness.

Keywords: National Science Foundation, broader impacts, broadening participation, underrepresented groups, science policy

Since 1997, the National Science Foundation (NSF) has guided reviewers to use two criteria to evaluate proposals: intellectual merit (the potential to advance scientific knowledge) and broader impacts (the potential to benefit society). The introduction of the Broader Impacts Criterion (BIC) was met with mixed reception from scientists. Many felt that the BIC focused much needed attention and overdue recognition on scientists with a passion for engaging society; however, many judged the BIC a burden and a distraction from the science they were trained to conduct (Holbrook 2005, Chodos 2007, Alpert 2009, Mardis et al. 2012, Frodeman et al. 2013). Confusion and frustration over the implementation of the BIC has inspired many assessments of the BIC, which tend to fall into three categories: case studies, which demonstrate the benefits or shortcomings of the BIC; policy analyses of the debate surrounding the BIC or its impact; and quantitative assessments of proposed broader impact activities (BIA; see table 1).

This body of work has highlighted challenges in BIC implementation that include divergent political pressures on the NSF, a lack of institutional infrastructure, and variation among scientific cultures in the BIC's perceived importance. Case studies and historical analyses provide excellent context and detail but may be limited in how their implications map onto policy and practices in individual divisions and directorates of the NSF. Quantitative assessments, on the other hand, have generally been limited by NSF confidentiality rules to public abstracts, which do not always include BIAs, even if they are present in the corresponding proposal (Watts et al. 2013, but see NSB 2011). Confidentiality has also limited assessments of the reported outcomes of proposed BIAs.

Here, we use data sets of public abstracts, panel review summaries, declined proposals and project reports spanning 2000–2010 to evaluate the implementation of the BIC in the Division of Environmental Biology (DEB). By evaluating proposals from submission through the reporting stage, we are able to assess the BIC in the policy context that has influenced its implementation.

The policy context

To fully understand the challenge of implementing the BIC, it is important to consider the tensions inherent in the NSF's role in federal research policy. The NSF's core mission is to provide "support for all fields of fundamental science and engineering" (except medical science; NSF 2011); currently, this support amounts to 21% of all federally funded basic research conducted at US colleges and universities (58% if medical research supported by the National Institutes of Health is excluded; NSF 2013a). In fact, in many fields, the NSF is the primary source of federal research funding (NSF 2013a). In environmental biology, the NSF supports

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Table 1. Examples of assessments of the Broader Impact Criterion (BIC) and Broader Impact Activities (BIA).

Category	Assessment type	Examples of literature
Case studies	Benefits or shortcomings of the BIC	Alpert 2009, MacFadden 2009
Policy analyses	Policy debate or impact of BIC:	
	• Historical analyses	Rothenberg 2010
	• Policy implications	NAPA 2001, Holbrook 2005, NSB 2011
	• Ethical considerations	Intemann 2009, Schienke et al. 2009
	• Professional society commentaries	Chodos 2007, Lucibella 2011, Widener 2012
Quantitative assessments	Analysis of BIAs	
	• Topic modeling or semantic data-mining analysis of proposed BIAs	NSB 2011
	• Quantitative assessments of publically available abstracts	Roberts 2009, Kamenetzky 2012, Mardis et al. 2012, Nadkarni and Stasch 2013

approximately 45% of federally funded basic research (NSF 2013b). The NSF's entire annual budget is approximately $7 billion. To put this figure in perspective, the Department of Defense's, Research, Development, Testing and Evaluation budget in fiscal year 2012 was more than an order of magnitude greater: approximately $73 billion (USDOD 2013).

In pursuing the agency's mission, NSF administrators respond not only to oversight from the Legislative and Executive Branches but to feedback from the research communities that seek funding through and contribute to the review process. Being an intermediary between federal research policy and the basic research community has, at times, placed the NSF in a difficult position. This tension is illustrated by the history of the NSF's efforts to broaden the impact of the research it funds.

From 1981–1997, the NSF review process applied four criteria: prior researcher performance, intrinsic merit of the research proposed, societal relevance of the research and its contribution to science or engineering infrastructure (NSB 2011). In 1993, the Government Performance and Results Act mandated program evaluation to improve performance and public accountability at federal agencies (GPRA 1993). In response, the NSF instituted a new merit review process in 1997. In addition to the two existing broader impact elements from the 1981–1997 system (in effect, benefits to society and enhancement of infrastructure), the new BIC added three more explicit elements: teaching, training and learning, broad dissemination of research, and broadening participation of underrepresented groups. Even though many of these five elements had long been components of the review process (Rothenberg 2010), the 1997 revision formally elevated the status of broader impacts relative to intellectual merit. The next 15 years saw mixed results from the NSF's attempts to promote the BIC (NAPA 2001, Holbrook 2005, NSB 2011). A more detailed history of the BIC is provided in supplemental table S1.

Despite persistent disaffection in some parts of the research community, pressure on the NSF to demonstrate broader impacts continues to increase (Frodeman et al. 2013). In 2010, reauthorization of the America COMPETES Act called on the NSF to develop policies that promote the integration of proven strategies and current research into BIAs; allow principal investigators (PIs) to allocate funds to assessment and evaluation of BIA outcomes; and provide training programs for NSF staff, reviewers, and applicants to understand the new policies (America COMPETES Act 2010). In the same year, the National Science Board (NSB, the governing body of the NSF) established the Task Force on Merit Review to inform the 2011–2016 NSF Strategic Plan. The task force emphasized that achieving broader impacts through its research portfolio need not compromise the NSF's core mission to advance the frontiers of knowledge but conceded that it would require better articulation of the BIC throughout the proposal, review, and assessment processes (NSB 2011).

Subsequent revision of the Proposal and Award Policies and Procedures Guide (hereafter, *Proposal Guide*; NSF 2012) required that the criteria for evaluating intellectual merit be applied in the same way to broader impacts in panel review, project reports, and program assessment. Therefore, broader impact sections of proposals must present a sound, creative, and—ideally—potentially transformative plan; appropriate and qualified individuals; and adequate resources and mechanisms to evaluate success. The 2013 Proposal Guide revisions require reports to include sufficient detail on BIAs to assess a project's benefits to society. The NSB also recognized that while methods for assessing intellectual merit are appropriate, those for broader impact outcomes have been unclear and inconsistent (NSB 2011). Because the outcomes of BIAs may not be informative at the individual project level, the NSB recommended that in some cases, broader impact assessments should be conducted at a more aggregated, program or institutional level. The NSB also promoted mechanisms that would encourage institutions to facilitate the broader impacts of the researchers they sponsor by coordinating their activities or even linking the BIAs in individual projects. Finally, the task force recommended the prioritization of broadening participation of underrepresented groups.

Underrepresented groups: The most underrepresented broader impact

Although increasing the representation of women, minorities, and persons with disabilities has been an official criterion of review since 1981 (see supplemental table S1), broadening participation remains one of the most challenging BIA categories across the NSF's entire portfolio (Sakai and Lane 1996, NSB 2011, Mardis et al. 2012). Reports from the National Academy of Sciences (NAS 2011) and the President's Council of Advisors on Science and Technology (PCAST 2012) still stress the urgent need for strategies that increase recruitment and retention of underrepresented groups in science, technology, engineering, and math (STEM) fields. As recently as 2006, 28.5% of the US population belonged to underrepresented minority groups but constituted only 9.1% of college-educated citizens in the science and engineering workforce (NAS 2011).

A broadly representative workforce brings varied perspectives and values, enhancing scientific understanding and increasing general recognition of the importance of science (Intemann 2009), but broadening participation is also a basic labor pool issue, because the most underrepresented ethnic groups are also the fastest growing populations in the nation (NAS 2011). Because the United States needs not only a diverse scientific workforce but basic science literacy in the populace (NSF 2011, PCAST 2012), we devote much of our analysis and discussion to the particular challenge of broadening participation.

Goals and objectives

From our analysis and review of the many assessments conducted since 1997, we believe that there are two main factors in the NSF funding process that have limited the effectiveness of the BIC: (1) the review process, which has shown a lack of clarity and consistency in panel review of proposed broader impacts, and (2) the reporting process, which has shown a lack of reporting requirements to adequately assess outcomes of proposed BIAs Confidentiality rules also constrain public access to proposals, making it practically impossible to externally evaluate the success of the BIC and limiting feedback to the research community regarding the achievements and gaps in BIC implementation.

Here, we analyze a DEB-wide data set that includes proposals, panel review summaries and project reports. We also include an expanded analysis, comparing abstracts (public) and proposals (not public) from DEB's Ecosystem Science Program (see Watts et al. 2013). We used these data sets to evaluate DEB's implementation of the BIC with regard to the *r*eview and reporting processes and to discuss in detail how challenges in the implementation of the BIC disproportionately affect broadening participation of underrepresented groups.

Identifying broader impact activities

Although the BIC was revised extensively in 2013 (NSF 2012), we use the five categories of BIAs that applied during the period corresponding to our data set (NSF 2002b). These five categories are as follows: *teaching*, or advancing discovery and understanding while promoting teaching, training, and learning; *dissemination*, the broad dissemination of research to enhance scientific and technological understanding; *infrastructure*, enhancing the infrastructure for research and education; *society*, creating benefits to society; and *underrepresented*, broadening the participation of underrepresented groups.

We applied a previously published protocol to identify BIAs (Nadkarni and Stasch 2013), using representative activities in memoranda accompanying the 2002 Proposal Guide (NSF 2002a, 2002b). The examples provided in these documents were not used prescriptively, but to determine the intent and scope of the five criteria. Examples and specific criteria that we applied for each BIA are provided in box 1.

Data sets

We expanded the analysis of the data set used in Watts and colleagues (2013), in which BIAs in publically available abstracts were compared with those included in the corresponding awarded proposals (hereafter, the *abstract set*). Because these data are restricted to a relatively small portion of DEB's portfolio (the Ecosystem Science Program), we also created a DEB-wide data set, which was based on self-study reports prepared for the triennial Committee of Visitors (CoV) reviews (hereafter, the *CoV set*; please see below for more information on the CoV process). These data include randomly selected panel review summaries, proposals, and project reports in all four DEB programs (see the following section for more detail). The abstract set was used to contrast publicly available and internal data on BIAs of awarded projects. The CoV set was used to assess the application of the BIC in panel review (the *review process*) and the reported outcomes of proposed BIAs (the *reporting process*; see table 2 for a sample distribution).

Sample selection for the abstract set

We examined proposals for 280 of the 296 Ecosystem Science Program awards referenced in Nadkarni and Stasch (2013). Data from 16 archived awards were not examined because they were not readily available. For all other awards, we compared the presence and number of BIAs in abstracts with that in proposals. Detailed methods are provided in Watts and colleagues (2013) and Nadkarni and Stasch (2013).

Sample selection for the CoV set

We examined a sample of 316 proposals, representing a random sample of submissions and awards from 2000–2010 for all four DEB programs (or their equivalent precursors): the Population and Community Ecology Program, the Evolutionary Processes Program, the Ecosystem Science Program, and the Systematics and Biodiversity Science Program. These proposals and their associated documents

Box 1. Categories of broader impact activities.

For each category we list the NSF's examples of representative activities (NSF 2002b) followed by specific criteria we applied to some activities.

Teaching: Advancing discovery and understanding while promoting teaching, training, and learning.

Examples. Mentoring high school, undergraduate or graduate students, graduate and postdoctoral teaching activities, developing educational materials, or partnering with K–16 educators.

For undergraduate teaching, individuals did not need to be identified, but we required a student training statement.

Dissemination: Broad dissemination of research to enhance scientific and technological understanding

Examples. Developing open access databases, engaging the public or industry in research or educational activities, presenting results to policymakers and broad audiences.

Dissemination required significant efforts beyond standard journal publications and providing supplementary materials.

Infrastructure: Enhancing the infrastructure for research and education

Examples. Establishing international collaborations, developing or expanding research/educational software or facilities

We sought evidence of mutually beneficial and enduring collaborative relationships in support of infrastructure. Therefore, we generally did not consider the following to constitute collaborations: co-PIs on the same proposal, individuals or institutions included in the proposal's budget, or those accessed solely for equipment, supplies or services.

Society: Creating benefits to society

Examples. Activities that increase scientific literacy of the general public in the proposed research area, integration of research results in the policy and practice of federal, state or local agencies.

Society is the least definitive category of BIAs. We required a convincing link between discovery and societal benefit through civic engagement (e.g., outreach at museums or nature centers, training of agency staff).

Underrepresented: Broadening participation of underrepresented groups

Examples. Mentorship of members of underrepresented groups ethnic minorities from high school through early-career scientists, developing partnerships with institutions that serve underrepresented or underserved groups, community colleges, non-PhD granting and minority serving institutions.

For the Division of Environmental Biology we included the following *Underrepresented*: Alaska Natives, Native Americans, African Americans, Hispanics, Native Hawaiians and other Pacific Islanders, persons with disabilities, women (but see below).

For recruitment activities we required a plan to target members of underrepresented groups.

We did not include noncitizens as members of underrepresented groups, although engaging noncitizen researchers or students may have counted in other categories, e.g., *Infrastructure*.

Because women are not especially underrepresented at the undergraduate level in DEB-funded research, we did not include activities solely targeting female undergraduate research assistants; however, activities at the institutional level (e.g., partnering with women's colleges) and supporting female early-career scientists did qualify.

Note: As a general rule, we required explicit description of activities or target individuals or institutions that would satisfy each category of BIA. When individual activities satisfied more than one BIA category, they were recorded as such.

(proposals, panel review summaries, and project reports) were drawn from CoV reviews in 2003, 2006, 2009, and 2012. Committees of Visitors meet once every 3 years to review the program portfolios of NSF divisions. Committee of Visitors reviews provide the NSF with external expert judgments in two areas: (1) assessments of the quality and integrity of program operations and program-level technical and managerial matters pertaining to proposal decisions and (2) comments on how the results generated by awardees have contributed to the attainment of the NSF's mission and strategic outcome goals.

The proposals were selected proportionally according to the funding rates for each program, on the basis of a stratified random sampling of 40–50 proposals per year. This set of proposals was then randomly subsampled to obtain 40 declined and 40 awarded proposals per program across the decade. Where low funding rates limited the sample size of awards in the CoV set to less than 40 in a program, additional awards were randomly drawn from across the decade to reach 40 awards. Where records were unavailable because of the expiration or conflicts of interest, we made matched replacements (year, program,

Table 2. Sample size of awarded and declined proposals for each program and year.

Abstract set		Committee of Visitors set											
	Ecosystem Science		DEB-wide		Population and Community Ecology		Evolutionary Processes		Ecosystem Science		Systematic and Biodiversity Science	
Year	Awarded	Year	Declined	Awarded	Declined	Awarded	Declined	Awarded	Declined	Awd	Declined	Awarded
2000	26	2000	6	8	3	4	3	3	0	1	0	0
2001	16	2001	5	12	3	4	2	7	0	1	0	0
2002	16	2002	8	11	4	2	4	7	0	1	0	1
2003	19	2003	21	13	3	2	5	4	10	2	3	5
2004	24	2004	14	17	3	6	4	4	3	5	4	2
2005	22	2005	16	13	3	3	4	3	4	4	5	3
2006	28	2006	21	14	4	3	4	2	6	5	7	4
2007	31	2007	16	28	3	4	3	5	4	6	6	13
2008	30	2008	16	12	5	4	3	0	4	5	4	3
2009	43	2009	21	14	3	2	6	2	6	7	6	3
2010	25	2010	14	16	4	5	2	2	3	3	5	6
Total	280	Total	158	158	38	39	40	39	40	40	40	40

outcome). Because of particularly limited availability of the documents from the years 2000–2001, we were unable to reach our target of 40 awards and 40 rejections in two DEB programs: the Population and Community Ecology Program and the Evolutionary Processes Program (see table 2).

Analysis of the review process

We assessed the presence or absence of BIAs in all proposals, whether those were awarded or declined. We also assessed the presence or absence of BIAs in the written review of one randomly selected reviewer for each proposal. The review panel summaries were occasionally unavailable or unrecorded; in these cases, we assessed the program's review analysis (a record of decisionmaking written by the managing DEB program officer).

Analysis of the reporting process

For awarded proposals, we assessed the presence or absence of BIAs in the most recent annual or in the final project report. To evaluate BIA outcomes, we also assessed how closely the proposed BIAs aligned with the activities detailed in the project reports. This comparison of proposals and reports yielded three overall classifications for this BIA alignment (see supplemental figure S1 for a flowchart of the NSF funding process and the protocol for assessing the CoV set): The first class was labeled *proposed and reported* and included those in which the PI both proposed and reported a qualifying BIA. In the second class, *not proposed but reported*, no BIA was proposed, but one was reported. In class 3, *proposed but not reported*, the BIA was proposed, but no outcome was reported.

The class 1 BIAs (*proposed and reported*) were further classified as *more extensive*, in which the reported activity exceeded what was proposed in programmatic scope or the number of participants; *equivalent*, in which the reported activity matched the proposed scope of activity; and *less extensive*, in which the reported activity fell short of proposed scope of activity.

The class 2 BIAs (*not proposed but reported*) were, in effect, more extensive, whereas, the class 3 BIAs (*proposed but not reported*) were, in effect, less extensive.

Potential biases

Although we adopted a system for identifying BIAs that had already been vetted (Nadkarni and Stasch 2013), its potential biases are important to bear in mind, especially for the *underrepresented* group, because its results differed substantially from those of other BIAs. Because the *underrepresented* category is inherently more explicitly defined than, for example, the *society* category, it may have been more likely for a given proposal or report to fail to meet the *underrepresented* criteria (see box 1).

There are two dimensions to consider here: the criteria, themselves, and the application of the criteria. With respect to the criteria, the definition of *underrepresented groups* has already been painstakingly established, and we thought it important to remain consistent with NSF and DEB practices. We considered the following as *underrepresented* or *underserved*: ethnic minorities (including Alaska Natives, Native Americans, African Americans, Hispanics, Native Hawaiians, and other Pacific Islanders), people with disabilities, women above the undergraduate level, and institutions serving these populations. We necessarily excluded from our tally activities that did not target these groups; for example, in a few instances, PIs presented activities targeting noncitizens of the United States as *underrepresented*. Nonetheless, the *underrepresented* category targets a large proportion of

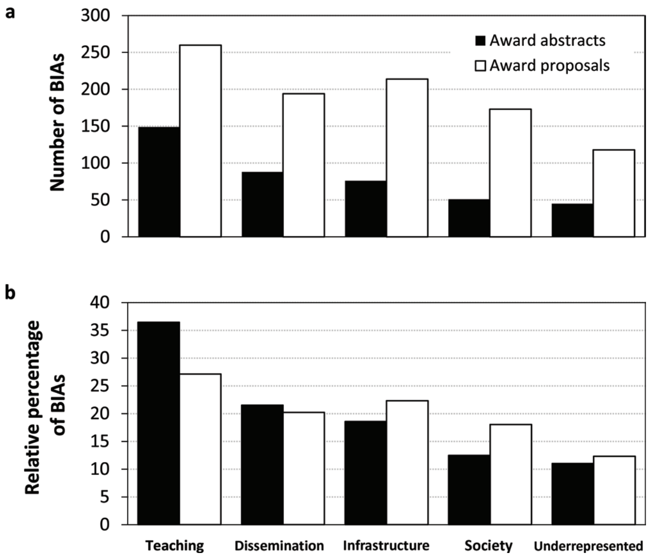


Figure 1. Abstract set: (a) Total number and (b) relative percentage of all broader impact activities (BIAs) by category in award abstracts and corresponding proposals. (See box 1 for category descriptions).

US citizens, so it is unlikely that a proposed activity would fail to meet the criteria simply because of the constraints of the criteria. With respect to application of the criteria, if PIs proposed to address the *underrepresented* category, they almost always stated their intentions and, in assessing the reports, it was relatively straightforward for us to determine whether those intentions had been met. Therefore, we do not believe that potential biases in applying the criteria resulted in *underrepresented* activities being over- or under-recorded in our tallies.

Results

In reporting our results, the individual proposal, panel summary, or report counts include only the presence or absence of each category of BIA, regardless of the number of qualifying BIAs in each category. The total number of BIAs is a tally of all qualifying BIA categories across the population of proposals. The relative percentage of BIAs provides the percentage of BIAs in one category relative to the total number of qualifying BIA categories.

For example, if every proposal in the abstract set ($n = 280$) had at least one qualifying BIA in each of the five categories, the total number of BIAs would equal 1400. By extension, the relative percentage of BIAs for each category would be 20%, if every proposal included a qualifying BIA in each category.

Publicly available abstracts versus proposals (abstract set)

Full proposals were much more likely to include BIAs than were public abstracts. As was previously reported (Watts et al. 2013), we found that 96.4% of the proposals included at least one BIA, but only 66.4% of the abstracts did. Although the NSF never required proposals to include all five categories of BIAs, the full proposals were more likely than their abstracts to include several activities: Only 1.1% of the abstracts included all five categories of activities, whereas 23.6% of the proposals did so. Notably, 78.9% of the proposals contained a section on broader impacts, but 26.2% of these did not include any broader impacts in the abstract.

With further analysis of the abstract set, we found that, across all five categories, the total number of BIAs in the proposals was, on average, 2.56 (standard deviation = 0.56) times greater than in the abstracts. However, the relative percentage of each of these BIA categories was strikingly similar between the abstracts and the proposals (figure 1). Importantly, in both the abstracts and the full proposals, the *underrepresented* category contained the fewest BIAs; the relative percentage of *underrepresented* BIAs was 12.3% and 11% for the proposals and the abstracts, respectively.

The review process (CoV set)

Altogether, the awarded proposals had 10.1% more BIAs than the declined proposals (534 versus 485; figure 2). The awards had more BIAs than declines in all categories except *society*, in which the awards had 16.7% fewer BIAs.

Across all of the categories, the proposals included more BIAs than were presented in the panel summaries (figure 2). There was little difference between the number of BIAs noted in the panel summaries of the awarded and those in the declined proposals, except in the *dissemination* category, in which the panel summaries recorded 12.5% more activities in the awards than in the rejections, and in the *society* category, in which the panel summaries recorded 26.8% fewer activities in the awards than in the declined proposals.

The reporting process (CoV set)

Altogether, the PIs proposed 5.5% more BIAs than they reported (534 versus 506; figure 3). This net difference was driven by the *underrepresented* BIAs: The PIs proposed 110% more *underrepresented* BIAs than they reported (82 versus 39), whereas 6.25% and 11.9% more BIAs were reported than proposed in the *infrastructure* and *dissemination* categories, respectively.

A considerable number of activities were reported but not proposed in the *infrastructure*, *dissemination*, and *society* categories (figure 4). In the *underrepresented* category, however, more BIAs were proposed but not reported (47) than all other classes of *underrepresented* BIAs combined (39 *less extensive*, *equivalent*, *more extensive*, or *reported but not proposed*).

Discussion

Taken together, our results suggest that, within DEB, (a)publically available abstracts do not adequately reflect the efforts of PIs to comply with the BIC from 2000–2010, (b) past reviewers and PIs have tended not to comment on all of the BIC components included in proposals, and

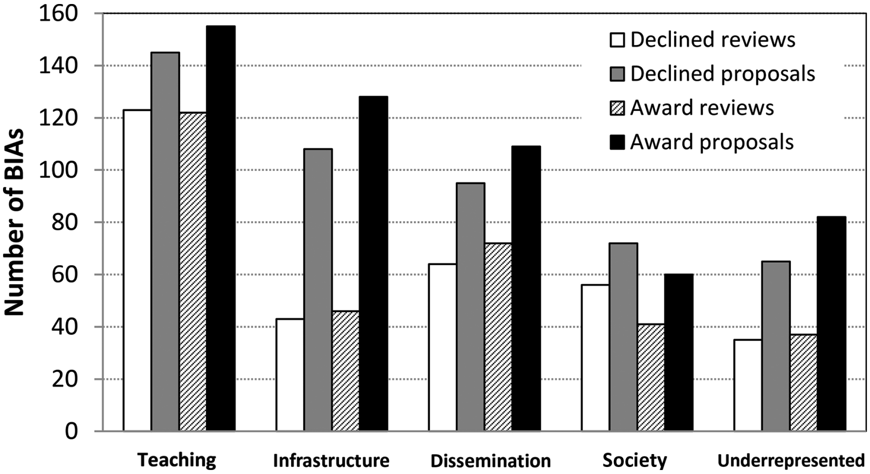


Figure 2. Committee of Visitors set: The total number of broader impact activities (BIAs) in declined versus awarded proposals and corresponding review summaries.

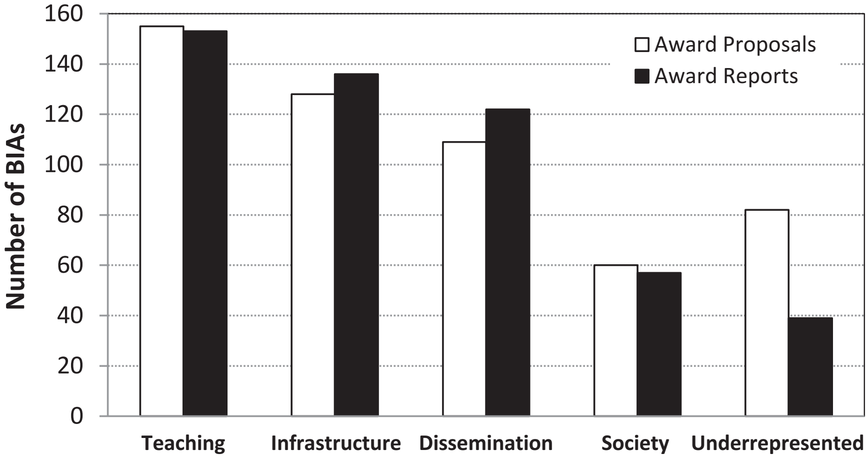


Figure 3. Committee of Visitors set: The total number of broader impact activities (BIAs) in awarded proposals versus corresponding project reports.

(c) project reports have not provided sufficient detail to measure PI performance under the BIC; this was particularly the case with *underrepresented* category, the least frequently mentioned BIC activity in all of the document types that we examined.

Publicly available abstracts versus proposals. The public has access only to abstracts, so, regardless of the BIAs proposed or achieved by the PIs, the public at large might easily conclude that the BIC is not being implemented (Watts et al. 2013). Although the NSF has the final say on what information appears in the abstracts, the PIs, themselves, generally appear to self-censor their BIAs when they draft them, which reinforces the perception that researchers do not ascribe as much importance to broader impacts as to intellectual merit.

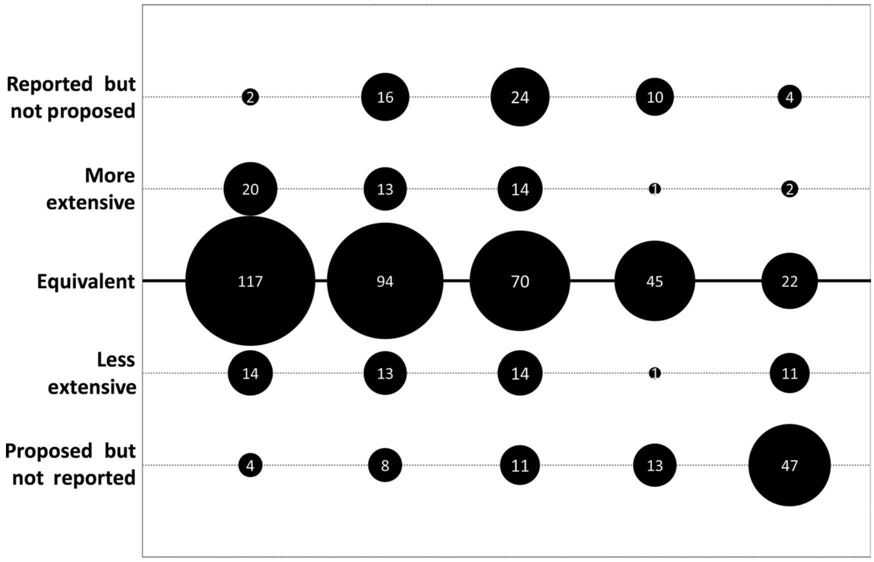
It is also clear from both data sets that because the BIC has not favored one type of BIA over any other, the majority of BIAs tend to be existing components of the research enterprise—teaching, in particular. Consequently, the most challenging BIA, the *underrepresented* category, is the least commonly addressed.

The review process. Although we do not suggest that broader impacts should be weighed more heavily than intellectual merit, the relative lack of BIAs in panel summaries suggests that they may have limited influence on panelist recommendations. That being said, it speaks well of the review process that, in most categories, we found more BIAs in the awards than in the declined proposals. It is notable that the BIAs for the *society* category were less common in the awards than in the rejections, which perhaps reflects reviewer discretion on the ambiguity or perceived importance of this BIA category.

The reporting process. The reported BIAs generally matched or exceeded the number of BIAs proposed in all but the *underrepresented* category. In fact, the PIs proposed more than twice the number of *underrepresented* BIAs than they subsequently reported. Our interpretation of these data is based on the assumption that if a PI did not report BIAs that were promised in the proposal, these activities were not done (or were not done well). If this assumption is correct, our results provide further evidence that the *underrepresented* category, in particular, is more fundamentally challenging than were the *teaching*, *infrastructure*, and *dissemination* categories.

The challenge of broadening participation of underrepresented groups

Much of the disparity that we observed between the proposed and reported BIAs in the *underrepresented* category is likely the result of well-intentioned but inadequate planning (George et al. 2001, Teitelbaum 2001). PIs may plan to recruit members of underrepresented groups as field or lab assistants but may use recruitment strategies that fail to resonate with members of those groups. Likewise, cultural norms and financial constraints can create obstacles that PIs may not anticipate (Taylor 2014). For example, independent research and summer field courses are crucial early experiences to train and inspire future researchers; however, they may directly conflict with family obligations and the needs of many students



	Teaching	Infrastructure	Dissemination	Society	Underrepresented
Reported	153	136	122	57	39
Proposed	155	128	109	60	82
Difference	–2	8	13	–3	–43

Figure 4. Committee of Visitors set: The extent of alignment of broader impact activities (BIAs) proposed by awardees with BIAs reported. The bubble size represents number of BIAs in each category that were reported but not proposed, more extensive than proposed, equivalent to proposed, less extensive than proposed, or proposed but not reported. The table below the figure lists the total number of BIAs in each category reported versus the number proposed, and the difference between these.

from underserved groups to dedicate summers to earning money for themselves or their families (Teitelbaum 2001, White et al. 2006).

Beyond the challenges of recruitment, the retention of members of underrepresented groups in the research workforce is also limited by inadequate infrastructure to support and promote their participation. Recent studies stress the importance of outreach in grades K–12 and mentoring in the first years of undergraduate education (NAS 2011, PCAST 2012). Many members of ethnic minorities are first-generation college students and lack mentorship or a peer support network that might otherwise keep them in the basic sciences. A 2005 survey showed that half of the freshman majoring in physical or biological sciences left these fields by their senior year (CoST 2010). Many women and members of other underrepresented groups see research careers as insufficiently linked to societal benefit (Kamenetzky 2012). Students from underserved backgrounds may also face a nearly insurmountable incentive to pursue seemingly greater financial rewards in other fields over unclear rewards of basic research careers (Teitelbaum 2001, White et al. 2006, NAS 2011). This is exacerbated by a research culture that tends to emphasize the passion and sacrifice necessary to pursue basic research science without also presenting the range of careers that are available to PhD scientists (CoST 2010, Fiske 2013). Retaining women is a particular challenge: Although, in 2006, women constituted a majority of biology students at the undergraduate level and approximately half of doctorates, less than 25% of tenured faculty and only 34% of tenure-track faculty were women (Hill et al. 2010). The causes of this attrition are numerous and persistent, including gender differences in hiring and job satisfaction, work–life balance, and unsupportive work environments (Sakai and Lane 1996, Hill et al. 2010). Basic recruitment and retention challenges are common across the spectrum of underrepresented groups. However, variations in the challenges each group experiences require coordinated and context-specific efforts to overcome (Taylor 2014).

Achieving broader impacts: 2013 Proposal Guide revisions

The 2013 Proposal Guide (NSF 2012) makes it clear that the NSB recognizes the need for improvements to the BIC's infrastructure and process, particularly for ill-defined or challenging goals like the *society* and *underrepresented* categories. Our results emphasize the importance of the following factors, which were recommended by the NSB and incorporated in the 2013 revisions of the Proposal Guide:

Proposals and panel review. The Proposal Guide revisions move PIs and reviewers away from a checklist approach in which the PIs often attempted to propose as many BIAs as possible—in some cases, regardless of their applicability or the PI's ability to implement them. By requiring that broader impacts to be assessed for their novelty, impact, and feasibility, the 2013 Proposal Guide should improve BIA outcomes and remove the incentive for PIs to see the BIC as a checklist (NSB 2011).

Project reports and regular assessment. The 2013 Proposal Guide explicitly requires PIs to report on results of their proposed BIAs. It is likely that many of the missing BIAs in abstracts and reports are false negatives, at least in part because of a lack of clarity among researchers about the importance that the NSF places on the BIC. Requiring more detail on BIAs in reports may promote more frequent and thorough assessments, which might, in turn, help the NSF promote the most effective broader impacts and increase societal awareness of the benefits of science.

Facilitation and institutional support. The NSB recommends PI training programs and the 2013 Proposal Guide promotes institution-level BIA links to facilitate the BIC; in particular, those associated with the *underrepresented* category. Our examination of proposals and reports uncovered huge variation in the novelty, enthusiasm, and a level of detail with which PIs discussed BIAs. Some scientists are simply more passionate about broader impacts than others. Likewise, some institutions provide more opportunities for engaging students from underrepresented groups than others. The new approach of assessing the BIC in the aggregate and links among NSF awardees may lower the threshold of participation for PIs less passionate about civic engagement while simultaneously expanding the reach of model BIAs (Alpert 2009, Burggren 2009). This new flexibility will, however, require panels to carefully weigh the relative merits of funding novel versus proven BIAs.

Fundamental science versus broader impacts?

As was discussed in the introduction, the NSF is challenged by its need to manage the motivations of its research communities while also assuring societal benefits that the Executive and Legislative Branches mandate. There is a legitimate debate to be had over the NSF's proper role in engaging society, but the fact remains that workforce development, enhanced infrastructure, public–private partnerships, international engagement, and increased awareness of the indispensability of science for society are critical to the long-term viability of the scientific enterprise. In addition to workforce arguments for investing in STEM education and outreach, US citizens will require a basic science literacy to make informed decisions about the increasingly complex environmental, social, and infrastructure challenges we face. There are many positive externalities of the BIC for all science, and it is clear that the BIC will remain in some form. Most scientists would agree that managing it internally is preferable to having it imposed from outside the agency (Frodeman et al. 2013).

Ways forward

There are many auspicious signs of a generational shift in scientists' perceptions of their role in society: blogging and tweeting scientists, the proliferation of crowdsourcing and crowd-funded research, and public–private partnerships for science literacy and public engagement (Nadkarni 2004, PCAST 2012, Wheat et al. 2013). Although academic researchers often pursue these broader impacts with little incentive, the NSF has a long history of innovative programs to support STEM education and outreach. Examples include Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics program (formerly the Course Curriculum and Laboratory Improvement Program); the Science, Engineering, and Education for Sustainability program; the Advanced Technological Education program; Discovery Research K–12; Graduate Teaching Fellows in K–12 Education; the Math and Science Partnership; Research Experiences for Undergraduates; Research Experiences for Teachers; the Robert Noyce Teacher Scholarship Program and the Louis Stokes Alliances for Minority Participation programs (e.g., the Bridge to Baccalaureate and to Doctorate Programs), and recent commitments to create a broader impacts infrastructure network.

BIC implementation will be much improved by continuing to develop these programs and improving links among the growing ranks of socially engaged researchers in public and private sector organizations and academic institutions. In fact, in 2008, the NSF produced a broadening participation framework for action in which it made recommendations similar to those of the 2011 NSB Task Force (NSF 2008). This comprehensive framework surely helped to increase BIC compliance since its release, and the 2013 Proposal Guide codifies these practices: clarity in review, reporting requirements to assess broader impact outcomes, efforts to train the PI community in these new requirements, and greater efforts to make the public aware of these outcomes.

The 2013 revisions to the Proposal Guide also present an opportunity to influence incentive structures for rank and tenure and to raise the profile of work on the thorniest broader impact challenges, such as broadening participation. The NSF actively supports interdisciplinary engagement with multiple academic stakeholders through programs like the Partnership for Undergraduate Life Science Education (PULSE; *www.aibs.org/education/pulseproject.html*); jointly funded by the Directorate for Biological Sciences and the Directorate for Education and Human Resources (EHR). PULSE's direct engagement of university administrations will hopefully increase the coordinating role of dedicated offices of diversity and inclusion, equal opportunity, and community engagement in the execution of BIAs. By linking EHR activities to those in other directorates, programs like PULSE can help create discipline-specific broader impact opportunities (e.g., women might be less represented in some directorates than others).

There is quite a lot of variation within the NSF in broader impact efforts. The Directorate for Geosciences recognized a striking lack of awareness among the general public about geology careers and developed Opportunities for Enhancing Diversity in the Geosciences in 2001. This program is rare at the NSF in that it funded efforts to broaden participation and to increase the perceived relevance of the geosciences separately from research activities.

Ultimately, research communities, themselves, may be the best source of ideas for achieving broader impacts. Excellent programs and PI efforts already exist in NSF's portfolio; press releases, workshops and speakers series at professional meetings can promote broader impacts and showcase best practices.

Conclusions

By examining both the mechanics of the BIC and the policy setting within which it has been implemented, we hope to contribute to the NSB's efforts to clarify the broader impacts concept and improve its effectiveness. Increasing the proportion of BIAs in the *underrepresented* category, in particular, will require renewed attention and extraordinary effort at the NSF and in the research community.

Greater internal communication among NSF directorates and divisions would help disseminate innovations for enabling broader impacts, as well as lessons learned from past practices. Keeping the research community abreast of policy changes that influence science funding will improve transparency of NSF processes that relate to broader impacts. Finally, enhanced NSF coordination with institutions may strengthen the integration of broader impacts with research endeavors, while relieving some of the burden on individual PIs.

It is much too early to judge the impact of the 2013 BIC revision, but if its requirements are well-implemented, they will bring much needed recognition to a generation of scientists who have toiled to engage society despite limited incentive from their peers, sponsoring institutions, or the review process. This will not only benefit society but will also support the NSF's mission to promote the progress of science.

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Supplemental material

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Sean M. Watts is the director of the Doris Duke Conservation Scholars Program at the University of Washington, in Seattle. He is a conservation ecologist working at the science–policy–public interface. Melissa D. George is a science, technology, engineering, and mathematics education specialist with the Lafayette School Corporation, in Lafayette, Indiana. She studies student cognition in situated learning environments. Doug J. Levey (dlevey@nsf.gov) is a program officer at the Division of Environmental Biology, at the National Science Foundation, in Washington, DC. He is an ecologist, who studies plant–animal interactions and landscape ecology.