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Implementation of the National Science Foundation's "Broader Impacts": Efficiency Considerations and Alternative Approaches

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The National Science Foundation (NSF) has, since 1997, attempted to diversify and enrich science research and education in the USA through the Broader Impacts Criterion (BIC), also known as "Criterion Two" or the "Second Criterion". In doing so, NSF has so successfully integrated BIC into its discovery grant funding programmes that it has become difficult to assess the efficiency (in an economic sense) of BIC activities, as opposed to cataloguing its products (number of trainees, publications, etc.). Moreover, current practice at NSF requires that each and every Principal Investigator receiving a discovery grant address both Science, Technology, Engineering and Math activities and broader impacts, despite the fact that their formal training is most likely to be in only one of these areas. Against this backdrop, I consider NSF spending on broader impacts, conduct a microeconomic analysis of effectiveness of BIC expenditures, and discuss alternative funding models and Principal Investigator profiles and expertise sets that might not only accelerate the goals of expanding NSF's broader impact, but additionally enhance the quality of science funded by this agency.

Keywords: National Science Foundation; Broader Impacts; Academic Specialization; Criterion Two; Discovery Grants

Introduction

The National Science Foundation's (NSF) "Broader Impacts Criterion" (BIC), sometimes called "Criterion Two" or the "Second Criterion", has been in force since 1997.

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In that time, it has generated a culture change both within NSF and, more importantly, among the scientists it supports. NSF can proudly point to a variety of impacts of BIC, including increased diversity of NSF-funded scientists and support for projects that have more relevance in industry, business, communities, and so forth. NSF's paradigm shift has, in fact, paralleled calls from the science policy community to move beyond Vannevar Bush's (1945) dichotomy between basic and applied research (Holbrook 2005). In short, NSF—at least from the perspective of many of the "consumers" of its products—has transformed itself through implementation of BIC, and in so doing has the goal of transforming US Science, Technology, Engineering and Math (STEM).

While BIC has been an integral part of both NSF policy and funding practices, it is difficult to assess the degree of resulting success, the opportunity costs of this approach, and whether alternative or next-generation approaches might be considered as BIC implementation matures. One of the mainstays of BIC implementation is that each and every scientist is expected to contribute to the goals embedded in this policy. As NSF Director Arden Bement commented at the October 2007 meeting of the NSF Biology Directorate, NSF "… won't be doing science for science's sake", and "Every NSF-funded scientist will be expected to contribute to the broader impacts mission of the Foundation". Indeed, while this egalitarian approach to BIC implementation effectively signals NSF's intentions, it begs the question "Is this the most effective way to achieve NSF's overall goals?" In response to this question, the present essay develops the following hypothesis: NSF's pursuit of broader impacts could be made both more effective —with a greater overall impact—and more efficient—at a lower cost—through a more flexible approach that accounts for specialization in human talents. This essay provides a rationale for this hypothesis, and then suggests some simple "thought experiments" that could shape future experimental approaches to its testing.

Broader Impacts: A Brief, Interpretive History

Before considering how best to enhance the broader impacts of NSF-funded science, let us first briefly review the history of BIC (but see also more complete accounts; for example, Holbrook 2005; and additional papers in this issue) and attempt to analyse NSF expenditures on this criterion.

In 1997 NSF introduced new, more comprehensive proposal preparation and evaluation guidelines for so-called "discovery grants". Foremost among the modifications was the division of both proposals and their reviews into two key criteria. The first criterion—the intellectual merit of the proposal—was familiar and indeed even comfortable to experienced Principal Investigators (PIs) as well as beginning scientists. In essence, a proposal writer was expected to convince the readers of their proposal as to why they were advocating a robust science project. That is, science was recognized as having intrinsic value and, if it was good enough science to be funded, then *de facto* it was good for society and the nation. However, under the leadership of then-NSF Director Neal Lane, in 1997 a second criterion was introduced that asked PIs to explain the "broader impacts" of their research. Indeed, this Second Criterion[1] has also become known as the "Broader Impacts Criterion" (BIC). BIC comprised at its introduction, and continues to comprise, a broad category of impacts designed to move beyond science for science's sake to produce science and engineering projects more pragmatically relevant to an increasingly complex world, while increasing the diversity of scientists (in terms of geography, gender, socio-economic groups and ethnicity) so that the face of US science reflects US society.

In the early years following the implementation of BIC, there were varying degrees of confusion, ambivalence, ignorance and even disdain among both PIs and reviewers struggling to react to the new emphasis of broader impacts (Holbrook 2005). Some PIs continued to focus exclusively on promoting a great science story, assuming that all science deserving of funding almost by definition had broader impacts in society. Training graduate students and involving undergraduates in research were routinely reported in progress reports and worked into new budgets, but neither were particularly emphasized nor necessarily explained. On the proposal evaluation side, some *ad hoc* reviewers and panel members alike either did not register the importance of the second criterion, or ignored it, often with little consequence.

During the early 2000s, however, the academic scientific community began to realize that BIC was ignored only at peril to the success of their proposals. Panellists at NSF began to reduce the ratings of both seasoned senior PIs and new applicants alike who failed to recognize the extent of the culture change at NSF, even as other PIs received higher panel ratings because they embraced the need for broader impacts of their research (or, cynically, embraced the need for emphasizing BIC if their proposals were to be successful).[2] Now, after a decade of promotion of BIC, the need for emphasizing broader societal impact in investigations funded by NSF is reflected in the increasing complexity and sophistication of proposed BIC activities (i.e. many PIs now go well beyond just pointing out that "students will be trained"), as well as the extent to which they are interwoven into the basic science fabric of funded discovery grant proposals.[3] Yet NSF has long been compelled to explain BIC to its constituents (for example, Holbrook 2005; Kafafi 2008; NSF 1996).

Given the integral nature of BIC in NSF funding, it seems of interest to ask a series of questions: "What is now being achieved that would not otherwise have occurred", "How much is NSF spending on Broader Impacts" and, from a venture capitalist viewpoint, "What is the return on additional investment in Broader Impacts?" Unfortunately, these questions are not easily answered. My goal is not to approach these questions as an auditor or oversight agency might, but rather simply to ask these questions in the hopes of either affirming current NSF practices or identifying pathways for even further advances. First, let us consider NSF's investment in research and science education.

Assessing NSF Spending on Broader Impacts in Discovery Grants

Can NSF BIC Expenditures be Identified?

NSF budget is divided into numerous categories comprising both discretionary and non-discretionary (mandated) expenditures (Table 1). In fiscal year 2007, NSF spent

Table 1 National Science Foundation Budget, in Key Categories, for Fiscal Years 2006 and 2007

Expenditure category	Fiscal year 2006 (US$ million)	Fiscal year 2007 (US$ million)
Research and Related Activities	4331	4666
Education and Human Resources	797	797
Major Research Equipment and Facilities Construction	191	191
Salaries and Expenses	247	247
National Science Board	4	4
Office of Inspector General	11	11
Total	5581	5916

Source: American Association for the Advancement of Science. 2007. *NSF R&D in fiscal year 2007 congressional appropriations*. 1 February.

approximately $4.7 billion dollars on Research and Related Activities (essentially, "discovery grants") and $0.8 billion on Education and Human Resources. Many of the laudable NSF efforts designed to expand the role of women and minorities are funded through dedicated programmes in the Education and Human Resources category, which comprises approximately 13–14% of NSF budget. However, these same key goals are also promoted through emphasis on the broader impacts criteria of discovery grants in the Research and Related Activities category (~78% of the total NSF budget).

Based on the broad budget categories evident in Table 1, there is no simple answer to the question posed earlier of "How much is NSF spending on Broader Impacts?" simply because it is not a line item in NSF's budget. Moreover, when asked this question by the author, a senior NSF staff member responded:

> There are no numbers breaking out budget investments between intellectual merit and broader impacts. Those categories do not really map strictly to budget categories maintained as records at NSF so there is not a good was to estimate budgetary investments associated with either of the two criteria.

This staff member then further volunteered:

> … As I think about this some more, we are encouraging the integration of education and research (a central mission of the NSF) so I suspect it would be difficult to make the case conceptually that one or another activity strictly is associated with either one or the other of the two review criteria.

In other words, NSF has apparently been so successful at inculcating and integrating BIC into its original discovery grant programme that it no longer can identify the specific expenditures involved in the promotion of broader impacts through funded discovery grant research programmes, and nor can cause and effect readily be determined with respect to changes in NSF goals centred on BIC. While this complete integration of STEM activities with BIC activities is NSF's goal, this approach nonetheless obfuscates an analysis of the relative contributions, funding levels and effectiveness of these two components in a discover grant.

This view from the Foundation would apparently be borne out by thoughts from NSF-funded scientists themselves. The author informally surveyed[4] a subset of 17 scientists, engineers and social scientists who received NSF funding in 2007 through the University of North Texas (Denton, TX, USA). When asked the simple question "What percent of your current NSF budget is devoted to funding the Broader Impacts Criterion (that is, the second criterion)?", most investigators informally surveyed provided some variation on the theme of "It's hard to say because I didn't separately budget these categories, but I would guess about (number) percent". Interestingly, the nature of the responses suggested considerable confusion about BIC *even among scientists successful at acquiring NSF funding*. For example, some PIs indicated that expenditures on student and postdoctoral stipends (and associated fringe benefits) comprised the vast majority of their grant expenditures, and so reported their BIC expenditures in the 40–80% range (Figure 1). Other faculty, however, who clearly supported numerous graduate students and postdocorate students on their grants, nonetheless reported numbers in the range of 3–10% or even 0%! With a huge range, then, of 0% to 80%, NSF-supported researchers at University of North Texas who responded reported that on average they spent 25% of the budget of their discovery grant on BIC components (as self-defined and self-analysed). Doubtlessly, there are true differences in expenditures by PIs on BIC and the average of 25% represents a simple mathematical average of non-normally distributed data. However, the high statistical variation in the responses along with anecdotal comments supplied to the author suggests confusion among PIs as to the nature of BIC, even though at some level they must have successfully promoted this criterion for them to be funded! Further study of the understanding of broader impacts even among successful NSF grantees would indeed be very interesting.

Returning to the topic of how much NSF actually expends on BIC through discovery grants, let us assume, based upon the admittedly imperfect survey data presented in Figure 1, that 25% of the budgets of discovery grants funded by NSF are expended on BIC. By extrapolation (albeit extreme), this would suggest that in fiscal year 2007 NSF invested approximately \$1.07 billion on broader impacts activities through its funded Discovery Grants. Assuming furthermore that all of the Education and Human Resources budget could be attributed to promoting the broader impacts agenda (although they certainly fund pedagogical research), this then leads to approximately \$1.15 billion investment in broader impacts activities.

Now, with a crude approximation of BIC expenditures in hand, let us consider the question "What is the return on investment for NSF BIC expenditures?"

Assessment of NSF BIC Activities: Outcomes Assessment or Economic Efficiency?

NSF's mission includes being broadly inclusive:

> … seeking and accommodating contributions from all sources while reaching out especially to groups that have been underrepresented; serving scientists, engineers, educators, students and the public across the nation; and exploring every opportunity for partnerships, both nationally and internationally. (NSF 2006a, 4)

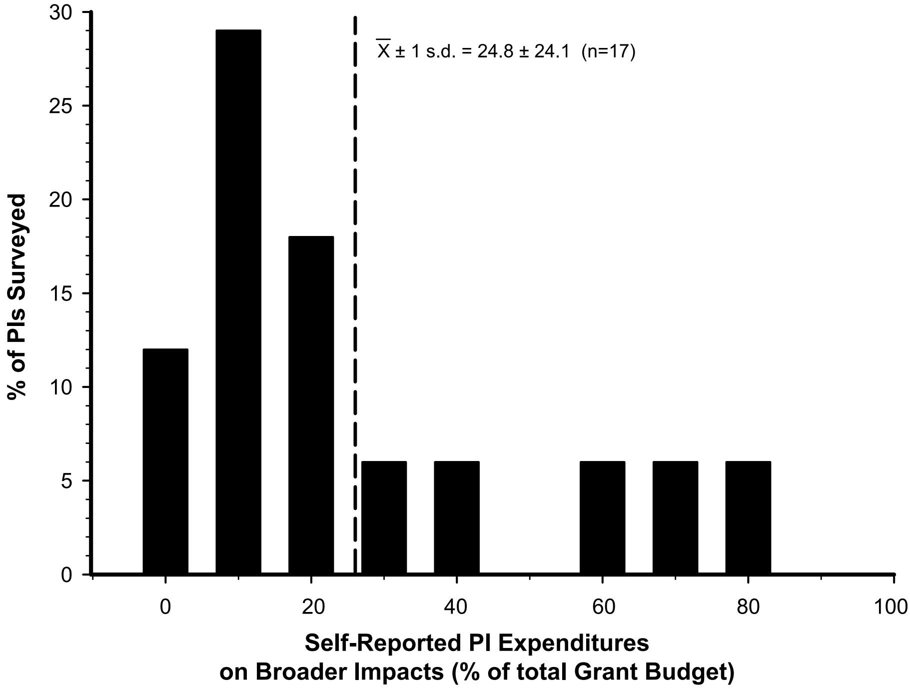

Figure 1 Discovery Grant Expenditures on Broader Impacts Self-Reported by NSF-Funded Principal Investigators.
Note: See text for additional details.

How is success in such a broad quest measured? What are the appropriate assessment tools? NSF has certainly focused a great deal on assessment of its programmes generally, and BIC specifically (NSF 2006b), and it is not my intent to either report upon or second guess these activities. However, in continuing the theme of this essay, let us continue to focus on the more difficult topic of assessing broader impacts achieved specifically through the discovery grant process.

One way to evaluate the broader impacts is to measure the totality of outcomes, defining outcomes as results that closely reflect stated goals. For example, in a statement from the Office of Management and Budget (http://www.whitehouse.gov/omb/rewrite/budget/fy2008/nsf.html), NSF reports that since 2001 it has advanced "… all fields of science, engineering, and mathematics by funding 59,000 grants at the National Science Foundation through a competitive, merit-based process". Similarly, in this same period NSF has "strengthened the foundations of the science and engineering workforce by directly supporting 69,000 graduate students and 28,000 undergraduate students". These achievements speak directly to the crucial role NSF has in promoting the training of a well-prepared (and increasingly diverse) scientific workforce. Yet, reporting these accomplishments as overall achievements in this manner represents an assessment methodology based upon indications of gross productivity, not what might be thought of as net productivity or efficiency. Thus, if NSF trains more students from one year to the next, this is reported as an improvement, irrespective of the efficiency with which it is obtained. Consider the metaphor of vehicle speed and gasoline mileage. A vehicle can be made to go faster by giving it more gasoline. However, drag (wind resistance) increases much more rapidly than velocity, so going ever faster takes increasingly disproportionately more fuel. If the goal is to increase vehicle speed, then moving from 60 to 70 mph can be assessed as a positive outcome. However, the gasoline mileage and therefore the efficiency of the vehicle decreases as speed increases.

Not surprisingly, NSF is struggling with how to assess the efficiency of the outcomes of BIC. What is (understandably) lacking is a control for their experiment. Simply put, what would have happened without an emphasis placed upon broader impacts in discovery grants? We might be able to predict on an anecdotal basis, but a validation of a rigorous cause and effect, as opposed to simple correlation, is currently lacking. Moreover, the calculation of economic efficiency of BIC-targeted funding in discovery grants has lagged well behind its implementation. For example, if two PIs facing renewal of their discovery grants are reporting their past achievements in, say, the arena of outreach programmes to inner-city youth, how do we gauge the relative effectiveness of two programmes that may on the face of it be quite similar? While as NSF grantees and panellists we are not used to assessing scientific programmes in terms of economic efficiency (as opposed to total output), one might nevertheless calculate that for Prof. X's programme it takes $22.40 to offer a full-day enriching experience to a child in a STEM outreach exercise, but it might cost only $13.20 to do so in Prof. Y's programme. The decision to fund Prof. X's discovery grant in the face of demonstrably less efficient outreach activity would then be revealed as a decision based on demographics, geography, diversification, or some other factor than efficiency. Such decisions can be justified, but the availability of efficiency data (in addition to outcome data) makes clearer the associated opportunity costs and tradeoffs for specific funding decisions.

Given the current uncertainty with respect to economic efficiency of human resource-related BIC funding at NSF, is it possible to imagine a paradigm that improves outcomes while achieving an increase in efficiency? One approach involves a focus upon the quality and background of the PIs themselves.

Implementing BIC: The Spectre of the Peter Principle?

The spectre of philosophical issues in the implementation of the broader impacts criterion was raised by Holbrook (2005). However, another spectre looms—that of the Peter Principle. In 1969 Lawrence J. Peter and Raymond Hull wrote the book *The Peter Principle: Why Things Always Go Wrong*, and subsequently gained a near-cult following. Essentially, the Peter Principle espoused that in a hierarchy, every employee tends to rise to his level of incompetence (Peter and Hull 1969). Practically speaking, it suggests that people with a certain set of skills and competencies may move into positions that require a somewhat, or even entirely different, skill set to succeed. Thus, for example, a muffler installer who is an excellent welder may get a job as the shop foreman, where organizational skills are required. A few years later, if that foreman has thrived (sometimes despite little or no training in store management) he may get promoted to the position of store manager, where excellent business and management skills are required. At each level in this example, there exists the potential for a person being good enough to be promoted into the new position, but subsequently neither good enough to be promoted once again but not quite incompetent enough to be demoted or fired. In other words, the Peter Principle predicts that people tend to stagnate in jobs for which they ultimately are marginally qualified or even incompetent.

The Peter Principle is evoked in this essay because of its focus on well-intentioned professionals who carry out tasks for which they are not fully trained, if not ill-suited. Relating the discussion to NSF funding for BIC, consider the following case study that, while hypothetical, is not atypical.

> A life scientist possessing a B.Sc., M.Sc. and Ph.D. has served for 30 years as a university professor, during which time she has authored numerous scholarly books, journal articles, and served as a journal editor-in-chief. During her career, this professor has consistently had NSF discovery grant funding to support her activities. As BIC has become an explicit part of discovery grants, this professor has reasonably concluded that "just" training graduate students and post-docs is not going to create the distinguishing factor that is the trademark of her science described in the intellectual merits of her proposals. Thus, the professor proposes some training activities that involve bringing high school teachers from schools with dense at risk populations into her lab for a series of summer experiences.
>
> The professor's grant goes to panel, where it is evaluated by scientists with very similar backgrounds (though in most instances not as senior or experienced). Based on the combined strength of the intellectual merits she proposes, and what sounds to the panel like a novel aspect addressing BIC, she receives a recommendation for funding of her discovery grant. The NSF Program Director is similarly impressed and makes the formal recommendation for funding the proposal. Ultimately, the professor is funded, with about $40,000 of her $700,000, four year discovery grant devoted to recruiting and training these high school teachers.

The Peter Principle is potentially woven throughout this scenario, which in variations on this theme plays itself out day in and day out at NSF. For example, although the senior scientist is at the cutting edge of her field, she has not paid much attention over the years to educational trends. She is experienced enough to spin a good yarn, but not necessarily knowledgeable enough to know how to approach the problem of truly producing better science and mathematics teachers and how to measure the effectiveness of university-based teacher training. This should be a major flaw in her proposal—except for the fact that the panel evaluators are themselves highly focused on the production and evaluation of scientific merit rather than BIC. The panellists are certainly well-intentioned, but they do not necessarily know either about the best and most efficient way to run such programmes. They provide a superficial evaluation—the best they know how—and rank the proposal as excellent for the Program Director—who has recently been drawn to NSF from among the ranks of the active, well-respected scientists, but has no formal training in broader impacts activities.

The hypothetical proposal described in the above scenario is:

- *created* by a PI with informally acquired skills in the BIC arena;
- *evaluated* by panellists with informally acquired skills in the BIC arena; and

- *recommended* for funding by a Program Director with informally acquired skills in the BIC arena.

The Peter Principle, with its notion that people end up doing things for which they have little training, lies in wait to emerge in this scenario.

With this scenario in mind, let us return to a broader view of who is requesting NSF funding, and who is making funding decisions.

NSF's Dilemma: Is Integration of STEM and BIC a Means or an End?

NSF faces an interesting dilemma. If there is a dollar to be spent, should it be given to a STEM specialist, who almost by definition lacks full competence (or at least experience) in as much as one-half of the stated objectives of NSF funding, or should 50 cents be given separately to a BIC specialist and to a STEM specialist, each of whom is operating completely within their area of training and competence? For the author, to even raise this question could be mistakenly construed as a wish to return to the "good old days" of "pure" science (Bush 1945; Rowland 1983). Far from it! Any NSF-funded scientist, engineer or mathematician should be able to describe the broader significance of their work, or they should not be funded. What is being proposed, instead, is the consideration of ways in which the broader impacts of relevant science can be more efficiently stimulated.[5]

So let us return to the question of whether we spend a dollar on a STEM-trained specialist now functioning as a generalist or 50 cents on each of two specialists. If the goal is to ensure that each and every NSF-funded scientist is involved in both STEM and BIC, the dollar must go to the generalist. As Frodeman and Holbrook (2007) have argued, allowing scientists off the hook for BIC activities could result in the delegation of the broader impacts of science to education and public outreach professionals. This would reinforce the division between STEM and BIC activities, rather than continue to integrate them as desired by NSF. But, is the integration of STEM and BIC activities at the level of the individual PI a means to an end, or an end in itself? Why must each PI participate in both activities? Are there analyses that indicated that full integration of these two functions is most efficient in achieving NSF's goals?

The current *de facto* policy that each PI should excel in both STEM and BIC activities (because only those that excel in both are now likely to be funded) could be construed as a policy designed to change the behaviour of scientists rather than to ultimately achieve concrete goals in science, education diversity, and societal benefit. Lacking quantitative evidence to the contrary, it may be that the most efficient pathway to NSF's overall goals is to separately fund the STEM expert to do great science and the BIC expert to professionally ensure that NSF is indeed promoting broader impacts. This dual approach staves off, or at least minimizes, the impact of the Peter Principle, while ensuring that the true specialists are integrated into an overall broad programme with multiple goals.

As philosophers, Frodeman and Holbrook promote the societal responsibility of scientists: "We philosophers believe that publicly funded scientists have a moral and political obligation to consider the broader effects of their research. To paraphrase Socrates, unexamined research is not worth funding" (2007). While no one would advocate unexamined research with no social benefits, publicly funded investigators also have a fiscal obligation to the taxpayer to constantly determine whether there is a more cost-effective alternative for achieving NSF's goals. What if, for example, separation of BIC and STEM activities is not only more cost-effective, but actually results in better and greater outcomes in both arenas? Resolving this issue is not a trivial question, for the analysis presented above suggests that up to approximately $1.1 billion in the NSF budget for BIC hangs in the balance!

An Alternative Approach to Broader Impacts Implementation

The spectre of well-intended reviewers and panellists lacking formal BIC training evaluating the BIC components of well-intended but inexperienced scientists who propose them begs the question "How can an additional professionalism be inserted into the process of proposing, evaluating and funding?" In the Introduction it was hypothesized that NSF's pursuit of broader impacts for its funded research could have a higher impact and be cost-effective through a more flexible approach that optimizes human talents and energies. What might this entail?

The "Problem" of PIs as generalists

Under the current expectations for PIs at NSF, each and every PI pursuing a Discovery Grant is expected to contribute in substantial ways to both the intellectual merits and the broader impacts. While this approach is changing the relationship between NSF, the scientific community and the nation, this approach also has a potentially large opportunity cost. To develop this notion further, let us specifically consider as an example a subset of broader impacts; namely, the important goal of encouraging women and minorities to consider STEM careers as middle and high school students.

Almost every US academic institution is involved in the attempt to increase the participation of women and minorities in STEM disciplines, often with activities addressing the "pipeline" issue of involving girls and minorities much earlier in the educational process. At medium to large universities, there are likely to be faculty who have been reasonably talented researchers, but who have also thrown themselves into BIC issues, received additional training, and are now standout leaders for budding STEM researchers and who also know exactly how to motivate and excite middle and high school students. Such universities are also likely to contain truly brilliant researchers with consistently innovative and visionary research ideas, but who not only are bewildered by the whole BIC environment but might set back the cause of science and math education by decades if they came anywhere near STEM-bound minority or female students in their formative years!

In this scenario, neither of these PIs would probably be funded because:

- the researcher with potential for significant broader impact proposes science that is good but not outstanding; while
- the brilliant, innovative laboratory researcher does not recognize, ignores or cannot effectively address the broader impacts in STEM activities.

From NSF's perspective, neither PI makes the grade. From a human resource perspective, there has been a system failure—because the system (in this case NSF policy) has failed to match its needs to the available human resources.

As an alternative approach, what if both of the faculty members mentioned above were individually funded to do what they do best, by setting aside the dual STEM and BIC component requirements of their programmes? That is, could NSF flout the Peter Principle by ensuring that NSF-funded investigators do what they know best, and only what they know best? This situation is shown in Figure 2, depicting situations in which NSF might actually achieve higher efficiency in all of its goals by funding both of these specialists (one in science and one in STEM education) instead of funding a scientist or engineer to function as an imperfect generalist. Putting this differently, the current necessity that each and every funded scientist be a dual specialist by satisfactorily addressing both criteria could in fact be reducing—not increasing—NSF's overall achievement in promoting STEM activities in minorities and females.[6]

The Problem of Journals as Specialty Outlets

In his book *The Ignorance Explosion*, Lukasiewicz (1994) argues from an historical perspective that both the specialization of scientific journals and the specialization of scientists have grown dramatically over the past two centuries—a conclusion shared by numerous other authors (for example, Bennion 1994; Hayes 1992; Ziman 2000). Specifically, Lukasiewicz says that "… it is likely that a modern scientist does not read more papers than his predecessors and … becomes inevitably more specialized" (1994, 118). And where are these specialists publishing their research? Analyses have revealed that approximately one-half of all science publications appear in approximately 3–5% of all science journals. This also means that the other one-half of all science publications appear in the vast majority of the nearly 20,000 science journals that represent very high degrees of specialization and very low circulations (for entry to the literature, see Bennion 1994; Lukasiewicz 1994).

This increasing specialization of science journals (and STEM journals, overall) complicates the overall implementation of NSF's merger of STEM research and BIC activities. On the funding side, NSF is pushing hard to fully integrate intellectual merit with the broader impacts (inseparably so, as we have seen from the budgetary analysis). Yet, the product of activities funded by NSF Discovery Grants—publication in peer-reviewed journals—remains highly segregated among a plethora of highly specialized science journals. Indeed, only a tiny fraction of discipline-specific (or sub-sub-sub-discipline-specific) journals publish articles that explicitly mention, let alone integrate, the broader impacts of the research. Consider, for example that a search of the NCBI PubMed database in life sciences, conducted in September 2008, yields only 133 papers

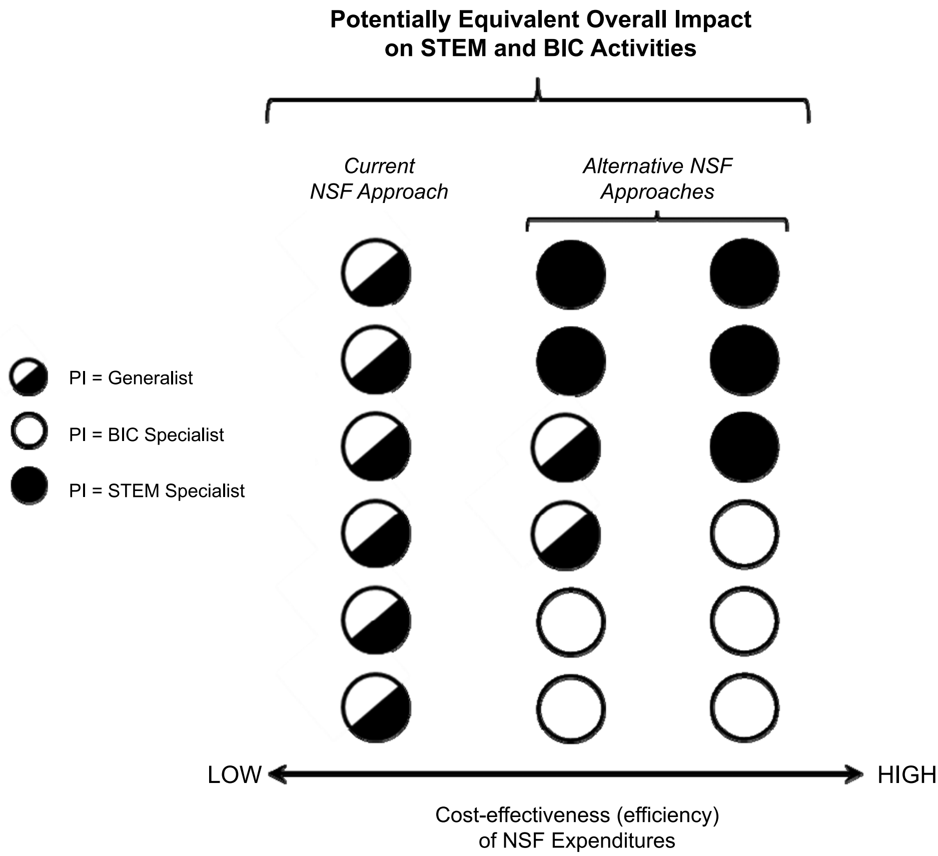

Figure 2 Approaches to Funding STEM and BIC Activities through the Discovery Grant Process.
Note: Currently, NSF funding guidelines require each PI to contribute to both STEM and BIC activities (for simplicity, 50% effort in each arena is symbolized). Alternative approaches would be to spend an equivalent amount of funding strictly on specialists in either STEM or BIC, or to adopt a blended strategy of funding some specialists for either STEM or BIC activities, and continuing to fund some PIs on the basis of a combination of STEM and BIC activities.

and 257 papers containing the words "ethnic diversity" and "outreach", respectively. For comparison, the search terms "blood" and "enzyme"—arguably fairly specialized terms—showed 142,563 papers and 104,126 papers, respectively.[7]

Clearly, the journals that publish specialized literature (as evident from the PubMed life sciences database) are not concurrently publishing BIC information (and presumably *vice versa*). Herein lies the dilemma. NSF is increasingly advocating an integration of both STEM and BIC activities. Yet the integration can only proceed so far if there is a paucity of valid publishing outlets reflecting this combined approach. Is this situation ultimately sustainable? Future discourse on what integration of STEM and BIC activities actually means is warranted, and could, for example, include recommendations to STEM-oriented journals that they encourage, or at least include, coverage of BIC activities.

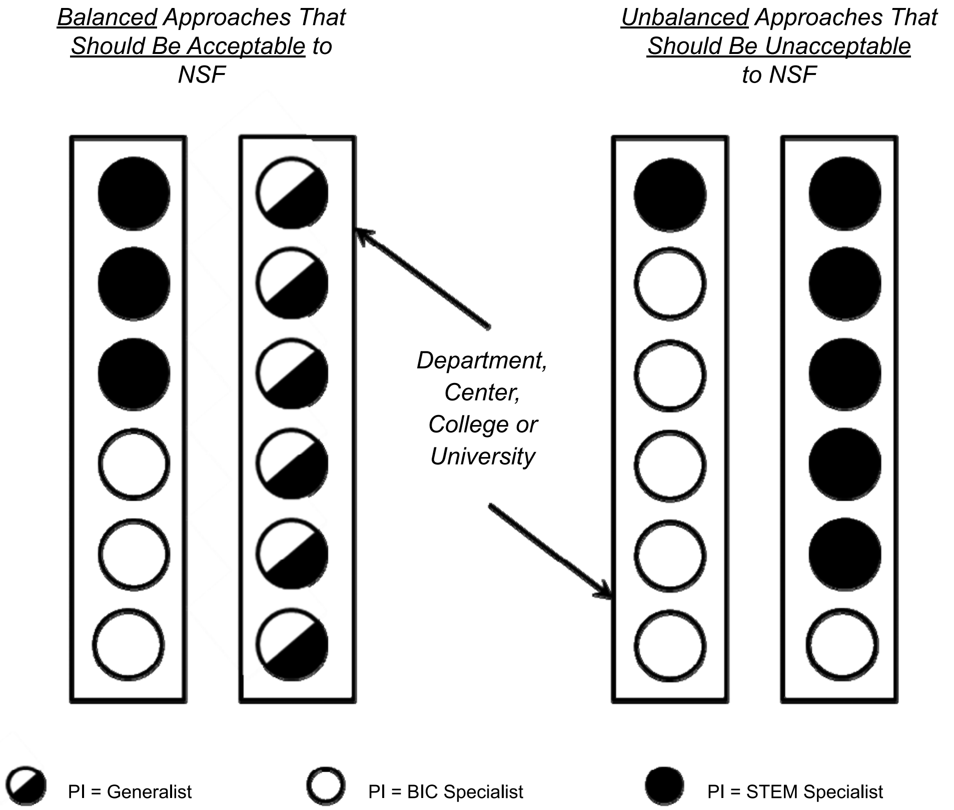

Figure 3 Aggregate Approach to Funding STEM and BIC Activities whereby an Administrative Unit—not the Individual PI—is Responsible for the Balance between NSF's Two Criteria for Discovery Grants.

Institutionalizing Broader Impacts Activities

Given potential "problems" with the specialization of both PIs and the journals in which they publish, I suggest that there are at least two alternative approaches to NSF's requirement that each proposal address both STEM and BIC evaluative criteria.

Model 1: encouraging—not discouraging—specialization

The first alternative approach is for NSF to transfer the burden of balanced discovery grant impacts from the level of the PI to the level of the PI's institution. Thus the institution, not NSF, oversees that, in aggregate, its investigators collectively contribute substantially to both intellectual merit and broader impacts as required by NSF. The phrase "in aggregate" is key to this model. Such a model frees up both kinds of specialists (the STEM specialist and the BIC specialist) at that institution to do what they do best, and holds at bay the Peter Principle as it potentially applies to the institution's laboratory investigators. The institution would then be responsible for ensuring adequate balance in its activities, and NSF oversight would subsequently assess (and reward or penalize) that institution at the end of pre-determined reporting period (probably measured in years) for carrying out activities reflecting NSF goals. If an institution submitted and had funded too many proposals that only or primarily addressed intellectual merit during the evaluation period, then at a minimum they subsequently would have to submit more proposals that emphasized broader impacts or suffer the consequences. This would require, of course, a carefully maintained institutional database that categorized the institution's previous and current NSF-supported STEM and BIC projects, to which each PI would have to refer when submitting their own proposal as evidence of institutional balance.

The strength of this approach is that it has the very best talent working in the areas at which they excel. Hypothetically, this leads to STEM and broader impacts activities that are both of higher quality and more cost-effective. The disadvantage, if it can be considered as such, is that institutions rather than PIs have to become seriously involved in promoting both criteria among their faculty and staff. Young scientists and engineers building their careers must also be cognizant of the significant tradeoffs between specialization and diversification as career pathways in these days of increasingly interdisciplinary research (Reyns, Langenheder, and Lennon 2007). Moreover, the ultimate impact of these tradeoffs may have to be considered in a gender-specific context (Leahey 2006).

Model 2: generalization—with institutional assistance

An alternative approach retains the generalist theme required by the twin NSF criteria. Each PI submits a proposal thoroughly addressing both criteria as currently demanded. However, the organization and implementation of activities in support of BIC, when in the domain of outreach and or education, becomes institutionalized. Certainly, a few large research universities are creating units that help coordinate BIC and related activities (e.g. Stanford University, University of Michigan). Another instance of this model is evident in some NASA grants, in which a small but significant fraction of a grant's budget is directed to an independent contractor (presumably and expert in educational outreach) to carry out education and public outreach components. In (too) many universities, however, the inventory of NSF-funded broader impacts activities in any given academic science department still consists of graduate and postdoctoral training along with a mixture (read hodge-podge) of individually mounted outreach and educational activities of varying quality and effectiveness—again, run by non-specialists in such activities. Indeed, this trend is only likely to continue because, whether accurate or not, the word on the academic street is that "just" promising to train graduate students and postdoctorate students is no longer regarded as sufficient to pass muster with increasingly more astute and demanding NSF panels.

In this approach, broader impact activities would be coordinated at the departmental or college level. Thus, as just one of many possible examples, an academic unit commits to develop a research experience programme for inner-city middle school children. The programme hires a professional programme director, skilled in all of the management aspects of such a programme—recruiting, transportation, permissions, budgeting—as well as developing the actual content of the programme. The Director is paid from the cumulative contributions of the department's NSF discovery grants. This requires that each proposal from this department requests funds specifically to support this activity. Rather than viewing this as a "tax" on their grant, I predict that faculty, especially less experienced junior faculty, will be grateful for the opportunity to offer up funding from their proposals and then gain involvement in a professionally run, high-impact activity that also represents a broader impact activity of the highest level.

Importantly, this should not be perceived by NSF as a faculty "buying out" their obligation to promote the broader impacts of their work. There are myriad ways in which faculty can be required to be involved in an outreach programme like that described above, including assisting a director in the preparation of curriculum, providing research opportunities for participating students, discussing with these students how experiments are designed and hypotheses tested, and so forth. Using this method, the STEM specialists essentially "subcontract out" for BIC expertise, and then participate in a professionally organized and run programme. While correctly assessing such approaches will be key, it is possible that both a larger STEM impact and a larger BIC impact will occur because all participants are doing what they have been trained to do.

Conclusions and a Possible Future

BIC is well established at NSF, and in the decade it has been in place is likely to have had major positive societal impacts in science, technology, engineering, mathematics and beyond. The societal responsibilities of the scientific community are clear (Frodeman and Holbrook 2007; Holbrook 2005). However, the successful interweaving of STEM and BIC objectives as well as the approach of emphasizing the dual contributions of both STEM and BIC in each individual discovery grant proposal has generated a series of unintended consequences, namely:

- The assessment of the efficiency (cost per achievement) of BIC funding, as opposed to outcomes (numbers or quality of results), is very difficult to carry out because of the fiscal as well as conceptual integration of STEM and BIC activities within the discovery grant programme.
- STEM and especially BIC activities are currently proposed, evaluated and administered primarily by STEM specialists that may lack the deeper level training required to make the most judicious funding decisions concerning BIC (shades of the Peter Principle?).
- Current funding approaches that call for each individual PI to address both STEM and BIC goals in their proposal have fostered an academic tent city of typically loosely coordinated BIC activities by PIs, each acting as an independent contractor striving to identify a compelling BIC activity.
- The skills and competencies of Committees of Visitors, Advisory Boards and other outside evaluators of NSF are often heavily weighted towards STEM rather than BIC assessment, making the effectiveness of programmes focused on BIC problematic.

Despite these unintended consequences of current BIC policy, there are numerous approaches involving some form of local "institutionalization" of the responsibility and implementation of BIC objectives that could result in more efficient expenditure of scarce research funding and actually improve the quality of both STEM and BIC objectives.

The grand experiment involving new approaches to STEM and BIC funding, complete with controls, statistical assessment, and so forth, is beginning to be conducted, and a few adventurous universities of formalizing and centralizing the pursuit of BIC activities. To conduct this experiment, an institution or group of institutions needs to receive NSF's indulgence in permitting that institution to report *its group activities in aggregate* in support of each PI's new proposal (i.e. a macro approach), rather than having NSF continue to insist on each PI's programme containing near equivalent amounts of STEM and BIC activities.

The stakes are high, not just in monetary terms but also with respect to the training of our future STEM scholars and teachers. NSF is likely to continue with its existing approach unless alternative approaches are supported by compelling evidence. Institutions that rely upon NSF for a major source of research funding (and indirect costs) are likely to be reticent to quite literally "experiment" with their crucial NSF support. The grand irony will be if this grand experiment fails to be conducted by the nation's chief experimentalists.

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Notes

[1] Staff members at NSF dislike the term "Second Criterion", which suggests that it is a lesser criterion.

[2] Panel deliberations and scores are not made public. The author reaches this conclusion based on anecdotal information from interviewing panellists and NSF staff members.

[3] A well-known phenomenon in epidemiology is the appearance of an increase in disease incidence simply due to an enhanced ability to diagnose that disease. This raises the question of whether NSF is now funding more relevant research due to the implementation of BIC, or whether proposers simply have had to go to greater pains to point out the broader significance and connection of their research.

[4] The author did not conduct a formal poll and presents these preliminary data as anecdotal—but nonetheless quantitative.

[5] This discussion is not intended to suggest that equal emphasis is (or should be) placed on the scientific merits and broader impacts of a project. NSF's instructions indicate that the reviewers should make the determination of the relative weights for each criterion. While both need to be prominently featured in any discovery grant proposal, this narrative does not address the probable large variation in relative emphasis by individual reviewers or panels.

[6] Of course, it could be argued that NSF funding rates are currently so low that panels only have to identify those unusual individuals who can indeed specialize in the current NSF duality (e.g. Quadrant 1 in Figure 1). However, this cynical view fails to recognize that left on the table are large numbers of exciting, high-impact proposals with either high intellectual or broader impact merit, but not both as currently required.

[7] The NCBI PubMed database contains a relatively high proportion of journals likely to publish National Institutes of Health-funded rather than NSF-funded articles, and so a decreased emphasis on BIC-related search terms is not surprising. However, the fact that only approximately 0.1% of the papers in that database contain common descriptors of BIC activities speaks to the issue of little coverage of BIC activities in mainstream STEM journals.

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