Re-evaluating the NSF broader impacts with the Inclusion-Immediacy Criterion: A look at nanotechnology research

*Thomas S Woodson, Department of Technology and Society, Stony Brook University, Stony Brook, NY 11720, USA; Thomas.woodson@stonybrook.edu

Elina Hoffmann, Department of Chemical and Biomedical Engineering, Johns Hopkins University, Baltimore, MD, 21218 USA, ehoffm20@jhu.edu

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*Corresponding author
Phone: 631-632-9974
Email: Thomas.woodson@stonybrook.edu, tswoodson@gmail.com
1412 Computer Science
Stony Brook University
Stony Book, NY 11794
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**Abstract:**

A major goal of government and non-profit scientific funding agencies is to support research and development (R&D) that has broad impacts, generates responsible innovation, and positively impacts society. This study proposes a new framework, called the Inclusion-Immediacy Criterion (IIC), that better assesses the inclusion and immediacy of research to determine whether the research helps marginalized communities, reduces inequality, and encourages inclusive innovation. To test the framework, the study analyzes NSF sponsored nanotechnology grant abstracts from 2013 to 2017. We find that 109 out of the 300 grants feature research that is inclusive, while 235 out of the 300 grants have broader impacts that either maintain the status quo or predominately help advantage groups. Using the IIC, scholars can better inform science policy decisionmakers on the impact that sponsored research has on marginalized communities.
Section I: Introduction

There is a powerful desire among government and non-profit scientific funding agencies to support research and development (R&D) that has broad impacts, generates responsible innovation, and positively impacts society (Bush 1945; European Commission 2018). To meet this requirement, science funding agencies require that principal investigators (PIs) show that their research extends beyond the laboratory (European Commission 2018). However, the current methods of assessing impact fail to account for two factors, the immediacy and inclusion of grant. The immediacy of a grant describes the way the research integrates broader impacts into the project. The inclusion of a grant considers the impacts of the research on marginalized communities. To better assess the impacts that research has on marginalized communities, this article outlines a new framework, called the Inclusive-Immediacy Criterion (IIC) (see Table 2).

The IIC is a novel framework that extends other scholarship that classify grants based on their broader impacts. Since the late 1990’s the National Science Foundation (NSF) has required scholars to discuss the broader impacts of their research, and consequently, there are studies that assess the broader impact activities (BIA). These studies classify the type and rate of BIA in NSF grants (Kamenetzky 2013; Roberts 2009; Wiley 2014). However, there are several gaps in the literature. First, it is not clear the extent that the NSF is funding research that helps poor and marginalized communities. The current broader impact categories intersect with inclusiveness, but there is research that is inclusive and is not be covered by the broader impact criterion (BIC). It is important to understand the impact that R&D has on marginalized communities in order to have the most equitable, just and effective innovation system (Cozzens 2007; Woodhouse & Sarewitz 2007). Second, scholars did not measure the extent that BIA are integrated into the research. Are the BIA a core part of the project or are they added as a side activity to the research? The degree
that the broader impacts are integrated into the research effects the type of projects proposed, funded and completed.

The paper has six sections. Section II of the article gives background on the broader impact criterion and the IIC, and section III discusses the methods used test to the framework. The team read and coded 300 NSF sponsored nanotechnology grant abstracts to evaluate the inclusiveness and immediacy of the scholarship. Section IV defines the new framework and gives examples of how it is used. Finally, sections V and VI discuss the results of the study and the impact of the framework for science policy.

**Section II: Literature Review and Conceptual Framework**

**Broader Impact Criterion**

Before the NSF existed, science policy makers, like Vannevar Bush, emphasized that scientific research could not be divorced from societal benefit. Bush saw science as a key component of national security, public welfare, the fight against disease, and education (Bush 1945). Since Bush, the prominence of connecting science to societal impacts has remained a constant focus of scientific organizations, such as the Department of Energy or National Institutes of Health (Roberts 2009). In 1997, the NSF formalized the need for research to make positive contributions to society by requiring grants to discuss the way the research will have broader impacts. A big part of the NSF’s shift was that Congress was increasingly concerned with improving the efficiency and effectiveness of government. Congress wanted to see measurable results on how government money was spent (J. Britt Holbrook 2005).

In Europe, policymakers and scientists assess the ethical value of research through the lens of Responsible Research and Innovation (RRI). RRI “is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the
(ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society) (von Schomberg 2011b)”.

The framework was first widely discussed in European policy circles in 2011 and it was adopted in the European Commission’s Horizon 2020 Strategy (European Commission 2018; Owen et al. 2012).

Despite the wide adoption of social standards to judge research, these types of programs are not universally popular and there are steady debates about the importance and value of the broader impacts and RRI (J. B. Holbrook & Frodeman 2007; Lok 2010). One complaint from grant applicants is that the BIC and RRI are ambiguous and vague (National Science Board 2011; Owen et al. 2012). Applicants do not know how to discuss the broader impacts nor are they sure how the proposed broader impacts will be judged. In response to the criticism, the National Science Foundation has regularly updated their guidelines on broader impacts (National Science Foundation 2014).

A second complaint is that requiring broader impacts makes it harder to get grants because scientist now have the extra burden of requiring that their research directly links to positive benefits for society (J. B. Holbrook & Frodeman 2007). This burden is especially felt by junior scholars because they may not have the bandwidth to do BIA and high quality research (Tretkoff 2007).

A third complaint attacks the philosophical roots of broader impacts and RRI. Some scientists do not believe research should be judged based on broader impacts (J. B. Holbrook & Frodeman 2007). These scientists argue that research may not have any apparent broader impacts for society, but the topics should still be explored to further scientific knowledge. Also, in the future, the research could become invaluable. For example, the first scientists studying the atom’s structure did not know their research would create a new source of power (Stokes 1997).
scholars argue that broader impact criterion is based on a flawed linear model of R&D and the requirements do not match that the reality of R&D (J. B. Holbrook & Frodeman 2007). Rather, models like Pasteur’s Quadrant, a two by two grid of consideration of use and quest for fundamental understanding, or the streams metaphor of R&D better match R&D (Fisher et al. 2006; J. Britt Holbrook 2005; Stokes 1997). Moreover, rather than forcing a natural science grant to include broader impacts, like broadening STEM participation, some argue that it would be more efficient to fund grants designed to have broader impacts. Currently, researchers must divide their attention and work on projects that are not their specialty (Tretkoff 2007).

Finally, a fourth criticism of the requiring broader impacts is grant peer review is an inadequate process to assess broader impacts (Bozeman & Boardman 2009; Bozeman & Youtie 2017). Peer review is based on specialized knowledge and most peer review panels feature experts on a given subject matter. In general, review panels do not include experts on broader impacts and outreach. As a result, the panelists are evaluating broader impacts without any skill in assessing the quality and potential benefit of the project (Bozeman & Boardman 2009).

Despite the criticism, requirements like BIC and RRI are not losing salience. There are steady calls from politicians to make science more accountable, transparent and applied (J. B. Holbrook & Frodeman 2007). In response, science funding organizations must keep enforcing BIA to match legislation (National Science Board 2011).

The NSF created the BIC in 1997 and Congress mandated that the NSF must consider broader impacts in the American COMPETES Reauthorization Act of 2010 (National Science Board 2011). The NSF does not rigidly defined the BICs, but rather the agency has purposefully stated that broader impacts encompass a range of activities from increasing diversity in STEM fields to sharing results with the public (National Science Foundation 2014). In general, broader
impacts are categorized into eight areas: infrastructure for science, broadening participation, training and education, academic collaborations, K-12 outreach, potential societal benefit, outreach/broad dissemination, and partnerships with potential users (see table 1) (Kamenetzky 2013). In 2009, Roberts studied the distribution of BIC. Roberts divides the eight broader impacts categories into criteria for science and criteria for society. She finds that of the grants that included broader impact statements “89% proposed broader impacts for science and 66% proposed broader impacts for society” (Roberts 2009).

Other scholars conducted similar studies but looked at certain fields. For instance, Kamenetzky analyzed broader impacts in biology, mathematical and physical sciences (Kamenetzky 2013) and Nadkarni and Stasch examined the broader impacts of Ecosystems Studies Programs (Nadkarni & Stasch 2013). Watts et al. examined the Division of Environmental Biology (DEB) (Watts et al. 2015). The Watts study had access to the full proposal, panel review summaries, and project reports of the DEB. They find that PIs proposed slightly more BIAs, 5.5%, than they accomplished. Another major finding was that awarded grants proposed 10% more BIAs than non-awarded grants (Watts et al. 2015).

The most comprehensive study of broader impacts was commissioned by the National Science Board. The researchers analyzed the broader impacts of about 100,000 grants and found that the most common broader impact was teaching/learning (about 60% of grants) followed by broadening participation (about 25% of grants) (National Science Board 2011).

Revising Broader Impact Criterion
The few studies on the distribution of BICs and the persistent concern from scientists about the BIC shows that the guidelines need to be reformed. In 2016, a team of NSF officials and PIs held an NSF-sponsored workshop on the BIC (Jacobson et al. 2016). They recommended the NSF
change the panel review guidelines, so the panel considers the immediacy of the BIA. Jacobson et al. define immediacy as the inherent nature of the BIA relative to the research and they divide it into intrinsic, direct, and extrinsic immediacy. Intrinsic immediacy means that the BIA are central to the research project. For instance, if a PI is developing a new solar panel, the broader impacts of producing clean energy, are intrinsic to the grant. Direct immediacy are broader impacts that are achieved while conducting the research. An example of direct immediacy is training graduate students while doing research. Training the student is not the goal of the research project, but it would impossible to finish the project unless graduate students are trained. The third level of immediacy is when the BIA are extrinsic to the actual project. If a PI visits a K-12 school to share the research results on nuclear physics, then the BIA are separate from the research and have extrinsic immediacy (see Table 2).

To the immediacy classification, this project adds a dimension on inclusivity to determine the types of people that benefit from the research. The current criterion does not fully account for who benefits from the BIA and consequently, the funding could be increasing inequality. The inclusivity dimension has three categories, universal, advantaged/status quo and inclusive. The first category, universal, means that the innovation helps everyone, regardless of status, and often grants with universal impact solve a market failure. For example, research to combat the effects of climate change solves a “tragedy of the commons” market failure (Hardin 1968). The research is important everyone and everyone benefits from the research.

Other innovations primarily help advantaged groups and maintain the status quo. These innovations could eventually diffuse to marginalized communities, but only after they have been redesigned or after power groups have fully benefited from the innovation. For example, research
to design better watches and fabrics is primarily for powerful groups, like the military or wealthy consumers, that can afford that technology.

The third category of inclusive innovation are innovations that are designed to help marginalized communities directly. R&D to create a low-cost malaria vaccine exemplifies this category because malaria predominantly impacts people in low income countries.

This project combines the immediacy and inclusion criterion to create a new model of assessing broader impacts called the Inclusive-Immediacy Criterion (IIC) (see Table 2). This new model fills a gap in developing and evaluating broader impacts because it determines the potential impact of research on marginalized groups. Currently, inclusion is not a prominent factor in BIA. Rather, the BIC focuses on economic competitiveness, national defense, workforce development and diversifying science (National Science Board 2011). By failing to account for the effect of funded research on marginalized communities, it is impossible to know the impact research will have on inequality.

In addition, this new framework does not classify broader impacts based on a list of eight criteria. As mentioned before, when the NSF generates a list of potential broader impact, applicants tend to simply add one of the listed impacts to the study and applicants are less likely to think of creative ways to have broader impact on society (National Science Board 2011). The new framework focuses on who will benefit from the project and how the broader impacts relates to the central goal of the grant. Therefore, it does not narrow the types of broader impacts to a few categories. Finally, the new framework can be applied to a range of funding agencies and projects.

By designing a framework that gives a general measure of inclusivity, it is possible to compare the inclusiveness of research across funding agencies and countries.

**Section III: Methods**
This study is the first attempt to apply the IIC to measure the inclusivity and immediacy of federally funded research proposals. To test the framework, this project examines nanotechnology grants. Nanotechnology is the study and manipulation of matter between 1-100 nanometers in order to make novel products and applications (Balogh 2010). Nanotechnology is an ideal case study for three reasons. First, over the past 15 years scholars have conducted numerous bibliometric studies of nanotechnology research, so there are reliable search strategies and tools to gather a random sample of nanotechnology grants and assess the impacts of nanotechnology (Cozzens et al. 2013; Philip Shapira & Meng 2009; Wang & Shapira 2011). Second, nanotechnology is a cross disciplinary field, and early in the technology’s development, there were many discussions on how nanotechnology could help low-income communities (Meridian Institute 2005; Salamanca-Buentello et al. 2005). Consequently, it is a good field to test the IIC to determine whether NSF funded nanotechnology research was inclusive. Finally, the authors have studied inequality in nanotechnology using case studies and other bibliometric techniques, so they have expertise in determining the impacts of nanotechnology research on marginalized groups (references removed for blind review).

To find nanotechnology grants for the analysis, the project uses the two-stage nanotechnology search strategy developed by Arora et al. (2012). In the first stage, the strategy uses a list of nanotechnology related words to find all the grants with those keywords. Then, the strategy uses a separate set of exclusion terms to remove grants that are not related to nanotechnology. Some of the exclusion terms are words like nanoplankton and nanosecond. We applied the search strategy on NSF’s publicly available awards using the advance search feature. The nanotechnology search strategy found 26,474 NSF sponsored nanotechnology grants from 2000-2017.
After developing the corpus of nanotechnology grants, we limited the analysis to the 6,854 nanotechnology grants from 2013 to 2017. In 2013, the NSF made major changes to the BIC proposal guidelines and required applicants to make their broader impacts and intellectual contribution more explicit in grant applications. The changes to the proposal and proposal summary do not automatically require abstracts to discuss broader impacts, but it increases the likelihood that the abstracts will have broader impacts. Previous studies on BIA from 2000-2010 found that 26.2% of abstracts did not contain broader impacts even though the main proposal discussed BIA. From this observation, the previous studies conclude that analyzing the abstracts from before 2013 is not very accurate (Watts et al. 2015).

Out of the 6,854 grants, the team randomly selected 300 research grants to code. For this project the team did not code education, infrastructure or capacity building grants. A sample of 300 grants gives the project sufficient explanatory power for an exploratory qualitative study (Bartlett et al. 2001; Raosoft Inc 2004).

Parallel to creating the corpus of nanotechnology grants, the authors developed a coding strategy for the IIC (see Table 2). The team reviewed the literature on broader impacts and inclusive innovation to develop a definition for each cell. Then, using a training set of grants, the research team defined a coding scheme and tested the coding strategy. Finally, the research team coded the sample of nanotechnology NSF abstracts to determine the immediacy and type of inclusion of the grant. The coders read and coded the whole grant abstract. However, due to NSF regulations for writing grant abstracts, most of the broader impact activities were clearly labeled in latter half of the abstract. If there was any conflict in the coding guidelines, the researchers would discuss the problem and mutually decide the best way to code ambiguous grants. The team
used RQDA to manage and code the grant abstracts. RQDA is package on the R statistical platform for qualitative data analysis (Huang 2018).

**Intercoder reliability**

To verify the accuracy of the coding, a third researcher in the team coded a 10% reliability sample of grants from the nanotechnology dataset. The sample was taken from the 300 grants used in the main analysis. In the first round of intercoder tests, the Krippendorff alpha score between the coders was moderately low (0.602). Upon close inspection, the scores of the tertiary coder systematically misinterpreted the codes for infrastructure for science, potential societal benefit and universal/intrinsic. When those errors were recoded based on the correct classification strategy, the Krippendorff Alpha score increased to 0.77. This sufficient high Krippendorff alpha score to determine that the coders are reliable (Hallgren 2012; Hayes & Krippendorff 2007; Krippendorff 2011).

**Section IV: Inclusion Immediacy Criterion**

As mentioned before, the IIC framework has two dimensions with three levels that form a 3X3 grid. Each cell in the grid represents a different type of inclusivity and immediacy. This is a departure from previous studies that classify BIAs based on Table 1. The IIC is not limited to a set of activities. Rather, it classifies the BIA based on the intended beneficiaries and the relationship between the BIA and research activities. By analyzing the depth and focus of the broader impacts, it is easier to understand which populations benefit from the research. For example, developing a new malaria vaccine and posting open source lectures notes online impact marginalized communities differently. The malaria vaccine directly targets a problem impacting individuals in low-income countries. Posting lectures notes will primarily help university students. The IIC framework recognizes these differences.
The chart is not a hierarchy. One cell is not better than another cell. Instead the cells represent different types of inclusion and immediacy. Depending on the goals of the project, it may be smarter to have broader impacts that are extrinsic to the research. Other projects must be geared towards the scientific community, which is an advantage community. For example, many hi-tech products, like military equipment or quantum computers, will first be used by businesses and wealthy people. Over time, the technology might diffuse to middle and low-income populations, but there is no promise that the technology will be adopted by marginalized groups or will improve their lives. There nothing inherently wrong with developing the next generation computer processor, but it is important that science agencies know which communities will mainly benefit from their funding.

*Intrinsic/Universal*

In this cell, the grant proposes research that could benefit everyone, and the broader impacts are intrinsic to the research. An example of a research project that is intrinsic/universal is research on a smart grid system. A smarter electricity grid will improve electricity distribution across the country, and everyone, regardless of a person’s income status, would benefit from the technology (Fang et al. 2012). Grid improvements are non-rivalrous and non-excludable. The broader impacts are also intrinsic to the research. Below is a quote from grant that is characterized as intrinsic/universal.

“Advanced combustion engines being developed for meeting our transportation needs achieve improved fuel efficiency by lowering exhaust temperatures. This put demands on the technology for catalytic converters, since these catalysts must become active at lower temperatures. The proposed research addresses the design
of these catalysts, leading to improvements in air quality and to societal needs for energy.”

In this grant abstract the researchers are developing technology to lower vehicle emission and improve air quality. The entire population will benefit from this research, so it is classified as universal, and the broader impacts are central to the research, so it is classified as intrinsic.

*Intrinsic/Advantaged*

Grants in this category are either geared towards advantage groups or maintain the status quo. Though technology developed for advantaged groups may eventually diffuse to marginalized communities, the most obvious and direct users will be people from advantage groups, like the wealthy, educated and politically connect. An example of a technology that fits in this category is 3D printers. The first users of this technology were advantage communities who could afford the printers and had the ability to design 3D objects. Eventually, the technology could be widely adopted by lower income users, but research shows that there are systematic failures that prevent 3D printers from automatically helping low income populations (Woodson 2015).

In the following example, the PIs propose a project to create software and a web portal for the chemistry community. The chemistry community is an advantage group because chemists tend to be a highly educated and wealthy compared to the rest of the population (Rovner 2014). As a result, this grant was classified as intrinsic/advantaged. The grant “develop[s] theories and computer software to model the motion on electrons…and also develop an open source chemistry web portal where the chemical community and educators can access and apply these tools without expensive computer hardware, software or expertise.”

The team codes grants that propose new infrastructure, materials or datasets as intrinsic/advantage. For example, one grants says “The goal of this project is to create a new type
of terahertz generator that is compact, inexpensive and works at room temperature.” The BIA is intrinsic to the research and the research will primarily help advantaged groups.

Intrinsic/Inclusive

Research in this cell targets marginalized groups. A clear example of research that fits into this category is R&D on developing a new malaria vaccine. Malaria is a disease that impacts people in low income countries, so the inherent goal of the research is to be inclusive. In the nanotechnology dataset there was a project to “develop an affordable device that will allow the visually handicapped community to access digital information in a robust format comparable to a mobile tablet computer”. This research clearly benefits a marginalized group.

Direct/Universal

Direct broader impacts are achieved while doing the research. The BIA is not the focus of the research, but it would be very challenging, if not impossible, to complete the research without addressing the BIC along the way. Universal broader impacts help everyone regardless of status. Direct/Universal grants are one of the harder cells to identify, however many partnerships with public sector organizations fall into this category. The collaboration is necessary for the research, and the collaboration is not the purpose of the research. Also, unlike industry partnerships, which are presumably focused on creating profit-making ventures, partnerships with a public sector organization should benefit everyone in the community, regardless of their income or status. An example of direct/universal grant discusses how their research will be “integrated into construction of hazard maps published by the Utah Geological Survey”. The partnership between the researchers and the Utah Geological Survey, a state government organization, is achieved while doing the research, so it is classified as direct. The partnership with the Utah Geological Survey is universal because the new map data will improve flood and earthquake protection in the state.
Direct/Advantaged

In this cell, the broader impacts are directly related to the research and the research maintains the status quo or helps advantaged groups. The most common type of impact that fits in this cell is training graduate students. In general, graduate students are advantage group. Only 9% of Americans between the ages of 25-29 will earn a Master’s Degree or higher and students with graduate degrees have many advantages over people without graduate degrees (U.S. Department of Education 2018). Therefore, programs for graduate students will, in general, help advantage groups and maintain the status quo.

Training graduate students is directly related to the research, but in most cases, graduate training in not the actual research. Training the students is a means to accomplish the end goal of the research project. Consequently, graduate training is categorized as direct.

We also placed sharing research results with other academics as direct/advantaged. Going to conference and disseminating results is a key part of research process, but it is not the main goal of most funded project. Finally, industry collaborations are considered direct/advantaged. Unless the industrial collaboration explicitly says that the R&D will help a marginalized group or serve the entire population, it is assumed that an industrial collaboration is profit seeking, and hence, will maintain the status quo or help advantaged groups. There are rare cases where the main goal of a profit seeking enterprise is to help marginalized communities, like in bottom of the pyramid innovation (Prahalad 2004), but again, the authors must explicitly state that goal. For example, one grant mentioned partnering with the graphic processing unit (GPU) industry and another project developed a strategic partnership with a global automotive firm. The results of these partnerships will help advantage groups.
A good example of an education program that is direct/advantage is a grant that helps “students in academic research to be able to interact and appreciate the industrial culture. As a result, a goal of this grant is to leverage these partnerships to enable alumni REU interns to be placed into industry internships.”

Direct/Inclusive

Grants in this cell are like direct/advantaged grants, but instead of the research helping advantaged groups, the research directly helps marginalized communities. The best example of a research that fits in this category is training graduate student from marginalized groups. For example, one grant says that “a portion of the funds will be used to develop a network of female STEM faculty in the XXX region which fosters the retention and promotion of STEM women in academia, and mentor’s women transitioning to academia from postdoctoral and graduate positions.” Another type of grant that falls in this category propose developing research infrastructure in a low-income country. For example, if the research team installs a water pump to supply their field station, the pump is necessary to finish the research, and the pump helps marginalized communities.

Extrinsic/Universal

Grants in the category propose outreach activities that are unrelated to the research and will have universal impact. The most common type of activities that fits in this category are developing a new K-12 curriculum that incorporates finding from the research. In theory, the new curriculum could help everyone regardless of status because every child in the USA is entitled to K-12 education. Other types of BIA that fall in this category are educating the public and working with public museums. Within our sample, a classic example of grant with an extrinsic/universal broader impact is “The results of this project are disseminated through a comprehensive set of education and outreach activities that include graduate curriculum development, undergraduate
laboratories, and a materials science exhibit at the Chicago Museum of Science and Industry”.

The first part of the BIA statement, creating undergraduate and graduate courses and labs, maintains the status quo, but creating an exhibit at the Chicago Museum of Science and Industry is classified as universal. The public museum mission is to “inspire the inventive genius in everyone” (Museum of Science+Industry 2018). This is explicitly a universal goal.

Extrinsic/Advantaged

This cell represents broader impacts that are not related to the research and help advantage groups. Some examples of broader impacts that fit in this category are creating science podcasts and developing new graduate courses related to the research. One grant proposed to “visit government staff and science journalists”. The coders believe that government staff and science journalists are advantaged communities and the outreach activities are in addition to the research project.

An example that was hard to classify was a lecture series at a senior citizen center that is “focusing on demystifying materials chemistry”. The coders debated whether the elderly constitute a marginalize community. They decided that in this instance the elderly community was not marginalized because the program is hosted in an exclusive retirement community.

Extrinsic/Inclusive

This final category represents broader impacts that are unrelated to the research and will help marginalized groups. Some potential activities that fit in this category are developing a class for disabled students or creating a STEM outreach program for low-income children. One example from the data set was an education program in Uganda. “The education plan involves collaborations with universities in Uganda and will use hands-on experiment kits and virtual teamwork to train students to work on diverse teams to tackle global challenges.

Section V: Results
Table 3 shows the distribution of coding across the nine cells of the IIC. On the immediacy dimension the most common category was direct (232) followed by intrinsic (200) and then extrinsic (110) grants had direct. Therefore, PIs are proposing research that is inclusive, 109 grants, but at lower rates than research that has universal benefit or benefits advantaged groups. In the other dimension, the most common type of inclusion was advantaged (235), followed by universal (213) and inclusive (109). Within inclusive grants 94% of them are about broadening STEM participation. We found only nine grants in the sample that were intrinsic/ inclusive. These grants proposed activities like water filtration systems, medical diagnostics systems, and energy storage for rural electrification.

When comparing the IIC to BIA in table 1, there are obvious overlaps (see Table 4). Grants that are universal/intrinsic and have potential societal benefit BIA are closely related. 160 out of 174 potential society benefit grants are considered universal/intrinsic. Similarly, K-12 outreach and Universal/Extrinsic are closely linked together. (See Sankey diagram in supplemental material for visual representation). 215 out of 219 Training/education grants are classified as direct/advantaged.

A smaller, yet important, finding addresses a prominent criticism of broader impacts. Some scientist argue that the broader impact requirement is inefficient because it requires scientists to do work, like developing K-12 curriculum, that is outside of their specialty (Tretkoff 2007). Critics of the BIC argue that it would be more effective for scientists to focus on their research and give grants to teachers, museums and community organizers to do broader impacts. This study does not find any grants that only proposed extrinsic broader impacts. If a PI proposed an extrinsic BIA, they also included a BIA that was direct or intrinsic. The project cannot determine the amount of
effort spent on extrinsic broader impacts, but extrinsic broader impacts are a small proportion of broader impacts.

**Challenges with coding**

The IIC addresses a persistent problem in broader impact statements of quality vs quantity. Previous studies on broader impacts state that scholars may simply use the broader impacts as a checklist and try to score as many points as possible as opposed to suggesting a quality project (National Science Board 2011). While reading the abstracts, it is easy to spot PIs who propose an inoperable number of broader impacts without any description of how they will achieve their goals. We code these type of grants as having broader impacts, but without details. For example, in one grant the PIs describe broadening participation by saying “The project-related activities also expand the curriculum and cutting-edge research opportunities in materials science and engineering with significant inclusion of underrepresented students.” This grant does not give any indication of how it will include underrepresented groups. Since the grant mentions that it is trying to have broader impacts, then it must be coded as broadening participation, even though the grant does not detail how it will broaden participation. In comparison, one grant says, “in order to provide an interdisciplinary science experience to high school students, Professor XXX will develop science workshops partnering with the YYY Foundation and the ZZZ Math and Science Program.” This grant gives specific comments on how they have broader impacts, so it is coded as with details.

To better understand the depth and focus of the broader impacts, the team coded five categories, academic collaborations, broadening participation, outreach/broad dissemination, K-12 outreach, and training and education as having “with details” or “without details” (see Table 5). In some categories, like academic collaboration, the grant abstracts contain a lot of details about
the proposed broader impacts, while other categories, like training and education, have a larger proportion of the grants containing less information. For this study we cannot determine why the grant abstracts have this type of trend, but future analyses of broader impacts and IIC need to be aware that grant abstracts can include a broader impact, yet not give no details about the project.

Another challenge is ensuring high intercoder reliability. This type of analysis requires significant training and continuous feedback to correctly classify the grant abstracts. For example, the team had a robust discussion about the inclusivity category advantaged. Does creating a video game maintain the status quo/ help advantage communities or does it target marginalized communities? Are elderly residents in retirement communities a marginalized population? Depending on an abstract’s explanation these types of grants could be categorized differently.

Fortunately, there were very few abstracts that were ambiguous. Most of the BIA were common like training graduate students, K-12 education and broadening participation.

Section VI: Conclusion

The new coding scheme based on inclusivity and immediacy better measures who benefits from the proposed broader impacts and the relationship between the BIA and the research. The IIC dramatically improves our understanding of the impact R&D has on marginalized communities, but it will not solve all the problems associated with requiring research to impact society. One critique of the BIC is that the grant review panels do not include experts on education, public outreach, and policy, and therefore, the expertise to decide the impacts of grants is not in the room. (Bozeman & Boardman 2009; J. B. Holbrook & Frodeman 2007). If science funding agencies fully adopt the IIC, but do not change the composition of the review panelists, then there will still be a mismatch between scientific expertise and assessing broader impacts.
This study is also limited because it examines nanotechnology research. Nanotechnology is more applied than fields, like pure mathematics, and therefore, it may be easier for nanotechnology scientists to directly tie their research to societal benefit. Scholars need to apply the IIC to other fields to determine whether research in those fields have similar patterns as nanotechnology. Also, the IIC will generate new challenges as PIs learn this system. How will PIs respond to the new framework and how will their change their grants to match the IIC? Finally, the IIC framework must be tested on several types of grants. How well does the IIC classify non-research grants, like education or infrastructure grants?

Overall, most of grants in the sample research will help everyone (universal), 213 out of 300, or advantage groups, 235 out of 300. 109 of the 300 grants proposed broader impacts that were inclusive and only 9 grants propose research that is intrinsic and inclusive. This means that most of the PIs propose research that was not specifically directed towards marginalized groups. Depending on the policymaker’s perspective these ratios can be viewed positively or negatively. There are robust debates in science policy and ethics on the purpose and goal of science. Critics of the BIC argue that science agencies should not consider them at all (Tretkoff 2007). Other philosophical traditions believe that growing inequality in a problem for the innovation system and funding agencies should work to be more egalitarian (Cozzens 2007; Woodhouse & Sarewitz 2007). This study cannot determine the ideal distribution of science funding, but it important to know who is being targeted by the BIA. By reexamining BIA through the lens of inclusivity and immediacy, scholars can better inform science policy decisionmakers on the impact that sponsored research has on marginalized communities.

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<table>
<thead>
<tr>
<th>Criteria for Science</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure for Science</td>
<td>Creation of new research methodology, tools, or data sources that will be useful to advance science.</td>
</tr>
<tr>
<td>Broadening Participation</td>
<td>Recruiting or including under-represented groups in research or in outreach efforts. Includes efforts to attract women to science and to keep them in the academic pipeline for all fields, but excludes funding female students in biology and social sciences.</td>
</tr>
<tr>
<td>Training and education</td>
<td>Includes mentoring undergraduates, graduate students and postdoctoral fellows in the laboratory and teaching classes.</td>
</tr>
<tr>
<td>Academic Collaboration</td>
<td>Research collaborations with other universities in the US or abroad.</td>
</tr>
<tr>
<td>K-12 Outreach</td>
<td>Outreach to K-12 students or teachers helps to get kids excited about science and ensure a pipeline of future scientists.</td>
</tr>
</tbody>
</table>

**Criteria for Society**

| Potential Societal Benefits | Direct claims that the research could help to inform policy, be useful for industry, or lead to some solution to a real-world problem. General statements of improved understanding of a natural |
or technical process (i.e. climate change or ecosystems) were not included

<table>
<thead>
<tr>
<th>Outreach/Broad Dissemination</th>
<th>Dissemination of research results for non-academic audiences in any form (web site, seminars, meetings, newspapers). Does not include K-12 outreach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partnerships with Potential Users of Research Results</td>
<td>Includes partnerships with industry, non-profits, government bodies and national labs</td>
</tr>
<tr>
<td>Inclusivity of broader impacts</td>
<td>Intrinsic</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Universal (everyone)</td>
<td>Developing smart grid technology</td>
</tr>
<tr>
<td>Advantaged/Status Quo</td>
<td>Smart watches/fabrics, infrastructure for science</td>
</tr>
<tr>
<td>Inclusive (marginalized group)</td>
<td>Developing new malaria medicine</td>
</tr>
</tbody>
</table>
Table 3 Grant distribution in IIC (*Note that the row and column totals does not equal the sum of the interior cells because grants can be coded in multiple cells)

<table>
<thead>
<tr>
<th></th>
<th>Intrinsic</th>
<th>Direct</th>
<th>Extrinsic</th>
<th>Total grants*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal</td>
<td>163</td>
<td>8</td>
<td>108</td>
<td>213</td>
</tr>
<tr>
<td>Advantaged</td>
<td>41</td>
<td>224</td>
<td>3</td>
<td>235</td>
</tr>
<tr>
<td>Inclusive</td>
<td>9</td>
<td>102</td>
<td>1</td>
<td>109</td>
</tr>
<tr>
<td>Total grants *</td>
<td>200</td>
<td>232</td>
<td>110</td>
<td>300</td>
</tr>
</tbody>
</table>
### Table 4 Comparing IIC to NSF categories

<table>
<thead>
<tr>
<th></th>
<th>Infrastructure for Science</th>
<th>Broadening Participation</th>
<th>Training/ Education</th>
<th>Academic Collaboration</th>
<th>K-12 Outreach</th>
<th>Potential Societal Benefits</th>
<th>Outreach Broad Dissemination</th>
<th>Partnerships with Potential Users</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic/Universal</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>160</td>
<td>1</td>
<td>2</td>
<td>162</td>
</tr>
<tr>
<td>Direct/Universal</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Extrinsic/Universal</td>
<td>0</td>
<td>40</td>
<td>51</td>
<td>4</td>
<td>99</td>
<td>0</td>
<td>14</td>
<td>5</td>
<td>108</td>
</tr>
<tr>
<td>Intrinsic/Advantaged</td>
<td>37</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>42</td>
</tr>
<tr>
<td>Direct/Advantaged</td>
<td>2</td>
<td>51</td>
<td>215</td>
<td>24</td>
<td>50</td>
<td>3</td>
<td>8</td>
<td>22</td>
<td>224</td>
</tr>
<tr>
<td>Extrinsic/Advantaged</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Intrinsic/Inclusive</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Direct/Inclusive</td>
<td>1</td>
<td>99</td>
<td>49</td>
<td>0</td>
<td>37</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>102</td>
</tr>
<tr>
<td>Extrinsic/Inclusive</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>101</td>
<td>219</td>
<td>77</td>
<td>101</td>
<td>174</td>
<td>23</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 Classification of the level of detail of broader impact statements

<table>
<thead>
<tr>
<th></th>
<th>with</th>
<th>without</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Collaboration</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>Broadening Participation</td>
<td>60</td>
<td>41</td>
</tr>
<tr>
<td>Outreach/Broad Dissemination</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>K-12 Outreach</td>
<td>68</td>
<td>33</td>
</tr>
<tr>
<td>Training and Education</td>
<td>129</td>
<td>90</td>
</tr>
</tbody>
</table>
Supplemental Materials

Figure 1 Venn Diagram showing the distribution of the immediacy of grants

Figure 2 Venn Diagram showing the distribution of the inclusion of grants
Figure 3 Sankey diagram showing how the IIC relates to the NSF BIC