Evaluating the NSF broader impacts with the Inclusion-Immediacy Criterion: A retrospective analysis of nanotechnology grants

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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. This study proposes a new framework, called the Inclusion-Immediacy Criterion (IIC), to determine whether research benefits 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 and grant activities that are inclusive, while 235 out of the 300 grants have research and grant activities that either maintain the status quo or predominately target advantaged groups. Of the 109 grants with inclusive broader impacts, 9 of them involve inclusive research that is intrinsic to the underlying work. In comparison there are 102 grants that feature inclusive research that is directly related to the research. Of those 102 direct-inclusive grants, 99 of them relate to broadening participation of women and underrepresented minority populations is science fields.

## Section I: Introduction

There is a strong desire among government and non-profit scientific funding agencies to support research and development (R&D) that 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 the inclusion of the grant. The immediacy of a grant describes the way the underlying research aligns with the project's societal impacts. The inclusion of a grant considers the impacts of the research on marginalized communities. To assess the impacts that research has on marginalized communities, this article outlines a new framework, called the Inclusion-Immediacy Criterion (IIC) (see Table 2).

The IIC is a novel framework that goes beyond the current policy and scholarship on broader impacts (BIs) to explore inequality in research outcomes. Since the late 1990's the US National Science Foundation (NSF) has required scholars to discuss the BIs of their research. The broader impact criterion (BIC) is a useful policy tool to show lawmakers and the public that the NSF funds useful research. It focuses on thematic impacts included in the research, such as training and education or industry partnerships, but the BIC fails to adequately account for the distribution and prioritization of research impacts. First, it is not clear to what extent the NSF is funding research that addresses the needs of poor and marginalized communities. 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, the NSF does not require investigators to discuss the extent that the BIs are integrated into the research. Are the BI activities a core part of the project or are they added as a side activity to the research? The degree that the BIs are integrated into the research effects the type of projects proposed, funded, and completed. The new perspective of the IIC addresses these issues and pushes forward our understanding on how research funding could decrease inequality.

The paper has seven sections. Section II of the article gives background on the broader impact literature and the IIC; section III discusses the methods used test to the framework. The research team read and coded 300 NSF sponsored nanotechnology grant abstracts to evaluate the inclusiveness and immediacy of the scholarship. Section IV gives examples of how the IIC is used. Sections V and VI discuss the results of the study, the impact of the framework for science policy, and gives some policy recommendations. Finally, section VII reviews the paper's limitations and conclusion.

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

*Broader Impacts*

Ever since science policy became a formal domain, 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, education, and the fight against disease (Bush 1945). Since Bush, the prominence of connecting science to societal impacts has remained a constant focus of scientific organizations, such as the US Department of Energy or US 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 BIs. A key impetus for the NSF's shift was the US Congress's increasing concern with improving the efficiency and effectiveness of government. Congress wanted measurable results from government spending, including money spent on federal research grants (J. B. Holbrook 2005). Congress mandated that the NSF must consider impact in the American COMPETES Reauthorization Act of 2010 (National Science Board 2011).

Other regions also grapple with social and financial accountability when determining the value of research. For example, the United Kingdom developed the payback framework to assess the impact of health services (Buxton & Hanney 1996; Donovan & Hanney 2011). The framework uses a logic model to assess potential payouts from research such as knowledge, benefits to future research, and informing policy (Donovan & Hanney 2011). 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 was adopted in the European Commission's Horizon 2020 Strategy (European Commission 2018; Owen et al. 2012).

Nevertheless, these types of programs are not universally popular and there have been debates about the importance and value of the BIs and RRI (J. B. Holbrook & Frodeman 2007; Lok 2010). Scientists have critiqued BI requirements in four primary areas. First, some scientists express concern that programs such as the BIC and RRI are ambiguous and vague (National Science Board 2011; Owen et al. 2012). Applicants do not know how to discuss BIs, nor are they sure how the proposed BIs will be judged. In response to the criticism, the NSF regularly updates their guidelines on BIs (National Science Foundation 2014).

A second criticism is that requiring BIs makes it harder to get grants because scientists have an additional burden requiring their research to directly benefit society (J. B. Holbrook &

Frodeman 2007). This burden especially impacts junior scholars because they may not have the skillset or resources to do BI activities and high quality research (Tretkoff 2007).

A third criticism attacks the philosophical roots of research impact. Some scientists do not believe research should be judged based on impact (J. B. Holbrook & Frodeman 2007). These scientists argue that research may not have any apparent impact for society, but the topics should still be explored to further scientific knowledge. Also, the research could have unanticipated societal benefits. For example, the first scientists studying the atom's structure did not know their research would create a new source of power (Stokes 1997). Other scholars argue that broader impact requirements are based on a flawed linear model of R&D that does not match the reality of R&D (J. B. Holbrook & Frodeman 2007). Rather, models such as Pasteur's Quadrant, a two by two grid of consideration of use and quest for fundamental understanding, better match reality (Fisher et al. 2006; J. B. Holbrook 2005; Stokes 1997). Some argue that it would be more efficient to fund grants specifically designed to have impacts rather than forcing a natural science grant to include BIs. This would prevent researchers from dividing their attention and working on projects that are not their specialty in order to meet the BIC (Tretkoff 2007).

Finally, a fourth criticism of BIs is that the grant peer review process is inadequate to assess them (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 BIs and outreach programs. As a result, the panelists are evaluating impact without any skills to assess the quality and potential benefit of the project (Bozeman & Boardman 2009).

Despite criticism, requirements such as 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 continue to enforce BI activities to match legislation (National Science Board 2011). However, the NSF does not rigidly define BIs, allowing for a range of activities to meet the BIC (National Science Foundation 2014). In general, BIs are categorized by the NSF 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).

To determine how these guidelines are interpreted and met by scientists, Roberts (2009) studied the distribution of BIC across grant recipients. Roberts divides the eight BIs 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 on BIs but looked at certain fields. For instance, Kamenetzky analyzed BIs in biology, mathematical and physical sciences (Kamenetzky 2013) and Nadkarni and Stasch examined the BIs of Ecosystems Studies Programs (Nadkarni & Stasch 2013). Both studies found that training/education was the most common BI activity.  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 BI activities, 5.5%, than they accomplished. Another major finding was that awarded grants proposed 10% more BI activities than non-awarded grants (Watts et al. 2015).

The most comprehensive study of BIs was commissioned by the National Science Board. The researchers analyzed the BIs 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). Clearly, scientists are responding to the BIC, though in some areas more than others. What is not clear, however, is *who* benefits from the funding, the alignment of the research with the broader impacts, the degree that the BIC is a simply a box checking exercise, and how these impacts might redress social inequalities (Watts et al. 2015).

*Immediacy and Inclusion*

In 2016, a team of NSF officials and grant 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 BI activities. Jacobson et al. define immediacy as the inherent nature of the BI activities relative to the research and they divide immediacy into three levels: intrinsic, direct, and extrinsic immediacy. Intrinsic immediacy means that the BI activities are central to the research project or that the BI are co-produced within the underlying research. For instance, if a PI is developing a new solar panel, the BIs of producing clean energy are intrinsic to the grant. Direct immediacy refers to BIs 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 be impossible to finish the project unless graduate students are trained. The training is directly related to the research. The third level of immediacy is when the BI activities are extrinsic to the actual project. If a PI visits a secondary school to share the research results on nuclear physics, then the BI activities are separate from the research and have extrinsic immediacy (see Table 2).

To the immediacy classification, this study adds the dimension “inclusion” in order to determine the types of people that benefit from the research. The inclusivity dimension has three categories; universal, advantaged/status quo and inclusive. The first category, universal, means that the innovation targets everyone, regardless of status. 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 to everyone and everyone benefits from the research.

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

The third category of inclusive innovation refers to innovations that are designed to help marginalized communities directly. A marginalized community is a group of people that are "peripheralized on the basis of the identities, associations, experience, and environments" (Leblanc 1997). Marginalization is broader than just poverty or being from an underrepresented minority group. In some countries, a person's dialect, gender identification, or religion could cause them to be marginalized. An inclusive BI might include increasing the participation of women in STEM fields or piloting new pedagogical approaches for children with special needs.

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

The new framework assesses BIs by tracking *who* will benefit from the project and *how* the impact relates to the central goal of the grant. The IIC does not narrow the types of impact to a few categories or define these categories in advance. The specific activity associated with the BI is less relevant to the IIC than the way BIs are implemented and the group membership of their beneficiaries. The IIC can be applied to a range of funding agencies and projects, allowing researchers to propose and innovate potential impacts that they see as best suited to their work. It is a tool to determine the extent to which BIs are inherent in the work and 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 materials and products (Balogh 2010). Nanotechnology is a rich 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 improve the lives of 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 about 100 nanotechnology related terms to find all the grants with those keywords. Then, the strategy uses a separate set of exclusion terms to remove grants that include words with "nano", such as nanoplankton and nanosecond, but are not related to nanotechnology. We applied the search strategy on NSF's publicly available awards using the advanced 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 BIs and intellectual contributions more explicit in grant applications. The changes to the proposal and proposal summary do not automatically require abstracts to discuss BIs, but it increases the likelihood that the abstracts will have BIs. Previous studies on BIs from 2000-2010 found that 26.2% of abstracts did not contain them even though the main proposal discussed BI activities. From this observation, a previous study concludes that analyzing the abstracts from before 2013 is not very accurate (Watts et al. 2015).

Out of the 6,854 grants, the team used a simple random search to select 300 research grants to code. Each of the sampled grants represents an individual project and is not a supplement or continuation of another project. A sample of 300 grants gives the project sufficient explanatory power for an exploratory qualitative study (Bartlett et al. 2001; Raosoft Inc 2004). For this project, the team only coded NSF research grants. The NSF funds a variety of activities like education or building large scientific infrastructure, but we excluded these types of grants from the study because we are interested in how NSF's funded research impacts inclusions.

Parallel to creating the corpus of nanotechnology grants, the authors developed a coding strategy for the IIC (see Table 2). The principal investigator, Author A, took the lead in developing the coding strategy, but he was assisted by the co-authors of the paper, Author B and Author C. The team reviewed the literature on scientific impact and inclusive innovation to develop a definition for each cell. Since marginalization is very context specific, this study uses the NSF and NIH definition of underrepresented communities. In their definition, marginalized communities are underrepresented minorities in STEM field, individuals with disabilities, and those from disadvantaged backgrounds, such as people that were or are eligible for foster care (National Institutes of Health 2020).

Then, using a training set of 30 grants from the randomly selected 300, the research team defined a coding scheme and tested the coding strategy for intercoder reliability. Finally, the research team coded the sample of nanotechnology NSF abstracts to determine the immediacy and type of inclusion of the grant. Author B primarily coded the grants, but if there was any conflict or ambiguity in the coding guidelines, the researchers would discuss the problem and mutually decide the best way to code the data. The team used RQDA to manage and code the grant abstracts. RQDA is a package on the R statistical platform for qualitative data analysis (Huang 2018).

*Intercoder reliability*

To verify the accuracy of the coding, an outside third researcher (credited in the acknowledgements) was trained. She coded a 10% reliability sample of grants. In the first round of intercoder tests, the Krippendorff alpha score between the tertiary coder and the two primary 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. The tertiary coder misclassified all the grants for these categories because she was not correctly trained on classifying these areas. When those errors were recoded based on the correct classification strategy, the Krippendorff Alpha score increased to 0.77. According to researchers this is a sufficiently high Krippendorff alpha score to make tentative conclusions about the results (Hallgren 2012; Hayes & Krippendorff 2007; Krippendorff 2011).

*Challenges with coding*

The IIC addresses a persistent problem in broader impact statements of quality versus quantity. Previous studies on BIs state that scholars may simply use the BIs as a checklist and try to score as many points as possible as opposed to suggesting a holistic project (National Science Board 2011). While reading the abstracts, it is easy to identify PIs who seem to propose broader impacts as more of a check box exercise. These grants discuss BIs without any description of how they will achieve their goals. 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 diversify STEM fields, we code it as broadening participation, even though the grant does not detail how it will broaden participation. By contrast, 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." The second grant gives clear steps of how they will have impact. The team finds that for some categories, like broadening participation, about 40% of the grants provided generic statements about reaching marginalized groups without giving any details on how they will reach those groups.

A final challenge is determining the targeted beneficiaries when not explicitly stated in the abstract. 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/ benefit advantaged 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. One principle that helped us resolve conflict was to "give the benefit of the doubt" to inclusion. If the grant made a reasonable attempt to say that the research was universal or inclusive, the team gave the grant the "benefit of the doubt" and coded the grant towards more inclusion. The consequence is that our results may be more skewed towards inclusivity. However, there were few ambiguous abstracts. Most of the abstracts listed common BIs like training/education (219/300), K-12 outreach (101/300) or and broadening participation (101/300). See Table 4 for more details.

**Section IV: Inclusion Immediacy Criterion**

As mentioned before, the IIC framework has two dimensions, each with three levels that form a 3X3 grid. Each cell in the grid represents a different degree of inclusivity and immediacy; the grid is not organized by a set of activities. Rather, it classifies the grant based on the intended beneficiaries and the relationship between the impact and research activities This is a departure from previous studies that classify BI activities as based on Table 1. By analyzing the depth and focus of the BIs, 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 aid university students. The IIC framework recognizes these differences.

A key characteristic of the chart is that it is a grid and not a ladder or hierarchy. The IIC does not dictate which cell is "better" for science, but rather the IIC describes the degree of inclusion and immediacy. The value of each cell depends on the goals of the funding organization and the project. Some funding mechanisms may have the explicit goal of supporting science and technology research that benefit marginalized groups while other projects support R&D for advantaged communities. For example, many hi-tech products, like novel medical innovations or quantum computers, will first be used by large 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.

*Intrinsic/Universal*

In this cell, the grant proposes research that could benefit everyone, and the BIs 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 or status, would benefit from the technology (Fang et al. 2012). Grid improvements are non-rivalrous and non-excludable. The BIs are also intrinsic to the research. Below is a quote from a 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 puts demand 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 BIs are central to the research, so it is classified as intrinsic.

*Intrinsic/Advantaged*

Grants in this category are either geared towards advantaged 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 advantaged groups, like the wealthy, educated and politically connected. An example of a technology that fits in this category is 3D printers. The first users of this technology were advantaged 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 assisting low income populations (references removed for blind review.

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 advantaged group because chemists tend to be 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/advantaged. 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 broader impact is intrinsic to the research and the research will primarily benefit 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 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 BIs are achieved while doing the research. The impact is not the focus of the research, but it would be very challenging, if not impossible, to complete the research without having an impact along the way. Universal BIs 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, but 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 the public. An example of a direct/universal grant is a project where the main goal was to quantify the friction generated heat from earthquakes. To achieve this goal the team partnered with the Utah Geological Survey, a state government agency. The grant is classified as direct because the partnership with the Utah Geological Survey was necessary to complete the research, but the partnership was not the main goal of the work. The partnership with the Utah Geological Survey is universal because the new map data generated from the project will improve flood and earthquake protection for everyone in the state.

*Direct/Advantaged*

In this cell, the BIs 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 an advantaged 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 advantaged groups and maintain the status quo.

Training graduate students is directly related to the research, but in most cases, graduate training is not the purpose of the research. Training students is a means to accomplish the end goal of the research project. Consequently, graduate training is categorized as direct. A good example of an education program that is *direct/advantaged* is a grant that allows "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."

We also placed sharing research results with other academics as direct/advantaged. Going to conferences and disseminating results is a key part of the research process, but it is not the main goal of most funded projects. Finally, industry collaborations are considered direct/advantaged. Unless the industrial collaboration explicitly says that the R&D will target 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 benefit advantaged groups. 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 likely benefit advantaged groups or maintain the status quo. 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 researchers must explicitly state that goal for the grant to be coded as such.

*Direct/ Inclusive*

Grants in this cell are like *direct/advantaged* grants, but instead of the research targeting advantaged groups, the research is directed towards marginalized communities. The best example of research that fits in this category is training graduate students 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 mentors women transitioning to academia from postdoctoral and graduate positions.” Another type of grant that falls in this category proposes 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 conduct the research, and the pump also aids marginalized communities.

*Extrinsic/ Universal*

Grants in this category propose outreach activities that are unrelated to the research and have universal impact. The most common type of activity that fits in this category is developing a new primary and secondary school curriculum that incorporates finding from the research. In theory, the new curriculum could improve every child’s life regardless of status because every child in the

USA is entitled to free primary and secondary education. Other types of BIs that fall in this category are educating the public about environmental hazards or working with public museums to disseminate science. 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 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), an explicitly universal goal.

*Extrinsic/ Advantaged*

This cell represents BIs that are not related to the research and target problems faced by advantaged groups. An example of a BI that fits in this category is developing new graduate courses related to the research. Developing a graduate course is extrinsic because the research could still move forward if the graduate course were not developed. It is classified as advantaged because, as mentioned before, graduate students are generally a part of an advantaged community. 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 marginalized 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 BIs that are unrelated to the research and address problems facing 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). In the other dimension, the most common type of inclusion was advantaged (235), followed by universal (213) and inclusive (109). Therefore, PIs are proposing research that is inclusive, 109 grants, but at lower rates than research that has universal benefit or benefits advantaged groups. Within inclusive grants, 94% 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 NSF's BIC from table 1, there are obvious overlaps (see Table 4 and figure 1). Grants that are universal/intrinsic are closely related to the NSF's requirement that grants have potential societal benefit. 160 out of 174 potential societal benefit grants are considered universal/intrinsic. Similarly, K-12 outreach and BIs that are 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.

Another important finding addresses the criticism that BIs requires scientists to do work, like developing K-12 curriculum, that is outside of their specialty (Tretkoff 2007). Critics argue that instead of scientists worrying about BIs, it would be more effective for them to concentrate on their research and give broader impact grants to teachers, museums, and community organizers. This study finds that scientists propose extrinsic BI activities (110/300) at a lower rate than intrinsic BI activities (200/300) and direct BI activities (232/300). In addition, in every grant where a PI proposed an extrinsic BI activity, they also included BI activities that were direct or intrinsic. Therefore, we believe that the criticism that BIs distract scientists is a small concern. The BIC may push scientists to consider impact, but in general, broader impacts align with the research.

**Section VI: Implications and Recommendations**

The new coding scheme based on inclusivity and immediacy measures who benefits from the proposed BIs and the relationship between the broader impact and the research. The IIC gives the NSF a tool to evaluate the distribution of impacts (at least at the point of funding). Given that the benefits of scientific research do not spread evenly across the population – and may even exacerbate inequalities (Bozeman 2020), measuring how benefits are distributed is critical to inform science policy. Indeed, technology and politics are neither neutral nor separate, but mutually constitutive (Veak 2000). This gives the NSF an important opportunity to shape the direction of science policy to encourage research that will advance societal aims.

To do so, sufficient evidence and information is key. As Rosenbloom and Ginther (2017) found in their study of how NSF programs influence diversity in computer science and information technology, evaluative tools like the IIC may not solve a problem but help researchers to better understand how to tackle it. The IIC can establish baseline data on the inclusivity and immediacy of NSF-funded research and evaluate the effectiveness of policy in these areas at later time points. Using the case of nanotechnology, this paper has shown that despite high expectations for this field (Selin 2007) current research in this area is most likely to maintain the status quo.

To harness the potential of nanotechnology to have inclusive impacts, scholars recommend participatory dialogue and the dissemination of clear information about the state of the science and how it interfaces with societal needs (de Bakker et al 2014, Schaper-Rinkel 2013). This allows for deliberation among the scientific and wider community to understand and influence research and design science policy (Genus and Iskandarova 2018). Such discussions require leadership and clear priorities because equality and inclusion are rarely a scientist's primary goal (Bronson 2019). However, there is ample evidence that equality and inclusion support NSF objectives of welfare, prosperity and security for the nation (National Research Council 2001, National Science Foundation 2014, Thorbecke and Charumilind 2002) *and* that government intervention and legislation are effective tools to mitigate elite capture of R&D (Asongu and Nwachkwu 2016, Fisher and Mahajan 2006, Hall and Matos 2014). The NSF can therefore use the IIC to make policy decisions that incentivize research for marginalized groups. It can also contribute to the prestige of inclusive research leading to an increase of research proposals from university academics (Hicks et al 2012).

While the IIC improves our understanding of the impact R&D has on marginalized communities which is helpful to inform policy interventions, it does 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). Even if science funding agencies fully adopt the IIC, there will still be a mismatch between scientific expertise and assessing impact if the composition of the review panelists remains unchanged. Indeed, across science funding agencies evaluation of BIs has been found to be "soft," requiring a report but without scrutinizing its contents (Langfeldt and Scordato

2015). This behooves institutions to train reviewers or bring in impact specialists to assist in the evaluation process. It may also be an opportunity to involve end users of the research through a citizen science approach (Sauermann et al 2020). If institutions introduces stricter monitoring requirements, universities might train academics to better plan for and implement their BIs.

In summary, it is recommended that science funding agencies, such as the NSF, consider the following policy recommendations:

- *Determine the agency's commitment to equality and inclusion and promote research that reinforces these aims*
- *Legitimize and celebrate inclusive research, contributing to its prestige and incentivizing projects with inclusive aims*
- *Involve scientists, the public, and experts in the area of social issues in open discussion, providing clear information about how research interfaces with their priorities*
- *Evaluate the inclusivity of funded projects on an ongoing basis*
- *Incorporate impact experts in grant-review panels*
- *Provide training to scientists to better plan for and monitor their broader impacts*
- *Provide avenues for end users of research results to submit impact feedback*

**Section VII: Limitations and Conclusion**

This study is 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, if the IIC, or something similar, is ever adopted, it will generate new challenges. How will PIs respond to the framework and how will they change their grants to match the IIC? Finally, the IIC framework must be tested on several types of grants and agencies. As the study expands, the classification strategy will improve and become more robust.

Overall, most of grants in the sample research will help everyone (universal), 213 out of 300, or advantaged groups, 235 out of 300. 109 of the 300 grants proposed BIs that were inclusive. This means that about a third of the grants propose research that was specifically directed towards marginalized groups. Depending on a 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 is 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 does provide a new tool to understand and quantify who benefits from science funding. By examining grants through the lens of inclusivity and immediacy, scholars can better inform policy decisionmakers on the impact that sponsored research has on marginalized communities. In the future funding agencies can apply lessons learned from this project to design and assess science funding mechanisms that incorporate immediacy and inclusion requirements.

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*Table 1: Broader Impact Coding Scheme of Roberts 2009*

| | |
|---|---|
| *Criteria for Science* | |
| Infrastructure for Science | Creation of new research methodology, tools, or data sources that will be useful to advance science |
| Broadening Participation | Recruiting or including under-represented groups in research or in outreach efforts. Includes efforts to attract woman to science and to keep them in the academic pipeline for all fields, but excludes funding female students in biology and social sciences |
| Training and education | Includes mentoring undergraduates, graduate students and postdoctoral fellows in the laboratory and teaching classes |
| Academic Collaboration | Research collaborations with other universities in the US or abroad |
| K-12 Outreach | Outreach to kindergarten to 12$^{th}$ grade students or teachers helps to get kids excited about science and ensure a pipeline of future scientists. Note: In the USA K-12 education is synonymous with primary and secondary education |
| *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 |
| Outreach/Broad Dissemination | Dissemination of research results for non-academic audiences in any form (web site, seminars, meetings, newspapers). Does not include K-12 outreach |
| Partnerships with Potential Users of Research Results | Includes partnerships with industry, non-profits, government bodies and national labs |

*Table 2 Inclusive-Immediacy Criterion (author generated)*

| | | Immediacy of Broader Impacts | | |
|---|---|---|---|---|
| | | Intrinsic | Direct | Extrinsic |
| | Universal (everyone) | Developing smart grid technology | Collaborating with public sector utility | Creating new K-12 curriculum |
| Inclusivity of broader impacts | Advantaged/Status Quo | Smart watches/fabrics, infrastructure for science | Training undergraduate research assistant | Developing new graduate course |
| | Inclusive (marginalized group) | Developing new malaria medicine | Training underrepresented groups in STEM | Building a water treatment facility in a poor country |

*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)*

| | Intrinsic | Direct | Extrinsic | Total grants* |
|---|---|---|---|---|
| Universal | 163 | 8 | 108 | 213 |
| Advantaged | 41 | 224 | 3 | 235 |
| Inclusive | 9 | 102 | 1 | 109 |
| Total grants * | 200 | 232 | 110 | 300 |

*Table 4 Comparing IIC to NSF categories (*Note that the row and column totals does not equal the sum of the interior cells because grants can be coded in multiple cells)*

| | Infrastructure for Science | Broadening Participation | Training/ Education | Academic Collaboration | K-12 Outreach | Potential Societal Benefits | Outreach Broad Dissemination | Partnerships with Potential Users | Total* |
|---|---|---|---|---|---|---|---|---|---|
| Intrinsic/Universal | 2 | 0 | 2 | 5 | 0 | 160 | 1 | 2 | 162 |
| Direct/Universal | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 6 | 8 |
| Extrinsic/Universal | 0 | 40 | 51 | 4 | 99 | 0 | 14 | 5 | 108 |
| Intrinsic/Advantaged | 37 | 1 | 1 | 1 | 0 | 5 | 0 | 1 | 42 |
| Direct/Advantaged | 2 | 51 | 215 | 24 | 50 | 3 | 8 | 22 | 224 |
| Extrinsic/Advantaged | 0 | 0 | 2 | 0 | 1 | 0 | 3 | 0 | 3 |
| Intrinsic/Inclusive | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 9 |
| Direct/Inclusive | 1 | 99 | 49 | 0 | 37 | 0 | 3 | 5 | 102 |
| Extrinsic/Inclusive | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Total | 37 | 101 | 219 | 77 | 101 | 174 | 23 | 29 | 300 |

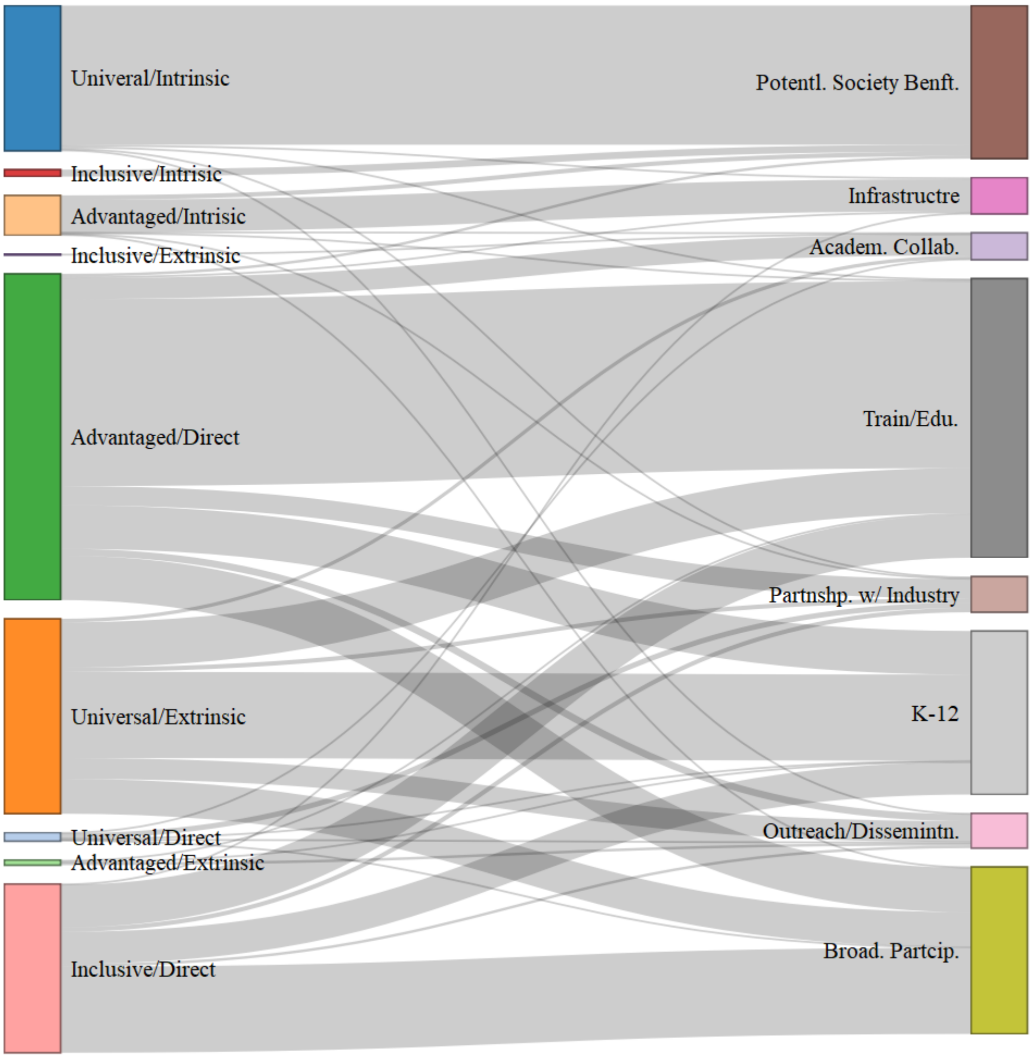


*Figure 1 Sankey diagram showing how the IIC relates to the NSF BIC*