AN ABSTRACT OF THE THESIS OF

Saskia D. Madlener for the degree of Master of Science in Marine Resource Management presented on August 19, 2014.

Title: Communicating Oceanographic Research Through Film: The Role of Film in Helping Scientists Develop and Meet their Broader Impacts Goals

Abstract approved:

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Funding agencies, specifically the National Science Foundation (NSF), are placing particular emphasis on the societal relevance and broader applications of scientific research, otherwise known as Broader Impacts (BIs). Scientists are required to address the BIs merit review criterion in their research proposals or they will not get funded. However, many scientists perceive the BIs criterion to be confusing and daunting, and developing activities to meet these requirements is often not within their expertise. One way to reach a vast audience and make scientific research more relevant and compelling to the broader public might be through documentary film. This study explores the relationship between film, science communication, and BIs.

To address this relationship, this study includes: 1) an analysis of existing interview data on scientists' perceptions of and experiences with BIs and 2) an in-depth case study of a small sample of scientists, some of whom were filmed conducting research on glacier melting in Greenland. Data were analyzed using thematic content analysis related to how the filmmaking process (1) influenced the scientists' communication of current research and (2) helped the scientists both develop and meet their BIs goals.

Findings from this study indicate that being filmed throughout the research process had minimal impact on the scientists' communication of their work. However, partnering with a filmmaker compelled these scientists to develop clearer and more compelling messages about the

societal relevance of their research. This research contributes to the understanding of what might drive scientists to develop BIs goals and engage with filmmakers or education and outreach specialists in order to meet their goals.

Communicating Oceanographic Research Through Film: The Role of Film in Helping Scientists Develop and Meet their Broader Impacts Goals

by
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A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirement for the
degree of

Master of Science

Presented August 19, 2014
Commencement June 2015

Master of Science thesis of Saskia D. Madlener presented on August 19, 2014.

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Saskia D. Madlener, Author

ACKNOWLEDGEMENTS

I am extremely grateful for the opportunities the Marine Resource Management program and the College of Earth, Ocean, and Atmospheric Sciences afforded me while completing my master's degree. My co-advisors, Flaxen Conway and Shawn Rowe, were instrumental in allowing me to pursue my dream to produce a film as part of my thesis research. I am grateful for their support and guidance when designing a research topic that would fit my intellectual and creative needs, and for grounding me when I was eager to make bold statements about the role of film in science.

To the participants of the Greenland Project specifically, I thank you for your patience, trust, and devotion throughout the long and sometimes arduous process of being filmed while conducting research; thank you for working with me to produce a film that could serve and benefit us all, despite some initial reservations and skepticism about involving an outsider in the field. I would like to thank Emily Shroyer specifically for advocating for my involvement to film the Greenland research and for serving on my committee. And thank you to John Becker-Blease for serving as my graduate council representative. I am also very grateful for the tremendous insight provided by the other two interview participants to help bolster some of the claims made in the study, specifically regarding film production in science.

Many thanks to the Center for Research on Lifelong STEM Learning at OSU for providing interview data to be analyzed for this study and for providing useful resources on the history and current standing of broader impacts. Thank you for the work that you do for researchers at OSU, you provide an invaluable service to the scientific enterprise.

Finally, I am eternally grateful for the support of my friends and family. I could not have shot, produced, and edited my documentary, Greenland's Glaciers, without your involvement in some way. I am specifically grateful for my mother, Dominique de Cock, and friends Cati van Milders, Frank Arentowicz, Patricia Wadzinski, David Reinert, Andy Menking, Matthew Berger, and Charlie Brooks. You all have made my pursuits as a science filmmaker possible and I will never forget your role in helping to shape my career and who I am today.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

COMMUNICATING OCEANOGRAPHIC RESEARCH THROUGH FILM: THE ROLE OF FILM IN HELPING SCIENTISTS DEVELOP AND MEET THEIR BROADER IMPACTS GOALS

CHAPTER I

INTRODUCTION

> Since its early modern origins, modern natural science has struggled to develop appropriate standards for quality assessment. In particular, one of the main issues has been the extent to which science ought to be judged only on its own terms. The history of science provides extensive literature on the effort to establish science as an autonomous human activity independent especially of religious or political manipulation. (Holbrook, 2012, p. 2)

Problem Statement

Historically, science was conducted for the purposes of discovery and of gaining a deeper understanding of the physical world and its inhabitants. Scientific research was not always a field that needed much justification; individuals like Galileo and Newton were able to act on observation and intuition to develop scientific theories without needing to adhere to societal demands. Bernal (2013), however, argues that society—or social and economic change—has informed scientific output since the Italian Renaissance. That is, different societal phenomena such as the end of feudalism or the birth of capitalism and industrialism dictated the directions in which science could advance. This is also true in modern times; science has a direct link to national security, human health, climate change, and resource management, and the criteria for funding research has evolved to focus on these contemporary human concerns.

Since the late 1990s, scientists have been tasked with identifying the broader implications of their research and reaching out to the public by communicating and disseminating their science in some way (Frodeman & Parker, 2009). In 2007, the US President's Advisor to Science, John Holdren, urged scientists to allocate 10% of their professional time to work "in ways that increase the benefits of science for the human condition" (Nadkarni & Stasch, 2013, p. 13). In a time when people are becoming less familiar with or connected to nature, bridging the gap between society and science, or people and nature, has been at the forefront of the scientific enterprise and has propelled research in the field of Informal Science Education (ISE) (Falk, Randol, & Dierking, 2012).

Formal and informal education in the sciences is important in terms of enhancing the public's scientific literacy, or "the knowledge and understanding of the scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22). The advantages of scientific literacy include increased environmental stewardship, support around pivotal policy, and more informed decision-making on both individual and societal levels (Hazen & Trefil, 2009; Hurd, 1998; Steel, Smith, Opsommer, Curiel, & Warner-Steel, 2005).

There are conflicting definitions and interpretations of scientific literacy, or how it can be advantageous to society and ultimately the natural world. However, the concept of increasing the public's understanding of science has galvanized a movement in professionalism and expertise in science communication; science communicators are key players in providing "educational and interpretive opportunities for the general public to better familiarize itself with science" (Laugksch, 2000, p.75).

A recent push on a national level to communicate science and to emphasize the societal impacts of scientific research—otherwise known as Broader Impacts (BIs)—has opened many doors for professionalism in science communication. BIs are becoming increasingly important in justifying scientific research, and taxpayers have the right to access the information that their hard earned dollars go toward funding in order to make better decisions for self and society (Frodeman & Holbrook, 2013).

Federal funding organizations such as the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) emphasize the need for student and public engagement in science to benefit society, enhance scientific literacy, broaden participation, and advance discovery (National Science Board, 2011). In 1997, the NSF introduced two sets of merit criteria that must be addressed in the proposal phase of all research projects: Intellectual Merit, which involves the potential to advance knowledge within science and to communicate that knowledge within the Science, Technology, Engineering and Math (STEM) or scholarly community, and BIs, which entails reaching beyond the STEM community by designing and implementing educational and outreach activities (Frodeman & Parker, 2009; National Science Board, 2011).

Intellectual Merit has been integral to the scientific enterprise for centuries, whereas BIs, though endorsed in theory and by the many scientists who support education and outreach efforts, require scientists to delve into the unfamiliar world of Education and Public Outreach (EPO) (Holbrook & Frodeman, 2007). The BIs criterion has faced mixed reviews from the STEM community. Some scientists find the requirements to be confusing, burdensome, or even punitive; others feel that funding should be awarded based on the quality of the research rather than the outreach (Tretkoff, 2007). Nevertheless, scientists are tasked with designing a suite of Broader Impacts Activities (BIAs) such as conducting educational activities for K-12 students or giving public talks, all of which extend well beyond their realm of expertise.

Whether or not the scientists themselves should be the ones to develop BIAs is another issue. Though one of the goals of BIs is to integrate STEM and EPO, many scientists do not have the interest, expertise, time, or the talent to conduct public outreach. The desired outcomes of BIs are perhaps totally missed with NSF's current model:

> "The current de facto policy that each [principle investigator] should excel in both STEM and [BIs] activities (because only those that excel in both are now likely to be funded) could be construed as a policy designed to change the behavior of scientists rather than to ultimately achieve concrete goals in science, education diversity, and societal benefit. " (Burggren, 2009, p. 229)

Burggren (2009) argues that the NSF should consider a model in which EPO experts are the ones funded to achieve BIs rather than the principle investigators (PIs). This is not to say that scientists should never engage in EPO themselves, in fact that would reinforce the division between STEM and EPO that the NSF is trying to overcome with the new merit criteria (Frodeman & Holbrook, 2013). Frodeman and Holbrook (2007, p. 29) also argue that scientists have a "moral and political obligation to consider the broader effects of their research," especially since they are publicly funded. They suggest including EPO specialists on review panels to encourage inter-disciplinary collaborations between researchers and EPO specialists.

One BIs tool that might be particularly useful to scientists and EPO experts as they seek ways to fulfill this outreach and engagement mandate is film. Film necessarily involves the expertise of someone in communications (Olson, 2009). Few studies have been conducted to find whether film or video, as a communications medium in general, could help foster a more scientifically literate public. However, television programs such as Cosmos: A Personal Voyage, hosted and written by astrophysicist and science communicator Carl Sagan, and science films such as The Inconvenient Truth, produced by politician and environmentalist Al Gore, have entered the mainstream and could contribute to inspiring scientific understanding in broader audiences.

Project Description

The goal of this study was to identify and understand the challenges associated with both developing and meeting BIs goals, and then to evaluate the role of film in helping scientists to overcome those challenges. Two sets of qualitative data were analyzed to address this issue. One set of data came from the Center for Advancement of Informal Science Education (CAISE). In 2013 CAISE commissioned the Center for Research on Lifelong STEM Learning (STEM Center), located at Oregon State University (OSU), to compile a report on scientists' experiences with BIs. The STEM Center was established as a service to scientists to provide expert EPO guidance and training, and they conducted a "Broader Impacts Invitational Workshop" on December 7, 2012. The goals of the workshop were to help move OSU in a direction to support BIs training and activities so as to improve the competitiveness of submitted research proposals out of OSU. They solicited information from 65 participating faculty from a broad range of disciplines across the nation to analyze scientists' perceptions, processes, and planning around BIs. The specifics of this study are covered in Chapter III.

The second set of data was collected specifically for the purposes of this study. This data was gathered from a group of scientists conducting oceanographic research in Greenland, henceforth referred to as the Greenland Project. A team of NASA-funded physical oceanographers and glaciologists from OSU and other institutions conducting research on glacier melting in Western Greenland are making measurements over a two-year period of two neighboring fjords in which glaciers are experiencing differential accelerations; one is receding while the other has held steady. These scientists predict that because the fjords are neighboring each other, dynamics in the fjords (in the ocean) might have more of an influence on glacier behavior than the overlying atmosphere. As the Greenland ice sheet is melting at an unprecedented rate due to warming in both the atmosphere and ocean, it is important to understand how that rate will change, what dynamics are contributing to melt, and how melting can impact other dynamics in the ocean, namely rising sea-levels and the introduction of fresh-water in the North Atlantic.

Recent studies have shown that ocean-driven melting may play a large role in the mass balance of the Greenland ice sheet. Marine-terminating outlet glaciers are especially vulnerable, with a predicted increase in Greenland's surrounding mean ocean temperatures of 1.7-2.0°C in the next 100 years, double the value of the projected global mean (J. Yin et al., 2011). Some of the identified ocean-driven dynamics include warm subsurface water and basal melting, seasonal variations to vertical stratification in the fjord, and different circulation modes in the tidal outlet glaciers (Holland, Thomas, Young, Ribergaard, & Lyberth, 2008; Mortensen, Lennert, Bendtsen, & Rysgaard, 2011). Other studies show that warmer, saltier subtropical waters from the North Atlantic can travel and become trapped in the subsurface layer of the fjord, flushing the glacier face year-round (Straneo et al., 2011). These and other possible ocean-driven dynamics are causing thinning rates to increase each year (Howat, Box, Ahn, Herrington, & McFadden, 2010). In order to refine sea level rise projections, it is important to maintain a synchronized examination of the atmosphere-ocean-ice interplay.

Lastly, for this study I produced a 22-minute science documentary about the first summer field season of the Greenland Project. The film follows three physical oceanographers as they both prepare for and conduct their research aboard the R/V Sanna in western Greenland in September 2014. The film utilizes human-driven narrative to acquaint the audience with the scientists behind the research. It "humanizes" the scientists, and ultimately communicates elements of the research that are relevant to the societal implications of their study, namely sea-level rise. The film was completed and screened in May of 2014 at OSU. The three scientists featured in the film were part of the film's review process; they viewed and critiqued several rough cuts of the film to ensure that their science and their image were properly and honestly presented. This process, and the film itself, provided the data used for analysis as well.

CHAPTER II

RATIONALE

The following rationale is by no means an exhaustive review of the literature on the interplay between film, science communication, and BIs. Instead, this review establishes the groundwork necessary to both justify and provide context for this study and its relevance in terms of scientists' experiences with film and BIs, as well as the potential for facilitating the transition to EPO, science communication, and BIs for scientists.

Due to the dearth of research on the role of film in science, science communication, and scientific literacy, this review explores several foundational topics to help frame this issue and, ultimately, contextualized the findings of this study. This section is therefore divided into four main sections: (1) Motivations in Science; (2) Science Communication; (3) Broader Impacts; (4) The Role of Film in Science and Outreach. The links between these themes and the findings of this study are explored in Chapter V.

Motivations in Science

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team, whether the conditions be peace of war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world. (Bush, 1945, p. 233)

Around the time when the NSF was being founded in post-World War II America, Vannevar Bush, then the director of the Office of Scientific Research and Development, became a strong advocate for autonomous, or "basic," science (Holbrook, 2012). He argued that basic research drove the economy and increased employment as new industries sprouted around technological advancements, such as plastics. Scientific advancement was necessary to accommodate the growing population of the 20th Century, to combat disease, and to ensure the nation's safety. The study of nature's laws and the pursuit of new knowledge were endeavors that would eventually lead to practical applicability.

Bush was especially supportive of educational and research institutions where scientists were afforded the freedom to seek knowledge without the “pressures of convention, prejudice, or commercial necessity” (Bush, 1945, p. 241). Among the *Five Fundamentals* to developing a governmental support structure for scientific research, what he would later refer to as the National Research Foundation, Bush especially advocated for unrestricted pursuit of science within the institution:

> “Support of basic research in the public and private colleges, universities, and research institutes must leave the internal control of policy, personnel, and the method and scope of the research to the institutions themselves. This is of utmost importance.” (Bush, 1945, p. 255)

In other words, Bush was wary of a funding institution that would impose strict requirements that could undermine the scientific process.

Basic science has been defined as “uncommitted research, prompted by disinterested curiosity, and aimed primarily at the extension of the boundaries of knowledge” (American Council on Education & Committee on Institutional Research Policy, 1954, p. 42). Applied science, in contrast, is generally defined as the pursuit of a solution to a particular problem and is driven by an implicit belief structure or set of values and norms. According to this distinction research that contributes only to scientific knowledge cannot viably position itself in the marketplace. Furthermore, “the scientist who invents for the market rather than for the cathedral loses his membership in the social system of pure science” (Shepard, 1956, p. 51). However, Shepard (1956) challenges whether these definitions truly distinguish basic from applied science. Even basic science is only supported so long as it makes contributions to the “great cathedral of knowledge”, making implicit its own set of values (Shepard, 1956, p. 50).

Gibbons et al. (1994) separate the sciences according to Mode 1 and Mode 2 production of knowledge, which generally align with the definitions of basic and applied science respectively. Mode 2 production is further characterized by multi-disciplinary efforts over a short period of time to tackle a specific problem in the real world (Gibbons et al., 1994). The Mode 1 versus Mode 2 model, however, perpetuates the notion that science can operate separately from external influences or from the interests of society. Mode 1 is a construct that fails to acknowledge that science has always been organized through networks, specifically according to a growing triadic relationship between university-industry-government (Dzisah, 2010; Etzkowitz & Leydesdorff, 2000). Scientists do not operate in isolation of economic or societal development, or of each other, and scientific output has for a long time been determined by the needs and wants of society (Baber, 2000; Bernal, 2012).

Traditionally, basic research is primarily supported (by public funds in many cases) for the sake of generating new useful knowledge for the public good (Salter & Martin, 2001). Critics of basic science operate under the misconception that research for the sake of extending the boundaries of knowledge rarely has economic or societal benefits (Pavitt, 1991). However, Salter & Martin (2001) found that the economic benefits from basic research come in a variety of forms and are not necessarily noticeable at the source. Benefits include: skilled individuals who contribute to innovation and industry, technological development both in instrumentation and methodology, expansive networks of experts and information that can trickle into government (policy) and industry, and, finally, “basic research may be especially good at developing the ability to tackle and solve complex problems” (Salter & Martin, 2001, p. 527) Whether or not these outcomes, especially within the realm of technological advancement, are ultimately beneficial to humans is a philosophical debate and extends beyond the scope of this study.

Solving complex, specific problems is generally the role of applied science but basic research can in fact lead to more profoundly influential and long-lasting solutions precisely because it is not framed by a specific problem (Klevorick, Levin, Nelson, & Winter, 1995). Furthermore, by incorporating basic research into applied science, which commonly occurs in engineering for example, industries can flourish and become more diversified, making them stronger competitors in the marketplace (Klevorick et al., 1995).

Nevertheless, the schism between basic and applied science causes problems for scientists today who are driven by “pure” science but who are still bound by the same criteria as those scientists developing malaria vaccinations or more accurate climate models (Dzisah, 2010). However, maybe this discord is not as insurmountable as it seems to some critics. Scientists in biotechnology, for example, have a dual occupation in that they publish scientific papers in their capacity as laboratory scientists on the one hand and patent and promote their discoveries on the other (Lehrer & Asakawa, 2004). *Science entrepreneurship* is the “simultaneous dedication of scientists to academic science and commercial profit" and thrives in the US due to the competitive nature of the scientific enterprise (Lehrer & Asakawa, 2004, p. 56).

Science entrepreneurship is a skill often overlooked in academic training; graduate students are taught to conduct formal scientific research internally within their specific disciplines but are rarely afforded the opportunity to externalize their research (Brown & Kant, 2008). Academia, though, could benefit from integrating the scientific enterprise with real-world experiences. One study shows that research scientists who are active in disseminating their research in some way actually perform better academically (Jensen, Rouquier, Kreimer, & Croissant, 2008). Furthermore, prestigious dissemination activities (press, radio, and television) are conducted by the academic elite, overturning the perception that only scientists who are less successful in academia rely on education and outreach to retain their positions (Jensen et al., 2008).

Dissemination activities are not necessarily the role of the scientists themselves, though, at least not without guidance or forming some kind of partnership with those who excel in science communication. Professionalism in science communication has flourished as the line between basic and applied science continues to blur and as science and society continue to merge.

Science Communication

> For scientists and for others who work in scientific organizations, effective communication can be conceived of as returning a debt created by public support. It can create favorable attitudes toward science and science funding among policy makers and the broader public by making clear the benefits that scientific activity offers to society. (Treise & Weigold, 2002, p. 311)

Science communication has two primary functions; science reporting (to inform the public of ground-breaking news and exciting developments) and to enhance the public's scientific literacy (to inform decision-making, bolster opinions on public policy and governmental expenditures, and ultimately, influence how people and societies behave) (Laugksch, 2000; Treise & Weigold, 2002).

Science communication is an essential component to scientific literacy, with parallel goals and ideals: “an educated public should be better equipped to choose from among competing technical arguments on topics such as energy conservation, solid waste disposal, pesticide risk, and social welfare policy” (Treise & Weigold, 2002, p. 311). In 1996 the National Research Council (NRC) issued a report on National Science Education Standards to publicize a national goal to “make scientific literacy for all a reality in the 21st century” (National Research Council, 1996, p. ix). This report encourages teachers, museum curators, administrators, parents, government officials, etc. to act together to emphasize inquiry and learning in the sciences, and outlines a set of standards for teachers to improve science curriculums.

There are, however, conflicting theories as to how truly beneficial scientific literacy is to society, and whether or not there are clear macro (national or societal-scale) or micro (individual-scale) advantages of promoting it. Some studies show that a scientifically-literate public will not necessarily form opinions that are always aligned with those of scientists, particularly around controversial issues such as climate change (Kahan et al., 2012). Other studies show that scientific literacy is essential to environmental stewardship (Hurd, 1998) and to being a contributing member of society; *using* science is just as important as *doing* science (Hazen & Trefil, 2009).

A national 2004 Pew Ocean Commission study found that informed citizens and enhanced knowledge and awareness of the ocean system led to increased support of policies concerning coastal conservation and restoration efforts, which is essential in light of rising sea levels due to the overall warming of the planet (Steel et al., 2005). The Ocean Literacy campaign is working towards education reform to include more learning about the ocean, which plays a huge role in the earth system but is commonly overlooked in conventional curricula (Schoedinger, Tran, & Whitley, 2010). Ocean literacy describes a person’s ability to understand the essential functions of the ocean, communicate these concepts effectively, and make responsible decisions regarding the ocean and its resources.

If scientific literacy is essential to participating in the modern world then effective science communication is crucial in making scientific discovery “usable” – or more easily transmitted to a broader, non-expert audience. Historically, the news media are seen as having the potential to fulfill the role of enhancing the public’s scientific literacy. More recently, however, scholars have identified several issues with the news media (Treise & Weigold, 2002).

Journalists lack scientific training and education, and tend to misrepresent or sensationalize science (Ankney, Heilman, & Kolff, 1996; Friedman, Dunwoody, & Rogers, 1986). Scientists are also renowned for using esoteric language or for being unwilling to cooperate with the media, and the public tends to feel alienated when information is too complex to understand (Lemke, 1990). Finally, despite the purported benefits of scientific literacy, media consumers are not always receptive to, or show little interest in, science (Miller, 1986).

Other scholars find that simply informing the public with the hope of filling knowledge gaps will not necessarily enhance scientific literacy. One particular study criticizes the conventional outreach "deficit" model of disseminating information to be absorbed by a public with varying ideologies, political affiliations, or religious views; the public cannot be blamed for a lack of knowledge or interest in important scientific matters because the problem lies in the modes of communication (Nisbet & Scheufele, 2009). A study by Treise and Weigold (2002) found that science communicators (writers, editors, and scholars) are unfamiliar with how their audiences acquire in-depth knowledge, making it difficult for them to craft stories or learning aids to advance public understanding.

Other challenges arise in science communication in terms of merging the interests of the public – and sometimes industry – with those of the STEM community. Debates on different issues such as climate change and stem cell research have become increasingly politicized or partisan, causing the public to discredit the scientific enterprise altogether. The public's mistrust in science is only perpetuated when information is convoluted or biased, which often occurs when dissemination is managed by either political or scientific institutions, and even scientists themselves (Wynne, 2006). Too many scientific messages are aimed at "selling" the public on a particular issue, and these "persuasion" methods are proven ineffective (Fischhoff, 2007). Science should remain unbiased, policy-neutral, and should not aim to advocate for anything specific or will otherwise be discredited as useful to decision and policy-makers (Lackey, 2007). Furthermore, poorly transmitted information can cause irreparable damage to certain industries (as witnessed with the mad cow disease epidemic) or hinder timely responses to certain human-caused phenomena such as climate change (Irwin & Wynne, 1996).

Alternatively, science communication efforts should be more participatory, engaging, and encourage discussion or debate over pertinent matters (Nisbet & Scheufele, 2009). Citizen science is perhaps the most successful instance of participatory learning but requires the participant to make the initial effort to engage in science (Irwin, 1995). Citizen science is one example of free-choice learning where people seek out opportunities to gain knowledge to "satisfy a personal sense of identity, to create a sense of value within the world and to fulfill personal intellectual and emotional needs" (John H. Falk, 2005). Free choice learning assumes that most of our learning—including aesthetic and sociocultural understanding, critical thinking, comprehension and retention of ideas, facts and concepts—occurs outside of formal education settings (John Howard Falk & Dierking, 2002). Research shows that ISE – in the form of nature and science centers, museums, aquariums, radio and video, newspapers and magazines, environmental organizations, etc. – can have long-lasting impacts on science learning for a broader range of people, especially since secondary education and beyond is a privilege not afforded to everyone (John H. Falk, Storksdieck, & Dierking, 2007).

One of the primary drivers for scientists themselves to engage with the public is a desire to increase the public's interest and enthusiasm for science (Martín-Sempere, Garzón-García, & Rey-Rocha, 2008). In other words, scientists want to garner support from their very own financial backers (in the case of public funding). Furthermore, scientists are interested in inspiring the next generation of scientists to bolster and preserve the scientific enterprise (Treise & Weigold, 2002). It is perhaps in their best interest, therefore, to either initiate dissemination of their research themselves or collaborate with professional science communicators (or EPO specialists) who can help them accomplish these goals, as well as meet the BIs criterion necessary to obtain NSF (and other agency) funding.

Broader Impacts

On July 10, 1997, the National Science Board (the Board) established two new merit review criteria to evaluate NSF research proposals: Intellectual Merit and BIs (National Science Board, 2011). Intellectual merit encompasses the relevance of the research in a scientific context in order to advance knowledge within and across scientific disciplines (National Science Board, 2011). Whereas BIs describes the greater purpose and societal impact of the proposed research (J. Falk & Risien, 2013).

The Board (National Science Board, 2011, p. 4) developed the following set of questions to assist both the reviewer and the proposer in understanding the intent of the BIs criterion:

- How well does the activity advance discovery and understanding while promoting teaching, training, and learning?
- How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, geographic, etc.)?
- To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships?
- Will the results be disseminated broadly to enhance scientific and technological understanding?
- What may be the benefits of the proposed activity to society?

After the implementation of the new guidelines, BIs faced overwhelming opposition from the STEM community. Scientists perceived them to be “irrelevant, ambiguous, or poorly worded” (Holbrook, 2012, p. 5). Scientists saw BIs as an impediment to basic research: “in much of basic research it is impossible to make meaningful statements about its potential usefulness” (Holbrook, 2012, p. 5) Furthermore, BIs “may easily be interpreted as introducing extraneous political, cultural, or economic concerns into the pursuit of basic research” (Holbrook & Frodeman, 2007, p. 1) In other words, scientists were concerned about imposing values on an enterprise that is objective in nature.

However, BIs gained more traction in 2007 when the Bush administration passed the America COMPETES Act (Public Law 110-69), which requires the NSF to report to Congress detailing the effects of BIs on the types of activities funded by the NSF and their impacts on society (Holbrook & Frodeman, 2007). The act was passed in response to a perceived deficiency of scientific learning in the U.S. and as a means to remain competitive globally in scientific, technological, and, ultimately, economic innovation (Frodeman & Parker, 2009).

In 2011 the law was updated (Public Law 111-358) to have the BIs criterion deal specifically with eight national goals, including:

> “increasing the economic competitiveness of the United States, developing a globally competitive workforce, increasing partnerships between academia and industry, increasing the participation of underrepresented groups in science and engineering, increasing national security, improving science education, and enhancing scientific literacy.”
> (Holbrook, 2012, p. 11)

These goals were developed by Congress as an attempt to help clarify the BIs criterion for those scientists who struggled to address them in their proposals (Holbrook, 2012).

Still, scientists were unclear as to how to meet the BIs requirements and often misinterpreted the requirements to be exclusively related to EPO, which led to weak proposals for BIAs. In a recent assessment of submitted NSF proposals, Nadkarni and Stasch (2013) discovered that most proposed BIAs catered to the academic community, especially graduate students, rather than branching out to decision makers and the public, where scientific research may have a bigger impact. They put forth five aims to better guide scientists when developing BIAs (paraphrased here): (1) reach broader audiences than students alone; (2) be specific when identifying target audiences; (3) collaborate with social scientists and outreach specialists; (4) involve the public; (5) engage underrepresented groups.

This third aim, to collaborate with EPO specialists, was also a prominent theme in Burggren's (2009) assessment of BIs. He argues that an overhaul of NSF's funding structure is necessary to the success of BIs, "it may be that the most efficient pathway to NSF's overall goals is to separately fund the STEM expert to do great science and the BIs expert to professionally ensure that NSF is indeed promoting broader impacts" (Burggren, 2009, p. 229).

In response to the national call for increased emphasis on BIs, and due to the perpetual confusion around and misinterpretation of the BIs criterion, the Board published an updated grant proposal guide in 2011 with notable differences in the guidelines:

- Which national goal (or goals) is (or are) addressed in this proposal? Has the PI presented a compelling description of how the project or the PI will advance that goal(s)?
- Is there a well-reasoned plan for the proposed activities, including, if appropriate, department-level or institutional engagement?
- Is the rationale for choosing the approach well-justified? Have any innovations been incorporated?
- How well qualified is the individual, team, or institution to carry out the proposed broader impacts activities?
- Are there adequate resources available to the PI or institution to carry out the proposed activities?
(National Science Board, 2011, p. 264-265)

One particular difference is the stated emphasis on the national goals as put forth by Congress. PIs are now provided with a list of specific goals ranging from education to national security to bridging gaps between academia and industry to help frame and design BIAs (Holbrook, 2012). This clause on national goals essentially replaced the former guideline asking about the proposed activity's potential benefits to society. Providing a specific list of goals may be beneficial in clarifying the intent of the BIs criterion to the STEM community, but may ultimately restrict scientists in their outreach endeavors and limit creativity (Holbrook & Frodeman, 2011).

These goals are further outlined in NSF's Proposal and Award Policies and Procedures Guide, otherwise known as the grant proposal guide, when talking about BIAs specifically:

> "Broader Impacts may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to the achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education. (National Science Foundation, 2012, p. II-9)

Although there are now specific guidelines for fulfilling the BIs criterion, scientists are generally not trained in designing and implementing BIAs that might lead to effectively enhancing the public's scientific literacy or increase partnerships across sectors and disciplines (Holbrook, 2012). The STEM community finds that the task of designing and implementing BIAs is both confusing (Holbrook and Frodeman 2007) and daunting (Tretkoff, 2007). Unlike the Intellectual Merit criterion, BIs require researchers to delve into an unfamiliar world of EPO and science communication – often with little to no training.

Organizations are emerging to fill this training gap. The Centers for Ocean Sciences Education Excellence (COSEE) is a consortium of ocean science research institutions, informal education organizations, and academic entities to link ocean research efforts with high quality educational programs. COSEE, which is partially funded by the NSF, provides trainings for physical scientists on EPO in order to improve their professional practices. In 2012, COSEE conducted a study of interview and survey data to assess the role of these trainings in helping scientists develop societally relevant research projects. The study was also interested in understanding COSEE's influence on scientists' perceptions of EPO (Chung et al., 2012). Findings indicated that COSEE had a positive impact on scientists' professional practices, including EPO, college-level teaching, and research. Seventy-three percent of respondents indicated that COSEE helped improve the quality of their work and seventy-two percent said COSEE gave them opportunities to plug into existing EPO efforts. There was a positive correlation between length of time spent working with COSEE and improvements in EPO. Finally, their report concluded that "substantial investment is required to meet NSF's goals for Broader Impacts and to transform relationships between scientists and educators" (Chung et al., 2012, p. 5).

Some scientists do demonstrate a keen understanding for the importance of bridging the gap between science and society, and have even enjoyed engaging in public outreach activities (Pearson, Pringle, & Thomas, 1997). Some research has even shown that scientists can benefit from engaging with people with diverse backgrounds, and that this enhances their own scientific and educational practices (Jensen et al., 2008). However, as both Burggren (2009) and Nadkarni and Stasch (2013) noted, partnering with EPO specialists and science communicators to develop and implement BIAs might be the best way to effectively address the science-society schism that the NSF hopes to overcome with the BIs criterion. Furthermore, COSEE's study emphasizes a need for formal training and long-term partnerships with organizations that specialize in connecting scientists with people outside of their fields.

The Role of Film in Science and Outreach

> Juxtaposed to any written medium, films as a visual form of expression and (re)construction of social reality have been recognized as an effective medium that engages its viewers. A photograph instantly draws the attention more than a few words about the same subject. Visual images – photographs, motion film/video clips, movies of all kinds (documentary, observational films, ethnographic/anthropological movies or feature films) – are able to hold the attention of viewers more than inert printed words. (Sooryamoorthy, 2007, p. 547)

Film has the ability to add sensory layers to storytelling. By combining multiple tracks to tell a story and stimulate the senses (image, sound, noise, music, and text), film can arouse emotions, encourage critical thinking, and "tap into the personal conditions and sensitivities of the viewers" (Sooryamoorthy, 2007, p. 548). In sociology, film can display social phenomenon in context and allow the viewer to explore varying levels of the human experience (Becker, 2000). Anthropologists use it to interact and engage more actively with their subjects, and to portray cultures in a realistic and "unprivileged" way (MacDougall, MacDougall, Barbash, & Taylor, 2000, p. 4). Finally, film can dramatically alter the way in which scientific concepts are portrayed to broader audiences by adding a human and narrative element to an otherwise overly complex idea or investigation (Olson, 2009).

Video and photography are being used in the sciences in a variety of ways. Anthropologists produce ethnographic films as both a means to collect data and as a way to get people interested in the sub-populations they study. Pauwels (2002) discusses one particular ethnographic film, *A Country Auction: The Paul V. Leitzel Estate Sale* (1984), which is successful in that it is thoughtful and visually expressive all while adhering to the same rigorous standards as written forms of science. Pauwels argues that visual representations of science, specifically video, "succeeds in transmitting scientific insight in a way that a written article could not, or at least not that well (Pauwels, 2002, p. 157). He goes on to explain that films of this nature should undergo similar peer-review processes as written publications to be accepted as "real scientific output" (Pauwels, 2002, p. 151).

JoVE, the Journal of Visualized Experiments, is the world's first peer-reviewed scientific video journal (www.jove.com). They publish research in a visual format to help overcome challenges associated with reproducibility and learning new experimental techniques. Their goal is to aid scientists in conveying their methodologies to other scientists who hope to expand or validate one study or another. Professional videographers and editors are hired to dynamically present scientific methods, data analysis, and results in an honest and accurate way. Though these videos are not intended for a general or non-expert audience, this type of dissemination is one example in which video – and collaborations with communications professionals – can have a positive impact within the science community.

Scientist-turned-filmmaker, Randy Olson (2009), talks about the importance of communicating science effectively to more people in a time when the degradation of our planet is ongoing, with scientists working to avert the crisis. Olson argues that scientists are poor communicators but that it is in their best interest to work towards enhancing the public's scientific literacy, "communication is not just one element in the struggle to make science relevant. It is *the* central element" (Olson, 2009, p. 9).

In his book, *Don't Be Such a Scientist: Talking Substance in an Age of Style* (2009), Olson describes his journey to discovering the leverage that film can have for science. In film school he learns and begins to believe that film is a language that is learned in early childhood and mastered with age. He discovers that film production is relatively inexpensive as a result of new video technology. He ultimately envisions a future in which scientists themselves excel in videography, editing, and promotion of their own films, sending out demo reels and speaking comfortably in front of a camera.

Cooper (2011) argues that film plays an essential role in engendering public trust in science, which is a necessary component to closing the gap between public knowledge and policy action. She criticizes traditional ISE in two ways: (1) ISE relies on the deficit model in learning, which assumes that a one-way transmission of information will fill knowledge gaps and inspire people to behave differently; (2) ISE does not address some of the negative impacts that the media has in exacerbating the policy gap (Cooper, 2011). Cooper calls for "a shift toward approaches that enable trust, emphasize empowerment through reasoning skills, and embrace the maturing discipline of media literacy education" (Cooper, 2011, p. 231).

There are, of course, several disadvantages and challenges to using video as a science communications tool. Scientists who have little experience with the press tend to fear it, seeing it as a manipulative and exploitative enterprise; they fear misrepresentation, inaccuracy, and loss of control when dealing with the press (Gascoigne & Metcalfe, 1997). That fear can include the use of video. Think tanks, for instance, can use video very effectively to steer the scientific conversation into something more value-laden and advocacy-driven, as is especially the case with climate change and climate skeptics (Cooper, 2011). It is imperative to maintain a clear distinction between fact and fiction in science, since films that sensationalize or misrepresent natural phenomena can have deleterious effects to people's long-lasting perceptions of those phenomena, especially in our youth (Barnett et al., 2006). And some videos are capable of actually intensifying the barrier between experts and non-experts because they are not produced with a specific audience in mind (Olson, 2009).

The barrier between experts and non-experts is further exacerbated by the use of technical language (Montgomery 1996), the cumulative nature of scientific discourse (Tallis 1994), and the "mystique of science" (Lemke 1990), which tends to make science impersonal, inaccessible, and too authoritarian or even inhuman.

Narrative, on the other hand, has always played an integral role in human interaction to help decipher surroundings, make sense of events, and communicate ideas (Avraamidou & Osborne, 2009). Narrative is transcultural (White 1981), can influence people's beliefs and worldviews leading to cultural and behavioral changes (Brock, Strange, and Green 2002), and is more memorable (Schank & Berman 2002). Using narrative as a science communication and teaching tool is becoming more ubiquitous throughout school curricula and even scientific talks (Avraamidou and Osbore 2009), and film is perhaps the brightest and most accessible manifestation of this. As described above, some have gone as far as promoting narrative film as a means to publish scientific articles, though this is still in its very nascent stages (Pauwels 2002).

Though BIs requirements and personal goals can be met in a number of ways (public talks, poster sessions, engaging students in the field), film has many advantages. Film can be formatted for different venues and platforms such as a website or a public screening on a large screen. Film can engage vast audiences on many sensory levels to better communicate difficult concepts (Nisbet & Scheufele, 2009). And film can inspire the expert (the scientist) to engage with a non-expert (the filmmaker or film crew) while conducting their research. This final concept is the principle driver of this research.

CHAPTER III

METHODS

This study was conducted using three methodological approaches. The first method entailed collecting and analyzing semi-structured interviews with three scientists connected to the Greenland Project. This data was featured in the film and became one part of the in-depth case study. The second method entailed collecting and analyzing semi-structured interviews with two scientists who have had experience being filmed conducting research in the past. The third method was used to access and analyze an existing data set of interviews (collected by CAISE) that focused on scientists' perceptions of BI requirements.

Table I provides a breakdown of these three methods including the research question, sample population (and data source), and the methods of data collection for reference. The following research questions were addressed:

RQ 1: *How does this filmmaking process change the way these scientists communicate their research?*

RQ 2: *How has the filmmaking process affected ocean scientists and their research in the past?*

RQ 3: *How does the filmmaking process influence these scientists' perceptions of BIs and development of BIs goals?*

RQ 4: *What are scientists' perceptions of BIs?*

RQ 5: *What are some identified challenges and benefits of conducting outreach in order to meet NSF merit criteria?*

Table I: Sample Population, Methods, and Research Questions

Sample Population & Size	**Methods & Source**	**Research Questions**
Greenland Project scientists: 3	In-depth case study, data collected specifically for this study	RQ 1, RQ 3
Scientists who have been filmed conducting research in the past: 2	Semi-structured interviews, data collected specifically for this study	RQ 2, RQ 3
PIs who participated in BIs workshop through the STEM Learning Center at OSU: 21	Semi-structured interviews, collected by CAISE	RQ 4, RQ 5

Greenland Project case study

Case studies are a research strategy characterized by data collected directly from an individual person, a group, a setting, or an organization in their natural context for the purposes of studying participant perceptions or attitudes (Leedy, 2010). A *flexible research design* allows for data collection to remain adaptive, especially when collecting in depth qualitative data, and allows the researcher to pursue patterns and causal relationships between variables as they emerge later in the study (Robson, 2011).

The initial research question (RQ 1) of this project focused on how the presence of a filmmaker might impact the scientists' rhetoric as they communicated their science in front of the camera over time. To address this question, semi-structured interviews (Robson, 2011) were conducted with these scientists before (pre), during, and after (post) the research expedition in Greenland. Observational data was also collected throughout this time and during several rough cut screenings of the documentary film with the scientists. The intention was to measure a change in rhetoric concerning the scientists' current research over time through the use of a control variable. The control variable directed the scientists to describe their current research project in two sentences only. This control variable was posed during the pre, during, and post interviews (Appendix A).

Semi-structured interviews

The second method used semi-structured interviews with two scientists who have had considerable experience being filmed doing research in the past. RQ 2 addressed how the filmmaking process impacted these scientists. The intention of this method was to understand and document their experiences with film while conducting research. Interview questions also addressed their perspectives of BIs and the usefulness of film in addressing BIs goals. The interview protocol is included in the Appendix (B). The interviews were digitally audio-recorded, transcribed, and analyzed together with the data gathered from the scientists involved in the Greenland Project.

RQ 3 emerged during the data collection and analysis process of both sets of data. This question is specifically geared towards understanding why scientists develop BIs goals in the first place.

Description of Setting and Participants

Three principle investigators (PIs) of the Greenland Project participated in the study: Emily, an assistant professor of physics of the ocean and atmosphere at OSU; Jonathan, a professor of physics of the ocean and atmosphere at OSU; and David, an assistant professor of coastal and estuarine physical oceanography at the University of Oregon. This study entailed including the researcher as both a videographer and as a student researcher in the field. Working alongside these scientists provided the researcher with invaluable qualitative data allowing for naturalistic observation and description (Auerbach & Silverstein, 2003).

Three in-depth, 30 to 45-minute semi-structured interviews were conducted with each of these scientists: first in April of 2013 at their respective offices in Oregon, second on the ship in Greenland in September 2013, and lastly in their respective homes (Jonathan was interviewed in a library setting instead) in Oregon between October and November of 2013.

The two scientists who were interviewed about being filmed conducting research in the past were recommended for this study as suitable research subjects. Bill (pseudonym[1]) is a scientist at Woods Hole Oceanographic Institute (WHOI) and has had considerable experience working with both amateur and professional videographers. Joe (pseudonym) is a paleoclimatologist and oceanographer at a small liberal arts college and was a willing participant in this study to discuss his experiences being filmed, as well as his thoughts on BIs. A professional production crew documented Joe as he collected samples to reconstruct past climate. In this case, Joe had been hired to provide some content for a large production television spot and had very little control over the final product. No observational data was collected for these final two participants.

The Institutional Review Board at OSU approved this research and the human subjects involved, deeming this study "exempt" due to the use of interview and observational procedures in an educational setting.

Methodological Considerations and Limitations

[1] Pseudonyms were used to provide confidentiality to protect these participants. Other participants did not require confidentiality because they were featured and identified in the film, and signed waiver forms.

It is important to note some methodological considerations and limitations. First, the sampling strategy used was not representative of a known population; it was not the intention of this study to make generalizations about scientists and their experiences with BIs. Rather, in flexible design research, as described by Robson (2011), qualitative data can still be extracted from a small sample size to make a case for that specific population. *Grounded theory* allows for the researcher to focus on a small non-representative sample of the population, called a purposive sample. This theory allows the researcher to make regular visits with and collect data on those participants in a chosen setting until no new information can be gathered, otherwise known as saturation. The scientists who participated in this research did so because they were the principle investigators (PIs) to the research and were interested in the possibilities of documentary film.

In-depth case studies with a small sample size may have several benefits and potential limitations. Though it was not the intention of this study to reach saturation or make inferences about the larger population of ocean scientists, case studies provide in depth knowledge about a particular group of people and each case can be investigated as individual experiments from which to develop theory (Yin, 2013). If more data had been collected with more participants, it is possible that different and more informed conclusions might have been reached due to the potential for additional information on the topics explored (Glaser & Strauss, 2009). However, the intention was to explore characteristics specific to the target population used in this study and the results are not intended to be generalizable.

Robson (2011) discusses three key factors to making a flexible design more valid: *description, interpretation*, and *theory*. An invalid *description* is defined by inaccuracy or incompleteness of the data, which can be overcome by audio and video recording. Both recording methods were used in the field and, therefore, confidence can be gained through the provision of a valid description of these cases. The *interpretation* of the data was documented; each step of analysis was justified so as not to impose a framework that might limit ideas and themes that could emerge during the study. However, this type of interpretation takes a lot of skill and expertise and it is possible that some of the data was interpreted as self-evident (Mason, 2002). Finally, *theory* describes the importance of considering alternative and opposing explanations of the phenomena studied, which was not specifically addressed in this study (this would have required additional data collection which was impossible due to time and funding limitations).

There are also limitations associated with collecting interview and observational data using a film camera. Besides the obvious discomfort participants might feel with opening up while being video recorded, Knoblauch, Schnettler, and Raab (2006) discuss the influence of technology on data collection. If relying strictly on video data to make observations, the researcher may miss important elements or layers of information that were not captured on video. Additionally, the technology might have unwanted influences on the events under study, otherwise known as "reactivity," where the presence of a camera "is a constitutive feature in the setting recorded" (Knoblauch, Schnettler, & Raab, 2006, p. 22). Written notes were recorded to supplement the observations made while viewing and listening to the video and audio materials.

CAISE interview data

The third method used was to access and analyze an existing data set collected by CAISE of interviews focused on scientists' perceptions of BI requirements. The CAISE project was conducted to gauge scientists' experiences with BIs following a BIs workshop at OSU (a copy of the Front-End report is in the Appendix C). The inclusion of this data in this research is intended to provide a foundation for how scientists perceive BIs requirements, and to compare this with the data from the previous two methods. This data was used specifically to answer RQ 4 and RQ 5.

Sixty-five PIs participated in the BIs workshop held by the STEM center at OSU. Out the 65 who participated, 21 (with current or recent NSF support) participated in face-to-face or phone interviews. Participants in the CAISE interviews represented a breadth of specializations within STEM, from the natural sciences to engineering. Participants were already engaging in a range of BIs activities such as after school and supplemental programs, public outreach using media outlets, and stakeholder workshops. About half of the participants were in the later third of their careers and the other half were young to mid-career investigators. The interview protocol used in the CAISE study (included in Appendix D) was semi-structured, and the focus of the research was to gain information on four themes: 1) Perceptions about BIs; 2) Planning and Processes; 3) Resources and Supports; 4) Marketing and Communication. Transcriptions of the de-identified data for only the first two themes – perceptions, and planning and process – were explored and analyzed for this research.

Method of Data Analysis

> Qualitative research is research that involves analyzing and interpreting texts and interviews in order to discover meaningful patterns descriptive of particular phenomena. (Auerbach & Silverstein, 2003)

Using a qualitative data analysis strategy described by Auerbach and Silverstein (2003), a *theoretical narrative* of the interview and observational data was developed. First, the *relevant text* from the data was extracted according to guiding research questions. Then, from the relevant text, *repeating ideas* of the data were established in order to combine the relevant text into themes that emerged throughout the analysis process. Finally, *claims* were developed to group the repeating ideas together into a common theme, making a conclusive statement about the data as relevant to the guiding research questions and overall purpose of study.

Table II provides an example of how a claim can be derived from the data. In this case, several statements were made about the difficulty of engaging people when the science is too complex, boring, or seemingly irrelevant, and this ultimately fit into a claim about the importance of involving EPO experts when communicating science.

Table II: Example of Relevant Text, Repeating Idea, and Claim

Relevant Text	"I think what your challenge is going to be is actually grabbing people without a charismatic mega fauna or some sort of living being that has a story with it." "Portraying the real science in a truthful way while making it exciting enough and having the plotline that you need I think is the challenge."
Repeating Idea	*Experts should be called in to help develop a hook when communicating complex science.*
Claim	**Outreach and communication goals are best met with help from an outsider: scientists are not EPO experts.**

Grounded theory (Auerbach & Silverstein, 2003; Glaser & Strauss, 2009) justifies the development of a hypothesis after data collection. This fit well with this study as it was initially motivated by the limited body of knowledge on film and science, and the influence of film on science communication and the scientific process. The intention of this study is to begin to fill a gap in the literature on the role of film in science. The following chapter includes the theoretical narrative that emerged from data analysis.

CHAPTER IV

RESULTS & DISCUSSION

The results and discussion of major findings of this study are divided into two sections. The first section provides an analysis of the CAISE study interview data to establish scientists' perceptions and experiences with BIs. The second section provides an analysis of the Greenland Project in-depth case study data together with the semi-structured interview data to answer questions concerning the role of film in BIs. All of these findings are organized into **claims** and *repeating ideas,* as outlined by Auerbach and Silverstein (2003).

CAISE Study Data

Outline of Claims and Repeating Ideas

Claim #1: It is difficult for scientists to take BIs requirements seriously; criteria remain ill defined and undermine NSF's original purpose, which is to fund scientific research.

1. *Scientists perceive that the NSF is placing more emphasis on outreach than scientific research, which ultimately impedes scientific breakthroughs.*
2. *Scientists have little faith in NSF's assessment and follow-up of proposed BIs.*
3. *The one-size fits all outreach model makes it so that BIs are ill defined.*

Claim #2: Not all science lends itself to BIs, or outreach in general.

1. *Science projects for which BIs are irrelevant get turned down.*
2. *Impacts cannot be drawn from all sciences at all stages and BIs perpetuates the conflict between basic and applied science.*
3. *Scientists find it difficult to communicate research or impact.*

Claim #3: Outreach is not the role of the scientist and there are too many tradeoffs associated with BIs.

1. *The time and costs associated with BIs are unreasonable.*
2. *Weak internal (departmental or university-level) support on outreach poses challenges for PIs.*
3. *Scientists are not extension officers, need for EPO specialists.*
4. *Scientists express a need for large-scale coordinated efforts for more effective BIs outcomes.*
5. *Scientists fear misrepresentation in the media or otherwise.*

Claim #4: Scientists find their own work to be meaningful, which can sometimes translate into easily developing and meeting BIs goals.

1. *Some scientists are in this field because they want to affect change.*

2. *BIs goals go beyond NSF's requirements; work is not important if there are no impacts.*
3. *Scientists express innate gratification with conducting outreach.*
4. *Education and leading the next generation of scientists is a natural component to research and fits within BIs.*

Claim #1: It is difficult for scientists to take BIs requirements seriously; criteria remain ill defined and undermine NSF's original purpose, which is to fund scientific research.

Scientists perceive that the NSF is placing more emphasis on outreach than scientific research, which ultimately impedes scientific breakthroughs.

Broader Impacts is a term coined specifically by the NSF to try and encompass all the ways in which scientists might reach a broader and more varied audience with their research, as well as emphasize and communicate the societal impacts of their work (Holbrook, 2012). However, the NSF uses vague terms and guidelines to aid scientists along in this endeavor and though scientists might be on board with different outreach activities (as proposed later in this analysis), they are generally frustrated with the NSF's BIs requirements and this is documented in the literature and validated by this research (Holbrook & Frodeman, 2007; Tretkoff, 2007).

An analysis of the CAISE data indicated that the main frustration of the scientists was that the purpose of scientific research is being lost in the pursuit of outreach. This was demonstrated by statements like, "there is the perception that the quality of science is not how they judge your proposal, it is all about the outreach." Or that outreach is now seemingly tantamount to concrete research outputs, conveyed by statements like "I see a tendency in the NSF to judge the merits more on what you have to say in progress reports than based on the research outputs." Some of the data went so far as to say that this new emphasis on BIs is "poisonous to science" or that the NSF has "lost its soul," most likely meaning that the NSF has renounced its original purpose, which is to fund scientific research.

Another finding that came from this analysis was that the review structure has changed dramatically within the NSF since the "merit review criteria" were introduced and this caused concern around funding in the scientific community. Statements from one scientist indicated concern that with a growing focus on deliverables, scientific breakthroughs would be missed: "It's fine for incremental work...but you miss breakthroughs that require a much higher risk funding structure." Along those same lines, scientists reported feeling that "pure" research or "basic" science is being threatened and that the NSF has lost a sense of its purpose as a national scientific funding agency: “NSF is supposed to be funding pure curiosity research; BIs is a drift away.” Claim #2 further explores this idea that basic science might be overlooked for the sake of more applicable research projects and that not all science can fit the outreach mold that the NSF loosely imposes.

Scientists have little faith in NSF’s assessment and follow-up of proposed BIs.

The NSF updated their merit review criteria in 2013 to address scientists’ poor commitment to both developing and following through on proposed BIAs (Nadkarni & Stasch, 2013). Not surprisingly, analysis of this data indicated that the scientists who participated in the study felt that they were putting in a lot of effort to “fill in the square” with almost no indication that their proposed BIAs would actually matter in the reporting phases. This was in agreement with previous research that stated that “there is inconsistent follow-up on PIs’ accomplishments in these [BIs] activities” (Nadkarni & Stasch, 2013, p. 14).

Further analysis of this data indicated that some scientists interpret this lack of follow-up as reverting to placing more relevance in the science, as evidenced by statements such as “Program managers are not rigid in holding you to promises, follow through is minimal. Clearly the process for BIs is just not as relevant as the science is.” Others indicated that they continue to view BIs as a trivial set of criteria because of poor follow-up compounded by the current funding climate, indicated by statements such as “Even with good ideas, the follow through isn't great because in the end all proposals are underfunded, we are in a bind; it's the BIs that's not going to get done.” Finally, the data indicated that scientists have little faith in even the assessment phases of merit criteria with statements such as “The assessment part is also a big issue, NSF doesn't know if their demands for assessment are making things better.” Analysis of this data indicated that scientists are wary of NSF’s process both in terms of assessment and follow-up, posing a huge challenge for BIs to be taken seriously by scientists.

The one-size fits all outreach model makes it so that BIs are ill defined.

Analysis of this data indicated that scientists are generally confused by the BIs criteria: “I never understood what BIs means, can interpret it as an application of your research or can interpret it as impact on education, but I do not know what they mean.” Part of the confusion may rest in the fact that the same set of outreach criteria are applied to all kinds of research; one participants suggests that “there is a feeling that NSF has gone too far in trying to use the same criteria for all proposals with regard to BIs.” This same participant expressed a causal link between making things up to meet the criteria on paper and the imposition of some universal application of the criteria: “People make up things extraneous and forced because of the imposition of the universal application of BI criteria.” Another participant in the study blamed the vague definition of BIs on the one-size fits all approach: “It shouldn’t be one size fits all, maybe that is why NSF declines to define it.” This point is a key factor to understanding how a blanket outreach initiative might be the wrong approach to imposing BIs requirements. Finally, analysis of this data highlighted that other participants summed up why it might be beneficial to the NSF to develop criteria that cater to the different sciences with statements such as “Different science approaches lead to different BIs.”

Claim #2: Not all science lends itself to BIs, or outreach in general.

Science projects for which BIs are irrelevant get turned down.

Analysis of this data indicated that participants generally agreed that not all scientific research has some broader application or societal relevance: “There are projects for which BIs are a wonderful thing and projects for which they are irrelevant, important for NSF to recognize that.” Evident again was some indication of frustration with the need to make all science fit the BIs mold, as shown with comments such as “Not all science lends itself to a good broader outreach, it is frustrating to try to do it when your science doesn't lend itself, for example, updating modeling code.” Updating modeling code, therefore, appeared to be an excellent example of an important component of the scientific enterprise but which might not have some broader application right away. Short-term economic and societal benefits of basic research are generally difficult to identify but basic science plays a large role in innovation, industry, and enhancing skills in different sectors (Salter & Martin, 2001).

The analysis also showed that some projects, on the other hand, have very obvious applications and that the proposer, or PI, would not struggle with meeting the criteria: “If they are relevant, then great. Then the reviewers think there are natural broader impacts and the proposer doesn't address it as a negative." Analysis made it clear that BIs can be addressed with optimism when the BIs component does not seem forced or out of place. This goes back to the notion that the NSF might consider imposing a different set of criteria depending on the research project. Negativity appears to arise when it seems that BIs requirement are too rigid, as evidenced by comments such as "It is important that the NSF doesn't become bound to BIs." Or when scientists feel they are being penalized for pursuing a project that has less broad implications, as evidenced with comments such as "I don't think NSF should penalize proposals for not having BI as part of proposals when it doesn't make sense."

Impacts cannot be drawn from all sciences at all stages and BIs perpetuates the conflict between basic and applied science.

The debate between the value of "basic" versus "applied" science came up very strongly in this data. Participants in this study indicated that they were frustrated around needing to communicate a science that might be too technical to a broader public: "Some projects lend themselves to interesting possibilities, others are just too technical and I don't understand how this is going to be translated [to audiences]." Some scientists placed themselves on the lower end of the BIs continuum (Appendix D Question #2) when thinking about pure science: "Depends on the program but in pure science research programs I am '1' or a '2'."

The data indicated that a lot of participants expressed concern that "pure" or "curiosity" or "breakthrough" science is being undermined with this new emphasis on outreach through statements such as "There is a place for people to work on things with no impact, to explore tangents, like looking at the electron (…), this has a huge impact later that is not planned." This concept that there are certain stages within scientific exploration that do not have broader applications, or that the impact might be seen later down the line when basic science informs more applied science, is further expressed by two other comments: "It is important to recognize that there are wonderful proposals whose impacts would not be seen at this stage." and "In history, important basic science was stimulated by practical questions." This participant went on to explain that the NSF does not know how to recognize that BIs can emerge when projects shift from the basic stages to the more applied stages. This idea that basic science can inform applied science down the line also came up in the literature (Klevorick et al., 1995).

Scientists find it difficult to communicate research or impact.

The NSF imposes the same set of criteria on all projects, as was explored in Claim #1. Analysis of the data showed that scientists feel the need to communicate even the most irrelevant science and that this poses challenges for them on a communications level: “It is challenging to transform high-level science to an audience,” or “My work doesn’t translate to kids or people.” These kinds of comment imply that scientists are not communications experts, as will be explored in Claim #3. One participant was wary of drawing people in when there is such little relevance to them or their values: “I really think some research lends itself to more translatable science and BIAs. Some research is hard to translate so that people care about it.” Finally, some participants in this research find that certain results are difficult to translate to a public, as evidenced by comments such as “We had unexpected results and we haven’t figured out how to put that out there.” One comment summed up the challenge of the lack of clarity with the criteria and how this relates to translating research to the public or a student with the comment “Detailed modeling research didn't make sense to share with students, might as well make a cookbook!” The data definitely highlighted some of the communication complications that might arise simply because there is confusion around what it means to make one’s research “more accessible.”

Claim #3: Outreach is not the role of the scientist and there are too many tradeoffs associated with BIs.

The time and costs associated with BIs are unreasonable.

In science, time and money are of the essence. Scientists who participated in the CAISE interviews perceive BIs as an added cost burden to an already expensive enterprise: “The budget part makes me uneasy, criticisms are already that research is too expensive, the minimum is perceived as too expensive. They are asking us to add costs now and that is a pain.” The cost aspect led one participant to express pessimism around BIs: “It's really expensive and it isn't making things better. A lot of people just write about what they did before.” In other words, the perceived cost burden of BIs might actually encourage scientists to pursue easier and less effective outreach avenues. Some participants shared that they were so on board with BIs that they see the value of doing outreach on their own time: “I haven't found funding sources for my impacts work. I just do it in my free time.”

This data also revealed that scientists are eager to engage EPO specialists, either because of the need for expertise or the lack of time to devote to outreach. However, they also indicated that they shy away from spending money on EPO support because budgets are already tight. Comments highlight this and explain why they choose to conduct the work themselves, such as “We don't really call on COSEE or other groups because the cost-benefit ratio is just not right.” or “All my interactions with external organizations adds enormous time to proposal development, and they always ask you to insert unreasonably large sums [making your budget less competitive].” This leads to another theme that emerged in this analysis about poor internal support. This relates to the perception that the tradeoffs of BIs seemed so high that they were discouraged to resubmit proposals to the NSF altogether: “BIs driven programs are a lot of work and NSF gives less and less money, and my department head [cautioned me] so I didn't resubmit.”

Weak internal (departmental or university-level) support on outreach poses challenges for PIs.

Analysis of the data illuminated that study participants feel that there is very little incentive or support on an institutional or internal level. Some PIs are left to their own devices when needing to meet BIs requirements: “It is not taken seriously by programs. I’m required to put the heading ‘Broader Impacts’ at the proposal decision level but there is almost nothing that weighs BIs, it's up to us what we do.” Whether the institution fails to place importance on outreach by providing incentives that reach beyond getting a proposal excepted by the NSF (such as “I don’t get any reward from the university for doing [BIs].”) or whether the institution simply isn’t geared to support BIs efforts (such as “Some institutions are just not providing much, especially research focused ones.”), scientists appear to be provided with minimal internal support for this. A similar shift, therefore, needs to happen internally in terms of recognizing the value in BIs (as it has at the funding level).

Scientists are not extension officers, need for EPO specialists.

"There is the perception that scientists should be an extension service, but that is not where our money comes from."

This is perhaps one of the most supported themes that emerged from the CAISE interview data. Though BIs can be perceived as a reasonable endeavor, participants felt that scientists are not outreach specialists: "Conceptually, BIs make a lot of sense, research with tax dollars ought to be of broad interest and use, (…). On the other hand [scientists] are not the educational experts." The theme that the role of the scientist was to conduct scientific research, not funnel energy into informal education programs for the public, emerged again and again, with comments such as "It is difficult for researchers to do their research and take on informal education projects. I learned a lot about the field [informal science ed], but it was very time intensive." There are advantages to conducting outreach as a scientist and previous research findings show that scientists who engage with the public will ultimately perform better as researchers and university professors (Jensen et al., 2008). Unfortunately, this theme was not explored within this study.

Findings did show, however, that scientists are discouraged when asked to do the outreach work themselves: "NSF is asking everyone to be an expert in this, and they aren't. So they are just going to do it poorly and it will be a waste of money. BIs are important but people should get help from experts and do it well." The theme of engaging experts to meet BIs requirements, and its benefits and costs, was expressed briefly under the previous theme. When an EPO specialist gets involved it does appear to relieve a lot of the pressure off the scientists: "Some organizations have their own outreach components. They have someone whose job it is to do this, an educator. We often try to plug into what they are doing, that seems really effective since I don't have to figure out what and how to do it. Someone has already done it." Almost three-quarters of the COSEE study respondents found it helpful to plug into existing EPO efforts (Chung et al., 2012).

This type of "leveraging" of support was acknowledged favorably with comments such as "Some institutions are set up with programs we can plug into, these are a godsend, and we try to leverage those." In fact, there was strong evidence that the way forward is to collaborate with EPO specialists. Comments such as "[Scholarship] of education is a whole other set of research skills and that gets hairy. Researchers wonder, 'how am I supposed to do this?' Collaborations will have to be the way forward." Collaborations allow for an exchange between scientist and educator that benefits everyone, according to two participants who made comments such as "I try to coordinate with experts on outreach and education, so I can offer my advice and we can work together." and "It has to be different and unique and build a team; you have to have a lot of people working with you, the right collaborators." Burggren (2009) was a big proponent of integrating EPO specialists into the BIs model.

Scientists express a need for large-scale coordinated efforts for more effective BIs outcomes.

Some participants promoted both collaboration amongst PIs within a certain field and coordinated efforts with EPO specialists, to reach success in BIs. The perspective was that BIs could thrive "if everyone who worked on earthquakes and was funded to do that research, worked together with a knowledgeable teacher to develop something really good." One participant even spoke to having the NSF coordinate efforts among PIs to "come up with something of national import," and that "NSF should really get all the PIs together to get funding from a program and update these things. It won't be tacked on to any specific research but it would be transformative." This same participant expressed that uncoordinated efforts could only lead to mediocre projects with the comment that "otherwise we are all working with different teachers on small little projects; it is not transformative it is mediocre."

Scientists fear misrepresentation in the media or otherwise.

Another theme that has emerged in previous research was that scientists are cautious when involving the media, especially when their research has provoked controversy in the public realm (Hmielowski, Feldman, Myers, Leiserowitz, & Maibach, 2013). This was echoed in this data where some scientists shared their fear of political implications as a result of having the media misrepresent their science: "There is a perception of an active movement to undermine [climate] science. A smaller portion [of scientists] is more hesitant to discuss BIs of results because they fear the politics, and it is the less established scientist who have cause to hold back." This point is interesting given that scientists with more established credibility and a stronger reputation are able to take greater risks with the media. In fact, scientists who have successfully climbed the academic ladder tend to get involved in more prestigious dissemination activities (Jensen et al., 2008).

Other scientists are tired of the negative spin that the media can impose on their work and share comments such as “My concern with the media is that they want a negative story, when bees die (…) pesticides all need to be banned. It is disappointing that the media loses interest when they don't get what they want.” Scientists generally perceive the news media to be overly sensational, which is also evident in the literature (Ankney et al., 1996). Furthermore, some participants expressed fear of losing the audience if the outreach is forced or done poorly through comments such as “There is an assumption that I am doing something useful, but you could be having the opposite effect. You could actually be turning people off to science instead of inspiring them.” or “There is something that can be done, but to force the outreach too much might actually discourage people [the audience].”

Claim #4: Scientists find their own work to be meaningful, which can sometimes translate into easily developing and meeting BIs goals.

Some scientists are in this field because they want to affect change.

Several participants in the CAISE interviews expressed a desire to affect change with their research. One participant expressed that their specific field could more easily lend itself to having an impact: “We are in this field [environmental sciences] because we want to affect change.” Another participant is actively seeking “practitioners” to make use of the information they put out by going to conferences: “We are going to conferences where practitioners, the people who will actually use the information, are attending and doing short courses.” Others still shared a specific interest in influencing decision-making through comments such as “I start by thinking of the societal impacts of my work (…) then I would think about how the research questions and outputs could be tailored to decision-making.” or “I do work in engagement with decision-makers, policy-makers, and technocrats in agencies. I think of that as the impact of my research.” Yet it appears that these are scientists who are thinking very far ahead in terms of the impact of their research in society, politics, and decision-making.

BIs goals go beyond NSF’s requirements; work is not important if there are no impacts.

Most of the participants in the CAISE study who place themselves higher on the BIs continuum (Appendix D Question 2) expressed that their outreach goals surpassed the requirements set out by the NSF: “If that is where the bar is, then we need to go over it.” Some find meaning in their work only if there is some broader implication to what they do, as shared through comments such as “Doesn't matter what I do if are not impacts, people don't know it exists or think it is relevant.” and “If there is not a broader impact I am unlikely to be interested in doing it.” This last participant goes on to say that their research is always applied, and though they “understand the value of science for science sake, there are so many questions that need to be addresses to solve conservation and management issues.” This goes back to the theme of the conflict between basic and applied science, and the possible resolution in applying different types of BIs criteria for different types of projects.

Analysis of this data appears to convey that these scientists find meaning in their work and are driven by the broader implication of science. Some of them are driven by personal experience, which also places them ahead of NSF’s requirements: “[Outreach] has been important to me long before NSF thought it was because I had experiences as a kid that hugely affected me and I want other kids to have that experience.” Others find that outreach comes naturally to them: “It’s easy in my case. I am active outside the university before BIs requirements. I didn't have to come up with something new. It is instinctive to me. I am atypical I am motivated by my own background to be involved.” Both of these suggest that scientists are driven by their own experiences and backgrounds, whether in childhood or their formal education, to conduct outreach because it helped them along the way.

Scientists express innate gratification with conducting outreach.

Comments from participants indicate that some find outreach to be innately gratifying: “I like to have the innate gratification of knowing that what I have done has an impact. I like seeing the WOW!” Others highlight that BIs can sometimes be a fun endeavor: “BIs can be fun and I want to bring people in to the work and I want to have fun with it and try different things.” Sometimes the sheer act of communicating science in some way can cause the scientist to think differently about their research, a theme that is not thoroughly explored here. One participant spoke about the transition to getting tenure and taking time to think about what really matters:

"Now I more enjoy thinking about this, because I have tenure and I started questioning myself about what really matters, and what is most satisfying. They are the things that contribute to the next generation of scientists or policy."

Education and leading the next generation of scientists is a natural component to research and fits within BIs.

Often times, and there was a lot of evidence of this in the CAISE data, BIs requirements are fulfilled by some sort of education initiative. The NSF promotes involving students from all levels (k-12, under-graduate, graduate, postdoc) and many scientists perceive this to be the main focus of BIs: "In a proposal I would emphasize the degree to which students are learning techniques and getting them to ask questions and take initiative - emphasize encouragement for students to take initiative and stimulate curiosity." Some spoke to how their hope was that this would advance STEM learning and career-building with comments such as "Simple [my] projects were trying to advance stem learning or impact STEM teachers." and "How can we develop intrinsic motivation with students and share that with their home campus and catalyze a greater interest in STEM careers." Others spoke to their involvement in research that focused entirely on education: "I'm totally committed to BIs as an educator, that's why I went into the professoriate."

Others did not perceive education to be fundamentally associated with NSF's requirements and see it rather as a natural component to research: "I also do the graduate education part but I don't really consider it a BIs, it is so integral to what we do." Other comments such as "these things are natural, including students, taking students on cruises, they are easy you just have to budget them." This last comment goes on to explain that BIs become more challenging when the "only time you have to think about it is when you go far outside the natural activities - public meetings, or publish in non-science journal." The literature also indicated that EPO is not necessarily the only goal of BIs and that scientists are compelled to think beyond the academic setting (Nadkarni & Stasch, 2013).

<u>Summary of CAISE Study Data</u>

In summary, the CAISE study illuminated that although many scientists are aligned with the educational aspects of BIs, and even find education to be a natural component of the scientific enterprise, many are motivated by something much greater than formal education. A majority of the participants in this study are interested in the broader applications of their research and find meaning in the impacts of their work. Some even find the act of conducting outreach to be innately gratifying and have discovered that potentially involving non-scientists in their work can actually help them improve their research. However, the challenges posed by BIs requirements and by the NSF can sometimes act as a deterrent to these scientists' natural proclivity towards outreach. Outreach efforts are disparate and under-coordinated. Comments were made about how the NSF tries to apply the same outreach model to all science projects, across extremely different and sometimes opposing disciplines, and that basic scientific research – the foundation to applied science and the work that leads to scientific breakthroughs – is being undermined in a funding climate that places too much emphasis on a specific type of outreach model (a model that remains vague and ill defined). It appears that the shift in science and outreach may come with the onset of a younger generation of scientists, which does not coincide with the findings of the COSEE study (Chung et al., 2012). Many shifts, however, need to occur on the funding level, and within the institutions, that support scientific research in order for BIs to be more effective.

<u>In-Depth Case Study and Semi-Structured Interview Data</u>

This analysis begins by tackling the following research question directed at the Greenland Project scientists: *How does this filmmaking process change the way these scientists communicate their research and help them meet their BI goals?*

Table III provides the scientists' answers to the control question of, "in two sentences only, please describe your current research project." This question was posed to each of the scientists in the pre, during, and post interview phases to document whether or not there was a change in rhetoric over time by virtue of being filmed while conducting research.

Table III: Content comparison of interview data

Scientist	**Interview: Phase & Setting**	**Content**
Emily	Pre, office in Oregon	So in Greenland we are going to compare the oceanographic conditions in two fjords, which have shown variable ice-loss in terms of the

		glaciers that terminate in the fjords. Is that one sentence? (laughs) Um and so, with the ultimate goal of being able to understand how these two fjords differ in the oceanographic circulation and what that means to heat flux to the glacier
	During, on ship at sea	So we've selected two fjords, one of which the glacier coming out into that fjord is accelerating and the other of which the glacier is holding relatively steady. And we're outfitting each of the fjords with instruments, with moorings, and we are going to be measuring the ocean properties in those two fjords, and we're hoping by comparing the differences in the ocean we'll be able to understand something about why the glaciers are behaving so differently.
	Post, at home in Oregon	So we have two fjord systems, and in the two fjords the glaciers have been experiencing different rates of acceleration; one has been accelerating rapidly and the other has been holding steady. And so the thought is, because these are both in the same region they have similar atmospheric forcing, that some of the answer might lie in the ocean and so by comparing these two systems we'll be able to tease apart what one system is doing oceanically than the other, and that'll give us some information about mechanisms involved.
David	Pre, office in Oregon	Greenland's Glaciers have been changing rapidly in the last ten years with some of them advancing and some of them retreating. In particular on the west coast of Greenland, glaciers are right next to each other, on is advancing one is retreating and our project is focused on understanding if the dynamics outside these glaciers are responsible for these differences.
	During, on ship at sea	We have a natural experiment because we have these two glaciers right next to each other, two fjords going up to them. And the glaciers are doing different things and we're trying to understand if there's a difference in the fjord that explains the difference in the glaciers.
	Post, at home in Oregon	This research is trying to untangle the question of, is it the ocean, is the atmosphere, or is it the rock, the geometry of the fjord itself that controls glacier dynamics. So it's a little bit of a natural experiment because we have two glaciers next to each other; one is accelerating and the other is sort of not doing much, and then we can test if the ocean is doing something different, is the atmosphere doing something different, or is there different bedrock geology.
Jonathan	Pre, office in Oregon	There are two fjord systems in Greenland in which glaciers in one fjord, the glacier is advancing its rate into the ocean and in the other one it is slowing down. We are studying the ocean dynamics in those two fjords to determine what factors are different in those two fjords from the ocean side that leads to the differential melting of those glacier faces.
	During, on ship at sea	We want be able to generalize on dynamics that we see in systems throughout the world's oceans where the glacier meets the ocean, and try to understand how those systems control the rates at which heat and

		freshwater move through the ocean. And so as we better understand those processes they will get better incorporated into numerical models and they will give us better predictions of future climate.
	Post, in college library at OSU	So the goals of this research are to elucidate the dynamics of processes that can cause changes in ice-speed in a glacier that is terminating into the ocean, and so we have this really nice pair of fjords in Greenland where we think there could be these very different dynamics in these two fjord systems, and that they could be having some controls on the rate at which those glaciers are moving and losing ice. If we can actually identify processes that are not incorporated in the current generation of numerical models that are doing predictions as to what the future ice-loss of Greenland is, if we can actually come up with some means of assessing the ocean's direct influence on these ice faces, we will have made a lot of progress.

Little to no change was detected in the scientists' rhetoric when communicating their research in front of the camera over time. In fact, the scientists provided more complex and sometimes even convoluted answers to this question by the *post* phase, using more technical language and introducing concepts like atmospheric forcing or fjord geometry, which might overwhelm and deter the listener.

All three scientists provided very broad but concise answers in the *pre* phase. They set the scene by describing the neighboring glaciers that are experiencing differential melting in Greenland, and described the basis of their research, which is to understand the ocean's role in that melting. Jonathan and David are more thorough in their explanations of differential melting, "the glacier is advancing its rate into the ocean and in the other one it is slowing down," and "some of them advancing and some of them retreating," whereas Emily provides a single term to encompass this idea, "variable ice-loss." Emily also introduces the term "heat-flux," which might be confusing to some listeners, but overall the terms she uses are relatively clear and straightforward. These answers might be suitable for non-experts to understand their research in Greenland.

The scientists provided very different answers in the *during* phase. Emily talks about using instruments, specifically moorings, to measure the ocean properties in the two fjords, which will allow them to "compare the differences in the ocean" to understand "why the glaciers are behaving so differently." She does not mention, however, that the fjords are adjacent to each other or introduce why they need to be looking at dynamics in the ocean and not the atmosphere.

A listener might get caught up in the term mooring or might not understand why this research is being conducted in the first place. However this idea that glaciers "are behaving so differently" might set a good foundation for a listener to inquire further.

David's description of the research has become somewhat rudimentary and disorganized, "we have these two glaciers right next to each other, two fjords going up to them," or "and the glaciers are doing different things." A listener might get lost simply because his description is not specific enough. It is also unclear what he means by "difference in the fjord," and it might be difficult for a listener to understand that this is an oceanographic study to measure the dynamics in the ocean within those fjords. Jonathan jumps to the scientific applicability of their research without describing the scientific experiment; he does not mention the neighboring fjords with glaciers that are melting at different rates. Instead he goes into how this research will contribute to more accurate models of future climate. Although communicating the broader implications of this work is important, which fits into the purpose of this study concerning BIs, he does not provide a clear picture of their research. In essence, he is not communicating the science.

The answers provided in the final *post* phase are more long-winded and slightly more complex than the *pre* answers but do provide more background and basis for the research than the *during* answers. Emily first provides a nice explanation of the different melting rates between the two glaciers, "one has been accelerating rapidly and the other has been holding steady." Though acceleration is a concept that many people might not understand without a background in physics, it is a term readily used in other contexts, such as driving, for speeding up. She then for the first time mentions how the influence of the atmosphere should be similar since the fjords are "both in the same region." However, the concept of "atmospheric forcing" might be lost on some listeners.

David also mentions the atmosphere for the first time, as well as other possible influences such as geology or the geometry of the fjord, which some listeners might not understand to mean the shape, size, and topography of the fjord. He mentions the "natural experiment" again, which could be lost on some people. However, he too provides a basic description of differential melting, "we have two glaciers next to each other; one is accelerating and the other is sort of not doing much." Although Jonathan provides a relatively thorough description of the research (though he fails to mention differential melting), his line of thinking and his language could confuse the listener. Again, he is focused on the broader scientific application of this research in terms of making more accurate predictions on Greenland's "future ice-loss," which is important but might take away from providing a clear description of the science. Furthermore, terms like "elucidate" or "terminating into" make the description more complex than it needs to be.

The phase and setting are important factors to consider in this analysis. The scientists got to know the researcher as a filmmaker and student researcher over time; this same question was posed three times by one person and they had become familiar with that person's understanding of some fundamental concepts in physical oceanography. They therefore did not treat the researcher as a fresh listener or a non-expert, which might explain the progression of answers over time. Furthermore, the *during* interviews were conducted on the ship while at sea where time was limited and when their primary responsibility was to manage all operations from navigation, to mooring deployments, to scheduling. Needless to say, the scientists were tired, distracted, and somewhat annoyed at being interrupted during this phase. Some challenges associated with having a videographer in the field emerged in the data analysis and are discussed under Claim #6.

During data collection, it became clear that being filmed would not impact the scientists' rhetoric over time in any substantial way, making the research question that drove this study more or less unanswerable. Fortunately, a flexible research design allows the researcher to explore a more important questions that emerged during data collection, and the following question guided the remainder of this analysis: *How does the filmmaking process influence these scientists' perceptions of BIs and development of BIs goals?*

Outline of Claims and Repeating Ideas

Claim #1: Scientists are motivated by an intrinsic love of the craft: math, physics, discovery, and inquiry.

1. *Love of science; natural propensity for STEM disciplines.*
2. *Getting to know new systems; discovery and exploration.*
3. *Love of nature; develop understanding through direct experience.*
4. *Many aspects of conducting science are enjoyable and gratifying; making measurements, developing instruments, teamwork, and travel.*

Claim #2: Scientists make a strong case for basic science: a desire for others to support, conduct, and feel inspired by basic science.

1. *Inspire and influence a future generation of scientists.*
2. *Anyone can learn something about the ocean.*
3. *New Frontier; studying dynamics that no one has explored in this level of detail.*
4. *Have impact within science community.*

Claim #3: Scientists make a strong case for basic science II: basic science is both necessary and relevant.

1. *This research is one cog in the machine to understanding the entire global system.*
2. *Foster scientific awareness; it's a challenge to make the public aware of the important pieces that are in the puzzle.*
3. *Broader implications; this is the type of research that is most relevant to large-scale climate dynamics.*

Claim #4: Scientists display a natural propensity for outreach but bogged down by the term "Broader Impacts."

1. *Scientists resist the term "Broader Impacts."*
2. *Scientists tend to resort to education efforts to fulfill BIs requirements.*
3. *Some scientists display a natural propensity for outreach; going above and beyond.*
4. *It is critical that scientists reach out to the public.*

Claim #5: Outreach and communication goals are best met with help from an outsider: scientists are not EPO experts.

1. *Scientists are not trained in EPO and can benefit from working with a videographer.*
2. *Experts should be called in to help develop a hook when communicating complex science.*
3. *Fear of expanded role in outreach; scientists are not advocates, economists, or political scientists.*

Claim #6: Though scientists face some challenges with the filmmaking process, the final film product can inspire scientists to develop clearer BIs goals.

1. *The filmmaking process can be disruptive to the scientific process.*
2. *Film is a way to reach a larger audience than scientists normally would.*
3. *Film is a way to capture people's imaginations and hook them in to further investigate the science.*

Claim #1: Scientists are motivated by an intrinsic love of the craft: math, physics, discovery, and inquiry.

This question of what motivates people to pursue science as a career became important when exploring the types of roles scientists can and will take to fulfill BIs requirements. Chung (2012) found no correlation between academic degrees, tenure and career status, or gender and race and impact of outreach training on education and outreach; scientists are not necessarily informed by their background or academic standing when thinking about outreach. If the NSF and other funding agencies are interested in integrating STEM and EPO and encouraging inter-disciplinary collaborations in research, it might help to know why scientists choose their professions in the first place. The following findings indicate that these scientists are fundamentally driven by the scientific enterprise, and not necessarily by the potential broader impacts of their work.

Love of science; natural propensity for STEM disciplines.

All five scientists expressed an inherent love for science, "most of the time the science that I do is for the love of science," the scientific method, "I like asking a question and getting to formulate that question into a proposal or problem," and math or physics: "I was always intrigued by science, the way things work, how the world works, in a physical sense," "I've always been interested in math and physics." Three of the scientists indicated that they fell into the sciences because they were good at math in school and their trajectories were formed from there. Some described that they had been passionate about science since childhood, rigging up science fair projects on fluid dynamics in their parents' basement over the ping-pong table. Jonathan indicated that what makes him tick is "understanding the basic physics of a process that nobody else knows about," and to contribute to the larger scientific enterprise; he is interested in questions that "go to the basic heart of how water masses mix, how fluid flows, (…) how ocean waters melt glaciers," which he quickly identified to be "pure science." Support for pure, or basic, science is further explored in Claims 2 & 3.

Getting to know new systems; discovery and exploration.

Three of the scientists expressed that they feel fulfilled by discovery and exploration in science. The Greenland Project scientists were particularly excited by their research where they are exploring a dynamic that is poorly parameterized in Greenland and elsewhere. David talked about his first field season in Greenland in 2008 and how he was excited to take some of the first measurements ever taken in these fjords. He went on to discuss the differences between working in a place like Oregon, which has been "more intensively measured over the past few decades," versus Greenland, which is "new, it's exciting, it's sort of this new frontier." David emphasized that he does not subscribe to some rigorous view of science in the lab, that for him, science is about "exploring the world and nature and trying to understand what controls how the ocean moves."

In his pre interview, Jonathan talked about how he gets tremendous joy and lives for "discovering something new, whether I'm on a hike discovering some new place or whether its science and some new process." In his during interview he spoke specifically about how their discoveries in Greenland will either be globally generalizable or specific to that region and a small set of processes. Either way, though, it is exciting to discover something new: "Whenever we put an instrument in the water there's something new and unique that we get out of it, so science is always exciting." Emily also expresses excitement around making measurements and "learning a little bit about what you proposed but also learning something new that you weren't expecting."

Jonathan sums up this notion of discovery very well in his pre interview: "It never ceases to amaze me that wherever we go, we have some preconceived notion of what's going on and then we get there and most of the time it's something different that really excites us, and that's what drives us I think." Some observations indicate that the scientists were often discussing glacier dynamics while at sea; there was always excitement about what possible processes could facilitate glacier melting, or how the measurements they were taking might lead to some important breakthroughs. Evidence for exploration and discovery as a primary driver for conducting science came up for the Greenland Project scientists especially.

Love of nature; develop understanding through direct experience.

A lot of the scientists expressed an appreciation for nature. Joe posits that a love for nature is a common thread to all earth scientists: “I always loved learning about the seasons and weather and the mountains walking around (…) I always loved to go outside- mountain biking, backpacking, so you put those together and you pretty much become an earth scientists.” Much like Joe, David’s love for nature, and water specifically, might have been informed by his direct experience with it: “I grew up swimming so I really love any sort of body of water, rivers are great, lakes are great, oceans are great, it just sort of happens that I went into oceanography and not limnology.” Jonathan justifies fieldwork and experiencing nature as a means to truly understanding a system: “Our goals are to understand dynamics of a physical system that you really can only understand by experiencing it.”

Fieldwork is an attractive aspect to research for a lot of these scientists. David said that though he is mostly looking at a computer back in Eugene, he feels lucky to be able to go into the field in Greenland: “We have great jobs, this is what we do!” Jonathan expresses that he would feel like he was “missing out on something” if he were “just doing science at home and writing papers or proposals.” The gratification of doing fieldwork is further explored in the following repeating idea.

Many aspects of conducting science are enjoyable and gratifying; making measurements, developing instruments, teamwork, and travel.

Aside from a propensity for the STEM disciplines, a desire to explore, and a love of nature, all of the scientists in this study expressed great enjoyment around the actual practice of doing science, especially when working in the field. According to Emily, going out in the field and actually making measurements is an “exciting and fulfilling thing to do.” She also expressed relief when all of the moorings had been successfully deployed: “It’s nice to have everything go smoothly and to have everything in the water, it’s going really well.”

Part of making measurements is getting to decide on, compile, tweak, and sometimes develop the instruments that are necessary to withstand the different conditions in the ocean. For the Greenland Project that meant designing moorings that could react appropriately to large passing icebergs overhead, or developing a remotely operated boat (ROB) that could make measurements right along the glacier, a feat that was too dangerous for the R/V Sanna. Jonathan is particularly driven by the technological aspects of research: "The other aspect of being an oceanographer is that we get to make things and I'm always making gizmos and new instruments because often you don't have an instrument that's available that can do the type of measurements we want." Observational notes suggest that Jonathan was constantly tweaking instruments, fixing a flooded sensor, or pushing to deploy ROB one more time to make more measurements or test the technology.

Observations of the Greenland Project scientists indicate that several of the scientists on board were technologically savvy and it took a diverse group of people to make that project successful, which makes research more enjoyable as well. Jonathan called this group of scientists his family; like a family they bicker and disagree but eventually find great solutions together. He is particularly enthralled by the teamwork aspect: "I love that it takes a team to make it work (…) I get to work with fantastic colleagues and we work as a team, we understand our limitations (…) we thrive on each other." Emily was particularly excited by the inter-disciplinary nature of her work: "I think what's unusual about our team is that we bring in different expertise from different backgrounds and hopefully together that's going to make a really nice end product." David agreed that everyone had something to contribute: "It's great to work with a team of people and have all the parts of the machine work."

There is a strong social aspect to being at sea; observations conveyed a growing bond between the three scientists as they formulated solutions together, each bringing a different set of expertise to the table. One particular instance was when they had to find a location for a smaller pop-up mooring; David has worked in Greenland before and understands the natural hazards of leaving a shallow mooring in the fjord for a year, Jonathan was able to discuss the technological limitations, and Emily referred to the bathymetric maps and kept proposing solutions that then everyone would discuss. The scientists also joked around, enjoyed meals together, and discussed personal matters on a regular basis while at sea and in between deployments, making the whole expedition rather enjoyable. Although they experienced some frustrating delays, the scientists really seemed to enjoy travelling together.

David expressed how doing research at home or on a computer, “wouldn’t really fulfill my desire or my need [to travel and explore]. That’s what I like about this job, is going in the field for a few weeks every year.” David seems driven by travel and culture, particularly in Greenland: “Just the ice bergs and the glaciers and the mountains, everything together- the seals and just the culture and how well these people live up here, it’s pretty amazing.” Emily was eager to experience the culture in Uummannaq, the town from where we embarked to sea. Observational notes indicate that she made a concerted effort to interact with the locals there; she went to the Christian church on Sunday, attended a community lunch, and spent time with an old widow whose walls were covered in old photographs representing a culture that now seemed dormant (seal hunting in traditional clothing, packs of sled dogs getting prepped for the next trip, men gathered after a hunt). These aspects of being in Greenland were particularly interesting to her.

Claim #2: Scientists make a strong case for basic science: a desire for others to support, conduct, and feel inspired by basic science.

Inspire and influence a future generation of scientists.

According to Treise & Weigold (2002), scientists are motivated to engage with youth in order to recruit bright candidates to pursue careers in science. Jonathan, Emily, and Bill emphasized a desire to influence and inspire others, particularly young people, to pursue science. Jonathan showed some initial resistance to questions regarding BIs and his intended audience; he was very particular about engendering interest and enjoyment in basic science in each interview phase, particularly the pre interview: “The thing that I most want others to take from what I do is that they too can do things that they love and they can do science, basic science, and that it can make them happy.” In this same answer he emphasized wanting to influence younger people: “I mostly want to encourage others, and I’m thinking mostly of younger people, that they can follow their hearts to try to do something even if it seems kind of esoteric.”

Jonathan is making a case for basic science; he provided an honest answer when considering the broader applications of his research and his goals are particular to inspiring the next generation of scientists in basic science: “I think it’s part of our responsibility to keep the excitement of science, (…) so being able to get whomever it is interested in these kinds of questions and to realize that we actually really need good people to be doing this work.” Jonathan provided this answer in the post phase when asked about his personal BIs goals and did not go into how outreach could help him reach this goal, unlike Bill who sees BIs as an opportunity to “connect to the general public” and “inspire young scientist.” Bill is driven by outreach at a “core level” to achieve his goals of inspiring the next generation of scientists.

Emily was mostly interested in education when considering BIs (which will be explored in Claim #4) but provided some emphasis on engaging and retaining children in science because she hopes that what she is doing now “will continue to be important in the future.” Much like Bill, she finds that BIs are important in terms of engendering “some interest from young budding scientists,” but coming from a formal education angle, and particularly middle school. Emily believes it is essential to catch people at a young age in order to retain them in science.

The three Greenland Project scientists engaged with a group of middle school children in Uummannaq and attempted to communicate their research by conducting small experiments and introducing them to some instruments. This was challenging because though there was a translator the students seemed disengaged and distracted, maybe due to language and cultural barriers, or maybe because oceanographic research is too foreign to them (a concern Jonathan expressed in the *during* interview). Nonetheless, Emily expressed a desire to “have an exchange with the local people in Greenland and get to know them and help them to get to know our science” because she hopes to engender support from them for subsequent field seasons in the same area. Jonathan takes this further and hopes to have some influence on their career paths, “it would be fantastic if some of those students saw what we were doing and then realized that they wanted to go to university or become an engineer or a scientists of sorts, if they had that ambition.”

Anyone can learn something about the ocean.

Both Jonathan and Bill shared experiences in which they recognized that science could be compelling to non-scientists. Bill talked about his personal outreach efforts to get people interested in physical oceanography specifically. The challenges around hooking people in and communicating complex sciences like physical oceanography are explored in Claim #5 but what Bill suggested is that certain outreach projects can be "compelling to the average person." In his case, he collaborated with a fiction writer to publish a book on a research expedition. The book chronicles the writer's journals in the form of essays and includes a disc with short videos. Bill praises the effort for having successfully communicated complex science to more people: "Here was a hook that I could get people interested in *physical* oceanography."

Jonathan shared an experience about having heard from a neighbor that a newspaper clipping about research he led on internal waves propagating off the Columbia River plume was laminated and hanging in a friend's house. Jonathan was excited to hear that these people, who are not scientists, cared about this kind of work: "It was super exciting for me to hear that it was important enough for the person to understand, know something, to learn something about the ocean. You know it wasn't their field. It wasn't something they specifically studied." He seemed to be particularly focused on the fact that this was not their field and that they could still learn some complex science from a newspaper article. Jonathan also shared some anecdotes about certain encounters on planes where people seemed fascinated to hear about ten to fifty-story waves that propagate beneath the surface (internal waves), these are instances where he feels he can have a positive influence on people's understanding of physical systems.

New Frontier; studying dynamics that no one has explored in this level of detail.

Scientists are motivated by discovery, as was discussed in Claim #1. Science geared towards exploration of unknown phenomena does not always have a direct or obvious application, and Jonathan in particular makes this point several times in each interview: "You know what we do here in Greenland may not have some direct application, what we're doing is very exploratory." David finds that this research is important for society *because* it is exploratory, "we're exploring new areas, so we're sort of opening up the frontier of sort of ice-ocean research, so it's a new world to explore." He then makes a case for why this is important to make better predictions concerning climate change and sea level rise, which is explored in Claim #3.

Jonathan continues to make a case for basic science in regards to making a new contribution to science, "the type of dynamics that we're looking at are the type of dynamics that really nobody has explored in the same level of detail that we're going to do it." Emily makes a similar case about making new measurements, "in some of these places [the physical process you discover] is going to be new to everybody." The Greenland Project scientists often emphasize the exploratory nature of this work to justify the research, because these processes are not well understood or parameterized, they find that this work is important. In other words, it has relevance in its own right. Claim #3 delves into how this research is in fact relevant to humans.

Have impact within science community.

Whenever asked who they hoped to reach with this research, the Greenland Project scientists' first response involved reaching, influencing, and drawing in peers within and across scientific disciplines. Emily has conducted a lot of research in the Arctic, which involves collaborating with glaciologists, whom she hopes to reach: "I hope to reach my community, which consists of scientists who do work in the Arctic and in Greenland, so both oceanographers as well as glacier people." This response was provided during the pre phase interview. She went on to emphasize that this work is "geared towards basic science" in her during interview, "which means our community will be interested in it so that includes physical oceanographers and glaciologists and in general earth scientists." This research is therefore relevant for a variety of scientists.

David has been working and collaborating with scientists doing work in Greenland since 2008 and is interested in drawing more people into this region to conduct research: "This research to me is exciting because we're trying to bring new oceanographers to this problem. So the ice-ocean community, which I'm a part of." This "ice-ocean community" has grown since glaciologists could not attribute melting solely to "surface air temperature or bedrock," and so physical oceanographers were brought in to try and see if anything was happening from the ocean side.

Jonathan was particularly interested in the implication of this research in terms of how it could be useful to other scientists: "It has specific implications to other scientists' perception of the problem, their ability to parameterize various processes. So other scientists find the things that I do useful." He went on to explain that there are no immediate applications to this work for "someone who lives in Portland" for example, but that this research will be "useful to a broader set of dynamics and it's going to be helpful to climate scientists for example." Here again is a case where inter-disciplinary research evolves out of basic science, and can eventually become relevant to society. Finally, he expressed that it was not his goal to reach people but to learn "more about ocean dynamics that are controlling the rate at which a glacier is being melted," and that he does not feel the need to be "advocating for something, (…) this is very exploratory."

Claim #3: Scientists make a strong case for basic science II: basic science is both necessary and relevant.

This research is one cog in the machine to understanding the entire global system.

The most prominent message here is that basic science provides the pieces of the puzzle that lead to a better understanding of a system and the feedbacks within that system, which in this case, according to Jonathan, "is a big system, it is the global system and the ice-ocean feedback." In his post interview he went on to say, "we are just one little cog in this huge set of gears and machinery that all have to function to get a better understanding of the entire global system." Jonathan, now having been confronted with the BIs question for the third time, explains that this research may not seem to have some "application to putting food on our plates or solving a transportation or energy problem, but all this basic understanding can give you a lot of understanding." Here again he is making a strong case for why basic science is essential, and how each piece functions to contribute to a greater understanding of the global system. Though Jonathan was certainly aware of the intent of the question on BIs, he instead emphasized that basic science is a necessary component to the development of applied science, a theme that prominently emerges in the literature (Bernal, 2012; Klevorick et al., 1995; Salter & Martin, 2001).

David supported this notion but took it a little further to include some broader implications of their research: "Our research is this little part of what role the Greenland Ice Sheet might have in driving global sea level rise up in the future." He was already making the connection to the overall applicability of this type of research and went on to say, "if the ocean plays a role in controlling how much ice comes off as melt, which also raises sea level, then we're doing our little part to understand that a little more." Emily also talked about how their science fits into "a larger picture, a global context," and provided evidence for how this research can be applied elsewhere and in the context of climate change: "One of the primary goals is to understand the dynamics in these two fjords so that we can (…) extrapolate what we learn here into other fjords. This is important because the Greenland ice sheet is melting and that melt is contributing to sea level rise, which will have impacts around the world as we enter a warmer climate." Several publications talk about the eventual applications that come out of conducting basic research (Klevorick et al., 1995; Salter & Martin, 2001).

One important component of understanding climate change is parameterizing feedbacks. Emily talks about the BIs of this research in her during interview: "[The BIs of this research] mostly have to do with our understanding of how the ice sheet is melting, how the ocean and individual glaciers interact, how they feedback with one another, and what that means in terms of the larger ice sheet and sea level rise." Jonathan, also in his during interview, talked about some of the gaps in knowledge concerning climate: "It's not yet clear how all these feedbacks work, some people say you increase the amount of freshwater coming off these glacier systems then you end up maybe altering the local climate (…) but there are lots of different feedbacks that could occur and we don't really understand the dynamics of those."

Jonathan claimed that there is no simple answer to the climate question: "There are some people who actually believe that there will be very rapid climatic changes and we are just trying to understand each of the pieces that fit into that because it's not just one simple answer to that question." Jonathan, in his pre interview, prefaced this statement by explaining that there are still so many holes in our ability to predict the future, and that this research seeks to fill some of those knowledge gaps. Enhancing the public's scientific literacy might help to clarify why there is no simple explanation for climate change (Hurd, 1998).

Emily talked about sea level rise and the ability of coastal communities to deal with it. She claimed that to answer those questions we "need to understand a whole range of scales of processes—time-scales, spatial-scales, and one of those things is to understand how the ocean is impacting glaciers and the larger ice sheet on Greenland as well as in Antarctica." Jonathan concluded by stating that "all of the small scale processes, which actually do the transports, the things that actually take the heat from the surface or carbon dioxide and move it through the ocean, those have to be parameterized with some empirical formulation."

Foster scientific awareness; it's a challenge to make the public aware of the important pieces that are in the puzzle.

These scientists feel that the public is unaware of the role of basic science as a necessary component to understanding the natural system in which we live, which could also be addressed with a focus on scientific literacy (Treise & Weigold, 2002). According to Jonathan, this lack of awareness disconnects humans from the role they play in nature: "As a society, we cannot think that we can act in isolation of the affects that we might have." Relaying the different pieces "that are in the puzzle of the whole atmosphere-ocean-climate system" to the public is a challenge, and Jonathan believes that "the important thing is being able to convey some basic messages about what we know about how the system works." Challenges regarding science communication efforts are further explored in Claim #5.

Joe, the paleoclimatologist, stressed this aspect of public awareness several times in his interview: "I think you've just got to connect people with the science, people should be much more aware of it than they are." He expressed this after listing off the many ways he would like to tie his research back to media outlets and education efforts, in regards to BIs. Joe has "always been pretty interested in the outreach component of climate research, (…) this is really relevant to people." In regards to climate science, "most people don't really have a good view on this whole topic, which it always seemed to me to be something that people should be aware of because this is going to be really important in shaping the world indefinitely for maybe the next 100 years."

David expressed several times that he thinks people do not "think about Greenland on a day to day basis or think about sea level rise or how connected we are to the oceans." According to him, people are perhaps unaware that what happens in Greenland "eventually gets communicated around the whole global ocean." Jonathan took this further by saying that people are perhaps unaware that even science has not provided all the answers: "I think that part of our responsibility is to (…) make the broader public aware that we don't actually know everything about the system, we don't know a lot about the system." This begs the question of why scientists, especially Jonathan, resist the concept of BIs (which will be explored in Claim #4). If they want people to reach a deeper understanding of the earth system and its many feedbacks in order to garner more support for basic science, scientists need to start thinking about how to raise awareness in people, whether on their own or with the help of EPO specialists (Holbrook & Frodeman, 2007).

Broader implications; this is the type of research that is most relevant to large-scale climate dynamics.

Though the broader implications of these scientists' research is not always very apparent, they are all acutely aware of how their research can fit in to the broader picture of climate change. According to Emily, "we have done things to our climate that has set our planet on a certain course and it would be nice to understand what is going to happen in the future, and you know maybe we can do things to mitigate where we're headed, hopefully we can." This ties back to the previous repeating idea that basic science plays an integral role in fully understanding "what is going to happen in the future." Joe, in talking about his love for science and for the outdoors, went on to suggest that climate change poses some interesting challenges: "It seemed to me that the really interesting questions and the really exciting science and the really relevant stuff was in climate change."

The three Greenland Project scientists clearly identified the two broader implications, primarily sea level rise, of glacier melting in Greenland: "If all of the ice that is currently sitting on top of Greenland were to melt it would add a large amount of freshwater to the northern Atlantic Ocean and that additional amount of water would also help raise sea level." "Ultimately we're trying to understand how the Greenland ice sheet loses mass and that affects global sea level rise." "There's like 7 meters of potential rise held up in that ice sheet."

However, Jonathan, for example, resisted identifying this as a broader impact when asked directly, "what are you BIs goals?" To this, in his pre interview, he answered, "well, it's possible that I don't have any!" This kind of resistance around the term "broader impacts" is further explored in Claim #4. He was, however, willing to identify the critical relevance of this research: "There are two really important consequences to the melting of ice on the continent of Greenland. The first is that it can raise sea level, the second is maybe more important from a physical dynamics perspective, is how it might also affect other dynamics in the area."

All three Greenland Project scientists talked about the relevance of this study in terms of improving numerical models and climate predictions: "it's fairly clear that understanding those dynamics is important and being able to predict how those dynamics will change in the future." "The understanding of those processes could have a very significant impact on, say, numerical models and our ability to predict and project and understand how these massive ice systems might change." "If we can understand these systems better then we can make models that then will allow us to predict how sea level will rise in the future and that's what everyone wants to know, what's sea level going to be in 2100."

Joe also explained that "we can't map out the future that well." If nothing else, scientists can agree that "the world that we live on and the climate that we are adapted to are definitely changing," and that all of the consequences of rising carbon dioxide levels, including changes in rainfall and rising sea levels, "tie back to society and economics in some form or another." He mentioned agriculture and coastal communities as two systems that will get "hit."

There are many human dimensions to the marine environment and the study of oceanography such as coastal resiliency, impact on weather, and natural disasters. David expressed that he found more meaning in his work in coastal oceanography because it ties directly back to humans: "It's sort of where humans interact with the ocean and so it just seemed more exciting and practical to me to study the ocean that people interact with more, it was more meaningful." Emily explained that physical oceanography is essential because the ocean has so many important functions on the planet, "when you talk about physical oceanography you are essentially talking about the environment that all the organisms in the ocean are living in (…) or the components of the ecosystem that inhabit that region."

Jonathan also stressed some points regarding the ocean's many essential functions, "the ocean is where a tremendous amount of biomass resides, it is where most of the carbon dioxide has been going, it's the thermal mass of the atmosphere system, it's where heat gets stored, and it plays a huge role in all sorts of things like weather predictions." He then elaborated on the importance of oceanography because we know so little about the ocean, "by and large we know so little about what is underneath the surface of the ocean. We've spent so much effort looking at the moon and going to mars and we really what we should be spending time understanding is what's right here on this planet."

Basic science also needs to be relevant as far as funding is concerned (Frodeman & Holbrook, 2013). According to Jonathan, "we are starting a downhill trend feeling a need for understanding basic science in this, globally, but in particular as we are having funding problems in DC. It is one of the things that gets hit." He then explained that this kind of work does not consume as many resources as, say, "operating an aircraft carrier for a couple of hours" and that though science takes a lot of resources, "it's not that much in the grand scheme of things." Emily recognized that funding was primarily driven by sea level rise, "sea level rise is probably the number one reason any of this science gets funded."

Finally, another theme that emerged from this portion of the data is that basic science is necessary for decision-making and response planning around climate change. Joe explained that we need a better understanding of the system to inform policy in adapting to climate change, "it's helpful to have better ideas of where the future goes – that all starts to change policy responses or changes the cost-benefit analysis of how we would respond to climate change." David talked about some of the missing pieces in regards to the Greenland ice sheet and sea level rise in the last Inter-Governmental Panel on Climate Change Report, and how he hopes to "reach people who are making decisions" with this research. Jonathan also mentioned that this research is important for society in terms of decision-making, on an individual level, "we actually need to be able to make decisions, educated decisions, about how we act in our daily lives." One of the goals of scientific literacy is to bolster decision-making for self and society, which makes a case for improving science communication efforts (Laugksch, 2000)

These scientists are filly aware of the broader implications of their research. They are also aware that though basic science is currently under funded, it is an important endeavor in terms of improving numerical modeling and climate predictions, which hopefully will trickle down to influencing policy and decision-making, as discussed by Salter & Martin (2001). Though there is some resistance around the term "broader impacts," these scientists are thinking about how their research can and will eventually be applied.

Claim #4: Scientists display a natural propensity for outreach but get bogged down by the term "Broader Impacts."

Scientists resist the term "Broader Impacts."

Several participants expressed some resistance around the term “Broader Impacts” specifically. Bill’s first reaction to the term involved him identifying BIs as a restriction; he then caught himself and switched to calling it a “concept.” Bill is very invested in outreach but mainly conducts it on his own terms; he has developed interactive websites with videos and podcasts about several different research projects, and he published a book with a well-known author. Although Bill is personally compelled to reach out to the public, he remains frustrated with the “concept” of BIs: “What does it actually mean?! What is its purpose and how are we supposed to deal with it as scientists?”

For Bill, the frustration lies in the fact the scientists spend a lot of time putting their noses “to the grindstone” to pursue their scientific dreams but now they are tasked to communicate that science to a broader and “unnamed” public. The theme that scientists are not EPO specialists is further explored in Claim #5. He expressed that BIs “is not only extra work, it’s ill defined work!” And due to the current funding climate, which is less supportive of “science for science’s sake,” scientists struggle with the extra responsibility of BIs.

Jonathan, too, resisted the term quite a bit. In the pre interview phase he was hesitant to answer the question, “what are your BIs goals,” and was frustrated with the assumption that he had these goals in the first place. In the during and post interviews he began answering the question by exploring the importance of basic science, as was discussed in the previous Claim (#3), and would only talk about the application of his research in terms of painting a more accurate picture of the entire ocean-ice-atmosphere system. He then elaborated on his desires to influence young people to pursue and enjoy science as much as he does. Upon further investigation, Jonathan expressed some goals in terms of improving the funding climate for basic science and having an influence on decision-making.

Emily, David, and Joe were all more receptive to the concept of BIs. They knew that by mentioning efforts along the lines of education, public talks, website development (specifically blogs), and potentially video (due to past experiences or to the experience they had with film on the Greenland Project), they would be meeting the requirements to obtain funding. Some of their stated goals did, however, extend beyond these requirements. It is important to note that these three scientists could be considered early to mid-career scientists, while Jonathan and Bill are both mid to late-career scientists, though career stage was not an important factor to outreach in the COSEE study (Chung et al., 2012).

Scientists tend to resort to education efforts to fulfill BIs requirements.

Emily and David both mentioned education efforts as a personal or research BIs goals in all three interview phases. Emily was more focused on the local population in Greenland and on middle-school education, “we are trying to do a little bit of education outreach as well, in particular with some of the children in Uummannaq,” and “hopefully we’ll be able to coordinate with some middle school classrooms and just keep touch and let them know what we’re doing, what science is like.” David seemed to be more focused on higher education efforts and one of his students, Dustin, joined the team in Greenland as part of his thesis research, “so the broader impacts for me at the start were to train a graduate student, so Dustin my PhD student came along on the cruise and he’s progressing on his research right now.” David emphasizes education to be “a big broader impact for us, as faculty we’re trying o train the next generation of scientists,” which could be tied back to Claim #2, *Inspire and influence a future generation of scientists*.

Some scientists display a natural propensity for outreach; going above and beyond.

Bill is exemplary of this idea and his unique outreach efforts were outlined earlier in this analysis. He self-identifies as someone who tends to do more than he outlines in his proposals: “I enjoy [outreach], I think it’s important, and I usually do more than I say I’m going to do. I’m sort of at the opposite end of the spectrum.” He started doing extensive outreach work in 2002 and claims that “once [he] got a little taste of it” he kept wanting to do more: “I saw the responses I was getting from friends family, some schools that we’re following, a person who donated the money for me to do this in the first place. Once I started getting the feedback I was like wow, this resonates with people.” For him, outreach is fun, fulfilling, and “drives [him] at the core level.” He also talked about the importance of internal support: “The reason I could get away with that way back then is because I had extra money internally at WHOI.”

David also displayed some active interest in “doing more” in terms of outreach. He has spent five summers in Greenland and has taken photos and videos to share with friends and family: “I just want to get my research out there more. You know we publish it in scientific journals but there’s so much more that we could do.”

It is critical that scientists reach out to the public.

Some of the scientists identified two reasons for why “it is critical to reach out to the public:” meaning and funding. Emily expressed some interest in both: “I think it’s critical that we reach out to the public, my work doesn’t have much meaning if the public doesn’t know about it or if it doesn’t somehow get shared beyond my immediate circle of colleagues.” For her, BIs is about “sharing what [she does] and why it’s important.” She then explained that she reaches out to the public for more practical reasons: “I depend on public funding to do my science and to receive that funding I need to show the public that my science is important,” which involved communicating her science beyond her “little subset.” The literature strongly reflects this notion that it is in the scientist’s best interest to consider the broader effects of their research (Holbrook & Frodeman, 2007).

For David, obtaining funding from the public means that outreach is an imperative: “I think as scientists we sometimes forget [outreach] sort of should be the real goal of science. Because if you don’t actually communicate your data to the public, or if you don’t communicate why science is important, science is not going to get funded in the future.” Because the public is funding this enterprise, they should directly benefit from it and the outcomes of research (Burggren, 2009).

Claim #5: Outreach and communication goals are best met with help from an outsider: scientists are not EPO experts.

Scientists are not trained in EPO and can benefit from working with a videographer.

This is a theme that also emerged in the CAISE study data and emerged only as a minor concern for some of the scientists in this study. Bill talked about the immense amount of training and work that goes into becoming a successful research scientist, “but now we’re being told we have to communicate [our research] in a very generic way to the public.” He went on to express some frustration with this: “Why should we be required to do that? I hear a lot of people, older people especially, are asking that question: why am I being required to do this? It’s taking away from my science." Scientists are already bogged down by so many tasks and BIs can take away from that, "we barely have time to write the proposal let alone analyze the data and we do the science that we love to do." Finally, though Bill has conducted the "ultimate kind of outreach," when referencing the book he published, he stated that he may not do that type of work again, "it was a lot of work."

Although David was keen to communicate his science to the public, he saw that scientists "get stuck in the rut of BIs," and he expressed a desire to receive some guidance: "It would be nice to learn about different ways of doing it." For the Greenland Project scientists especially, having a videographer on board caused them to think a little bit more about how their science could be represented and disseminated to more people. For one, the videographer was a non-specialist on board asking questions that they normally do not think to communicate while in the field: "What is this instrument for, why is this measurement important, how could current velocity factor into glacier melting, or what is the implication of bedrock erosion in the fjord?" Secondly, including the scientists in the editing phases of the video production caused them to think about ways in which to distill some basic messages about their research to the public. This last point is essential to this study and is further explored in Chapter V.

In this case, working alongside someone who is tasked to communicate their research, and who has some expertise in science communication, compelled the scientists to consider the broader implications of their research more seriously as well as develop clearer messages about the importance of their research. The final film product, Greenland's Glaciers, which was screened at OSU in front of a small student and faculty audience, followed by a Q&A with Jonathan and Emily, inspired these scientists to consider developing a film that could include the results of their research; this film only covers the first field season of a three-season study. Jonathan mentioned in the Q&A that he would be interested to film their final summer field season to include footage that would communicate some results, leading to a more fully developed film about their research that could leave the audience with some concrete information about how the ocean influences glacier melt in Greenland.

Experts should be called in to help develop a hook when communicating complex science.

The three Greenland Project scientists expressed concern that a film about research in physical oceanography would not appeal to many people. When answering how she anticipated film would help her communicate her research, Emily said: “I think what your challenge is going to be is actually grabbing people without a charismatic mega fauna or some sort of living being that has a story with it.” Jonathan talked about needing a “cool factor” and a plot with a conflict and a resolution; the challenge is to draw people in without misrepresenting the science: “Portraying the real science in a truthful way while making it exciting enough and having the plotline that you need I think is the challenge.” In reference to posting a video on YouTube, David joked about doing some stunts to reach people: “Maybe if we jump in the water and freeze our butts off then we could get some more hits!” The importance of narrative in science communication comes up in the literature as well (Avraamidou & Osborne, 2009).

Bill talked about the challenges associated with developing a compelling series of essays on a study in physical oceanography to publish a book, “you know as physical oceanographers a lot of the stuff we do is pretty dry, in terms of the general public.” He talked about communicating concepts that are “difficult to grasp for laypeople,” and that some of the terminology would cause “people’s eyes to glass over.” At one point the writer exclaimed, “you can’t even see the water move!” Bill’s research on tracking a newly discovered current seemed to him to be a “hook that could get people interested in *physical* oceanography (…) this is something you can connect to the public with, (…) someone goes out and discovers a new current, that’s really great!” In order for people to keep reading, the writer “has to couch it in a way that the public is totally enamored with but he also has to be scientifically accurate,” which agrees with Jonathan’s statement.

Emily sees film as a great way to capture people’s attentions to then communicate the science. With the Greenland Project especially, Emily hoped to draw people in with the stunning scenery of western Greenland, and “once that interest is captured we can actually put in some of our findings and science.” David has edited some video clips together and compiled photographs to try to convey to people what it is he actually does in oceanography, “I think film can also help but I think it has to be more directed, something I’m not very good at.” He went on to explain that in order to convey the “scientific method of what we’re trying to do from hypothesis to testing it to results in film,” it needs to be edited in a professional way, “I just don’t now how to do it." This idea ties into the previous repeating idea about bringing in professionals to aid in the outreach, as Bill has done with writers, videographers, bloggers, and radio producers.

Fear of expanded role in outreach; scientists are not advocates, economists, or political scientists.

There are some dangers associated with spinning a story around a scientific study (Gascoigne & Metcalfe, 1997; Hmielowski et al., 2013). Lackey (2007) argues that scientists risk losing credibility if they advocate for something according to personal biases. Joe had an experience with a professional film producer hoping to release a segment to a mainstream television channel on caving. The producer was interested in Joe's geological work to reconstruct past climate but pressed Joe to come up with a specific topic that the audience would be interested in. They eventually came up with hurricanes: "Hurricanes, everybody will get that—global warming!" Though Joe was happy to bring some attention to his science, he was wary of sensationalism: "I was really careful about making certain statements and I was always a little on guard, (…) I didn't want to say stuff like 'this [sample] right here could save a ton of people because we will now avert the climate crisis.'"

Joe took this further to say that he did not want to advocate for anything: "I have to be really careful of not ever trying to push one policy or one response, that's not my expertise, I'm not an economist or political scientist." Joe stressed that it is important to keep the science separate from advocacy when communicating science, "it just has to be clear when it's talking about science or when it's talking about things that go beyond the science, like using value-laden words versus just describing what we're doing." He is also wary of the politicization of certain issues and talked about films like The Inconvenient Truth that "helped fuel this super intense partisan divide and politicization of this issue." Along those lines he emphasized again that scientists need to keep fact separate from policy and economics. Cooper (2011) discusses the dangers of merging science with advocacy, which can be a common pitfall to science filmmaking or video production.

Bill had a similar experience with National Geographic who wanted to cover an expedition of his. Aside from some complications that arose with the videographer (which will be discussed in Claim #6), Bill was disappointed with their objective to focus on dramatic sequences: “National Geographic was bummed, they wanted rough seas, they wanted you know here are these tough oceanographers going out from Iceland to learn about how dense water is being formed.” This experience led him to forgo working with National Geographic or similar production companies: “They’re coming in with an agenda and they’re not willing to listen. I am interested in the pubic getting a glimpse of this exciting science, and the public totally had no clue what our program was about by watching that national geographic show.” Though he was interested in reaching the public he became fearful of being misrepresented, which also comes up in the literature (Barnett et al., 2006).

Claim #6: Though scientists face some challenges with the filmmaking process, the final film product can inspire scientists to develop clearer BIs goals.

The filmmaking process can be disruptive to the scientific process.

Bill’s unpleasant experience with National Geographic started early on in the production. He was initially wary that having a videographer on board might cause some “tension between him and the science being done,” especially because ship time is expensive: “When you finally do get something funded, it’s precious, and you want to get 110% of the time spent doing the maximum amount of science that you can.” So when he had to work more slowly or repeat an action, like deploying a certain instrument, he found the process to be disruptive, despite his desire to support this kind of outreach: “I’m willing to do some of this stuff but it does impact the science, that part in and of itself you could call negative.”

Bill identifies as “a pretty shy person” and the thought of having a camera in his face “was kind of scary.” Nonetheless, he accepted to have a videographer come out to sea with him and even obtained an extra day of ship time to accommodate the production. Unfortunately, the videographer did exactly what he warned he would do: “He warned us that he was going to be in our face with his camera, and man he wasn’t lying.” And though Bill found being filmed “two inches from our faces” to be disruptive, he found that “after about a day it almost got fun.” He also expressed that often with experiences like these, “the positives far outweigh the negatives” because of his successes with outreach: “We’ve engaged all of these people in science, in oceanography! That’s awesome.”

The Greenland Project scientists only expressed some discomfort with the videography phase of the production in their interviews. Jonathan expressed that being filmed can sometimes distract him from the task at hand, especially when he was being interviewed at sea: "It's a little bit awkward at times. It's partly a personality thing, I want to be everywhere at all times." David expressed that he was not really affected by the camera except when chatting casually on deck: "It's maybe more so when we're hanging out and chatting and stuff, that's maybe when I notice the camera." Emily expressed that sometimes "it's a little frustrating cause the camera is right there."

Ultimately though, all three stated that that they were happy to work with a videographer. Jonathan seemed pleased with my ability to assimilate with the scientists: "I totally appreciate the fact that you can merge in here and get good footage." David found the process to be easier because I became involved with the project early on: "It's nice that we got to know you a little bit before you came on board." He went on to express that it is nice knowing we are all working towards the same goal, "at least in terms of broader impacts. You know you're trying to communicate our science and we want to do that too!"

Alternatively, some observational notes indicate that the videography was in fact disruptive to the Greenland Project scientists, especially on deck and during mooring deployments when the scientists needed to be attentive and meticulous about their operations. Other notes indicate that the scientists initially shied away from the camera, especially when talking casually amongst themselves about both personal and scientific matters. Throughout the course of the expedition, however, the scientists warmed up to the camera and were able to ignore it, allowing me to capture sincere reactions and conversations concerning their research. Finally, there were some instances when they requested a break from the camera during more stressful moments when an instrument was failing or when we were working at night and unable to see certain operations.

Film is a way to reach a larger audience than scientists normally would.

Though this is a pretty obvious idea, all of the scientists in this study mentioned reaching a broad audience as an advantage to film as an outreach tool. Emily sees film as a "visual record people can refer to on a website in the future," or a "means of distributing our information to a larger audience and people we normally wouldn't reach out to." Jonathan listed many examples of videos that successfully reached a broad audience distributed though National Geographic that he normally would not reach: "To sort of bring that to a broad audience is something that we don't do, we write our papers in peer-reviewed journals." David referred to a recent film entitled *Chasing Ice*: "There's an example where film influences a lot of people." He went on to say that people could really engage with the dynamics the film was trying to portray. Bill and Joe both elaborated on how film is useful in reaching a variety of different people that they normally would not have access to as scientists. According to Bill: "There are so many different kinds of people with different backgrounds that now get a little taste of what we do!"

Film is a way to capture people's imaginations and hook them in to further investigate the science.

This finding strongly aligns with the repeating idea in Claim #5, *You need a way to hook people in when communicating complex science,* and a lot of the data is the same. However, there were some specific statements about how film, specifically, is particularly useful in drawing people in to compel them to investigate the science a little further.

David talked about how seeing the science is "more powerful in film" than routine outreach efforts, such as giving a PowerPoint presentation. He finds that film can communicate the science better, "or at least get people interested in our problem. I think that's the first step, people have to care and then you can try and tell them a little bit about the science." Emily agrees that film can provide the hook to then communicate the science: "Once you kind of capture that visual interest we can add a little bit of science to it." Emily expressed that video could be the preferred method of obtaining information from her website: "It's just one more avenue of pulling people in and letting them know about what's going on, maybe rather than reading the website and getting information that way, they'll just click play!"

Joe finds that the most effective science videos are "a mix of the science, entertainment, and drama." Before introducing the "process of science" or "the kinds of things you have to do to answer science questions," videos should "engross viewers in exciting adventure."

Several participants expressed that film could provide another perspective to science that could not be explored in other mediums. David mentioned exposing the field site, the culture, and other elements involved in travel: "It might be interesting to hook viewers in with the [Greenlandic} people." Much like a travel documentary, science film can "show beautiful scenery, beautiful places." He also talked about the specifics of doing research in Greenland: "Film also conveys how we do the research on the boat, which I think is unique to Greenland." Jonathan talked about exposing the different aspects of science more effectively through film: "We're doing a variety of different things from small boat operations, remote boat operations, moored operations, operations very close to glaciers, operations in the open ocean."

<u>Summary of In-Depth Case Study and Semi-Structured Interview Data</u>

Findings indicate that the filmmaking process did not have a substantial impact on the Greenland Project scientists' communication of their current research. However, the editing phase of the production process seemed to have an impact on how the scientists handle BIs; upon seeing a rough cut of the film, the scientists developed clearer messages about the broader implications of their research and wanted these messages to be at the forefront of the final film product. Though all three participating scientists were optimistic about the effectiveness of film in science and supportive of this project in particular, they were concerned that their science did not seem relevant to most people in this initial rough cut. Jonathan and Emily especially aware of the importance of having a clear and relevant message for viewers during the Q&A at the screening at OSU; several audience members asked questions to elucidate the science, which proved that there was interest around the topic.

Other findings show that participants are involved in science mainly because they are naturally skilled in scientific disciplines and enjoy and respect the scientific enterprise, as well as the natural world. All participants made strong cases for why basic science is both necessary and essential to achieving a better understanding of the entire global system (the natural system) and to making more informed decisions both for self and society (emphasizing policy). Some of the participants, though they display a propensity for outreach and public engagement (particularly with youth), resist the concept of BIs and feel that BIs requirements take away from the scientific enterprise. Participants found the task of communicating their science or conducting outreach to be difficult on their own, making a case for involving EPO specialists in their BIs efforts; there are also perceived complications to communicating science without advocating for something specific.

Participants were generally comfortable and excited about the use of video as a communications tool; they all agreed that it was an effective medium with which to reach a broad and varied audience. However, some participants had bad experiences with both the process of being filmed and with the final film product, particularly when larger production companies were in charge. Finally, participants expressed overall optimism for the ability of film to capture and retain an audience, using more exciting aspects of the research (scenery, people, culture, and technological aspects) to first captivate the audience.

Overall, the relationship between BIs, science communication, and film emerged as a strong one in this study. Film is an effective medium with which to communicate even complex concepts of science and to reach broader audiences with the relevant aspects of even "pure" or "basic" science such as physical oceanography. Collaborating with a filmmaker and developing clearer messages about the research in question could help meet BIs requirements. The Greenland Project scientists are satisfied with the film that emerged from this collaboration and expressed continued support for this kind of outreach; hopefully this will be a growing trend in many disciplines of science.

CHAPTER V

CONCLUSIONS

I initially designed this study to document how the filmmaking process might impact the scientists' ability to communicate their research over time; effective science communication is essential to enhancing the public's scientific literacy (Laugksch, 2000), which is an important component to meeting the BIs requirements as established by the NSF (Holbrook, 2012). However, during the data collection process and as I became involved in the field working alongside the Greenland Project scientists preparing for and conducting research in Greenland, other more relevant and important themes began to emerge.

Though scientists need to be better communicators themselves (Lemke, 1990; Olson, 2009), it became clear that perhaps working alongside and partnering with a science communicator, or in this case a filmmaker, might lead to some beneficial and long-lasting outcomes: when it came to finalizing the film product for their research the scientists felt compelled to communicate clearer and more societally relevant messages about their research, despite some initial resistance to the concept of BIs and despite some attachment to the "basic" science nature of their research.

The CAISE study data was useful in terms of laying the groundwork on how scientists respond to outreach training and the concept of BIs. Ultimately, the participants in this study and the CIASE study are peers within the STEM community and provided similar insights about their perceptions of and experiences with the BIs requirements. This study provides additional information as to the role that film can play in developing and implementing BIs goals.

The following pieces of evidence combine findings that emerged from the three datasets and synthesize the major components of this study: motivations for science, science communication, BIs, and the role of film in science and outreach.

Evidence for adjusting NSF's funding model

Findings indicate that scientists are receptive to engaging with the public about their research; many participants from both the CAISE study and this study either demonstrated a desire to exceed the BIs requirements or conveyed that outreach is the very purpose of science. Funding, after all, does come from the public and providing an explicit return on that investment is a moral obligation of scientists (Holbrook & Frodeman, 2007). Other participants pursued science because they wanted to affect change or because education is extremely important to them, especially in terms of inspiring young people to pursue science. These final two findings emerged from all three sets of data.

The BIs criterion, however, continue to cause confusion and frustration among scientists, especially those seeking funding for basic research, as illustrated in this study and in the literature (Holbrook & Frodeman, 2007; Holbrook, 2012; Tretkoff, 2007); participants in this study and the CAISE study used terms such as “restriction,” “ill defined,” and “penalizing” to describe their perceptions of BIs. Participants expressed concern that a funding model which requires scientists to conduct outreach, an endeavor that often exceeds their realm of expertise, would undermine the very foundations of the scientific enterprise; basic research is a necessary component to informing high-quality applications of scientific research, as well as ultimately enhancing innovation, industry, expertise in the workforce, policy-making, and problem-solving (Salter & Martin, 2001). The case study and interview participants for this study provided evidence for how basic science can become relevant down the line; each piece of research is one cog in the greater machine towards better understanding the global natural system.

Participants felt that research proposals for which BIs are irrelevant should not get turned down. Alternatively, scientists should be aware that even basic research can become of interest to people outside of the STEM community; with enough determination and ingenuity, discoveries in physical oceanography can become compelling and relevant to a broader public. Bill’s outreach work with the science writer is a prime example of this. Perhaps one way to address how basic research will be supported in the future is to avoid imposing a “one size fits all” outreach funding model to all research proposals. Findings indicate that scientists might be more receptive to engaging in outreach if the requirements more specifically reflect the nature of their research, whether it be enhancing tools to develop faster and more accurate modeling software or measuring small-scale fluid dynamics in the fjords of Greenland.

The NSF updated the BIs criterion in 2012 to address scientists’ frustration with their meaning and their intent. However, the requirements remain vague so as to allow PIs to develop creative BIs efforts rather than just adhering to a list provided by the NSF (Holbrook, 2012). This freedom and vagueness may continue to face opposition from the STEM community but could ultimately benefit PIs as they develop new, original, and research-specific BIAs. If the objective of BIs is to enhance the public's scientific literacy, which nicely encompasses all eight National Goals, a consideration for the NSF would be a funding model that could better stimulate more effective BIAs; too many proposals focus on limited audiences, and usually within academia (Nadkarni & Stasch, 2013).

I propose the following funding model to encourage more effective BIAs and to help inspire scientists to embrace the new criterion. The following aspects of BIs should be funded separately:

1. Communications expert
2. Evaluation process
3. Publication of BIAs

Findings from this study suggest that partnering with EPO experts or professional science communicators can encourage scientists to embrace the concept of BIs with more confidence and optimism. Burggren (2009) suggests partnering with BIs experts (which includes EPO experts and professional communicators) so as to produce more effective BIAs in any and all scientific disciplines. If the original purpose of the NSF is to support basic research "in the public and private colleges, universities, and research institutes" then scientists might be more receptive to a funding model that tackles science and BIs separately (Burggren, 2009; Bush, 1945, p. 255). Scientists should not have to shy away from attempting to obtain funding from a federal source simply because they do not think they will be successful due to the "irrelevant" nature of their research. Instead, the NSF should continue to support basic research while funding communications experts separately to develop and even implement BIAs, ideally in collaboration with the scientists themselves. Inter-disciplinary projects and collaborations with communicators are proven to be beneficial to the scientific enterprise, which will be explored in the next piece of evidence (Jensen et al., 2008).

Funding an evaluation process would also encourage high-quality and more effective BIAs. Findings from this study suggest that scientists lack confidence in NSF's follow up of BIs. Though scientists are required to report on their BIs efforts from past funded research projects, reviewers simply check a box stating the requirement had been met with little scrutiny of the actual activity. This is also made difficult by the fact that scientists are not encouraged to publish their BIs efforts, whether that be posting their videos on a personal or institutional website, designing and implementing a temporary exhibit in a museum or science center, or publishing and disseminating a detailed report with various success metrics. If the NSF were to fund publishing and evaluation efforts, scientists could access and learn from past projects, would trust that their efforts are worthwhile and taken seriously on an agency level, and would ultimately feel compelled to produce more effective, high-quality BIAs.

Evidence for partnering with BIs experts

The scientists I worked with are fundamentally driven by doing science; by designing and implementing experiments, exploration and discovery, working in the field, and by propelling the scientific enterprise on a basic level. Some participants expressed overwhelming support of outreach in science; only a couple of the participants actually resisted the term “broader impacts” but were either heavily engaged in outreach anyway (Bill) or were able to convey the broader implications of their research in some way (Jonathan). All participants, however, were receptive to using video as an outreach tool, especially in terms of reaching a broader audience, which is why they got involved in this study in the first place.

Burggren (2009) claims that collaborations between BIs experts and scientists are a key component to the success of BIs. Findings from the CAISE study data indicated that scientists were eager to both gain internal support from their institutions to accomplish BIs and to work with professionals to develop outreach activities. Findings from the data for this study also suggested that scientists would benefit from partnering with BIs experts, especially in terms of developing a hook to draw more people when communicating complex science.

The Greenland Project scientists readily included me as a videographer so that their research on glacier melting in Greenland could be made more accessible to a broader audience. Though I am not a BIs expert or a professional filmmaker, I was able to utilize some professional training in film production to put together a short documentary on their first field season. The greatest challenge was to edit together a compelling film, using principles of narrative as discussed by Avraamidou & Osbore (2009), without access to any results; the scientists will not obtain results until the summer of 2015 when they retrieve all of their moorings. Nonetheless, I was able to piece together a 22-minute documentary conveying their research in a dynamic and entertaining way.

I developed several rough cuts of the film for the scientists to review. It became apparent very quickly that the societal relevance of their research needed to be highlighted at the beginning of the film in order to captivate and retain an audience. Jonathan, in particular, was quick to express that people simply will not watch the film if they do not know why this research is important, which seems antithetical to his previous notions about BIs. Emily suggested that I have them do voice-overs to convey some very basic but poignant messages about ice-melt, sea level rise, coastal impacts, and climate and the implications of overall warming on the Greenland ice sheet.

I worked closely with them to generate clear messages about sea level rise, population displacement, and coastal impacts, and used text to reinforce these messages in the first thirty seconds of the film. At the May 2014 screening, it became apparent that the film did not successfully convey some basic messages about the science during the Q&A session; the fact that they were comparing two neighboring fjords that are experiencing differential melting, which might be attributed to dynamics in the ocean, was lost on many audience members. This compelled Jonathan and Emily to consider inviting me to document their final field season in the summer of 2015 to produce a more complete film.

Also, working closely and partnering with a filmmaker seemed to address some of the fears that scientists have associated with the media such as misrepresentation, sensationalism, inaccuracy, advocacy, and politicization, themes that emerged both in this study and in the literature (Ankney et al., 1996; Cooper, 2011; Gascoigne & Metcalfe, 1997; Lackey, 2007). I intentionally worked *with* the scientists so as not to make them feel as though they were losing control of the video content, or the content of their research. Jonathan expressed some sustained skepticism from the very beginning when I was invited to join them until the editing phase when he viewed the first rough cut, which he feared would lose audiences. However, the final film product reflected the comments, critiques, and desires of all three scientists and Jonathan was ultimately extremely satisfied with the process and the documentary; he has in fact become its biggest proponent and promoter.

Though the science communication element was unsuccessful with this particular film, the process of working closely with a filmmaker, especially one who was personally invested in better understanding some of the intricacies of their science, proved beneficial to these scientists' perceptions of outreach. And although BIs seem to cause problems for some of these scientists, they were more eager to convey clearer and more compelling messages about the societal relevance of their research due to the production process of this film.

Recommendations

I developed a series of recommendations upon completion of this research and separated them according to the different stakeholders involved in the scientific enterprise, which now necessarily involves BIs: the NSF (or other funding agencies who place particular emphasis on outreach in science), scientists (or PIs seeking funding from said agencies), BIs experts (or EPO experts and professional science communicators), and the public (or the people who the National Science Board hope to access with BIs in order to enhance their scientific literacy).

NSF:

- The BIs criterion should remain vague and encourage PIs to think outside of the box.
- Adjust your funding model to fund BIs experts separately from the PIs. This will not only generate more effective BIAs but PIs who are focused on basic research will have a better chance at funding by working with an expert to propose BIAs.
- Adjust your funding model to include separate funds for an evaluation process of completed BIAs. This will not only encourage high-quality BIAs and compel PIs to take the requirements seriously, but will also inspire scientists to learn from each other.
- Adjust your funding model to include separate funds for the publication of BIAs. This again will encourage high-quality BIs efforts and will allow PIs to learn from past efforts.
- Institutionalize evaluative and publishing efforts either within your agency and within the hosting institution to streamline and formalize these processes.

Scientists:

- Adjust your perceptions of BIs and view them as an opportunity to bolster the scientific enterprise. By reaching out to the public and communicating your science in an effective and compelling way, you are garnering support from the taxpayers who fund you.
- The media historically poses challenges to scientists by misrepresenting, sensationalizing, and inaccurately portraying science. However, working closely with a BIs expert and developing a partnership with them will allow you to have more control over the content that will ultimately be disseminated to a broader public and will lead to a high quality outreach product, whether that be in an informal or formal education setting.
- When working with a filmmaker specifically, it is important to develop a clear set of shared goals for the final film product. Draft and adhere to a contract so that your science will not be misrepresented and so that you are able to use the final film product to meet your proposed BIs goals, whether you are interested in a longer documentary type film for a larger screening or short videos to post on your website.

BIs experts:

- The BIs requirements is an opportunity for you to exercise your expertise in communicating science to a broader public in some way. Take advantage of this.
- Develop strong partnerships with scientists. This is best accomplished by clearly defining shared outreach goals, communicating how these goals can be met most effectively, and drafting and adhering to a contract developed by you and the PIs.
- Encourage a trusting partnership with scientists by spending time with them to better understand their science specifically. It is useful to interview scientists about their motivations, their past and current research, and their fears and hopes associated with BIs
- Filmmakers specifically, clearly communicate your filmmaking process (from the shooting to editing phase) with your client before beginning the production of your film. Scientists are resistant to working with you because they fear misrepresentation and are often reticent on camera. Make sure to work within their comfort levels and to include them in the process by agreeing on when and where to shoot. Also, and perhaps most importantly, work with the scientists during the editing phase of the production (screen

several rough cuts of the film) and seriously consider their comments, critiques, and concerns when developing the final film product.

Public:

- You are being bombarded with scientific information every day through formal and social media outlets. Learn to be discerning when receiving this information and do your own research before making important decisions based on this information.
- Support the scientific enterprise by engaging in informal science education, whether that be attending public talks, touring science centers or museums, or watching videos, films, and television shows with scientific content. You will ultimately benefit from these experiences and enjoy the learning process.

Concluding Remarks

This study only begins to scratch the surface of the interplay between film, science communication, and BIs. Many limitations, namely time and funding restrictions, made it difficult to pursue some major gaps in the body of knowledge on the role of film in science. For example, there is little to no research on how effective science film can be in terms of communicating science or enhancing the public's scientific literacy, or influencing people's ability to make better decisions or support important policy. Though this study was unable to fill this knowledge gap, this research provides some evidence for how and why film should be pursued as an outreach tool in the sciences, and makes a case for involving a BIs expert throughout the research process. The BIs criterion may seem daunting to many scientists but involving BIs experts can help alleviate some of the pressures associated with NSF's merit review criteria. The NSF should encourage such partnerships by funding BIs experts separately, and should inspire PIs to produce more effective BIAs by funding publishing and evaluation efforts.

Communicating science can be a pleasurable and beneficial experience for all the stakeholders involved: the NSF, the PIs, the BIs experts, and the public. The goal of BIs is to ultimately encourage scientific discovery and learning for everyone, which can more easily be accomplished with the recommendations that emerged from this study.

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APPENDICES

Appendix A: In-Depth Case Study Interview Protocol: Greenland Project

Semi-structured Interview Guide for Pre-Interviews of Greenland project scientists.

1. Describe why you became a scientist.
   a. What are some of your interests in oceanography?
   b. What are some research projects you have enjoyed doing in the past?
2. In two sentences only, please describe your current research project.
   a. How would you describe your research to a 10-year old?
3. What do you enjoy about this research in Greenland?
4. Please describe the broader impacts of this research project.
   a. Are broader impacts important to you?
   b. What are *your* broader impact goals?
      i. How do you hope to reach other people with your research?
      ii. Who are those people?
      iii. What are the broader impacts of you getting involved in this particular aspect of ocean science?
5. How do you anticipate film helping you meet these goals?
   a. How do you anticipate film helping you communicate your research?
   b. How can film be an effective tool for scientists?
6. In what ways is your research important to you?
7. How is your research important for society?

Semi-structured Interview Guide for During-Interviews of Greenland project scientists.

1. Please describe for me what it's like for you to be conducting research in Greenland?
2. How is your research going?
3. In two sentences only, please describe your current research project.
4. Who do you hope to reach with this research and why?
5. Please describe the broader impacts of this research project. What are your broader impact goals?
6. How do you anticipate film helping you meet these goals?
7. How does it feel to be filmed while conducting research?

Semi-structured Interview Guide for Post-Interviews of Greenland project scientists.

1. Please describe for me what you accomplished in Greenland. How does it feel to have accomplished this portion of the research?
2. In two sentences only, please describe your current research project.
3. Why is this research important to you?
4. What does this research hope to elucidate?
5. What are your broader impact goals now that you have come this far?
6. How do you anticipate the final film product will help you meet these goals?

Appendix B: Interview Protocol: Two Scientists Who Have Been Filmed in the Past

Semi-structured Interview Guide for Case-Study Interviews.

1. Why did you become a scientist?
2. You have been filmed conducting a research project in the past. Please briefly describe that research project and what was important about this research project to you? How was this research important for society?
3. What were your broader impact goals of this research? Were broader impacts important to you? Why or why not?
4. How did this film either impede or help you to meet these goals?
5. What were the goals in filming this project?
6. What was the final film product? Who was the target audience?
7. How did the filmmaking process make you feel as a scientist? Did it affect how you conducted your research?

Appendix C: CAISE Front-End Report

CAISE Convening November 19-20 Front-End Report

Introduction

The analysis contained in this report is a result of work conducted in October 2013 by Julie Risien and John Falk of the Center for Research on Lifelong STEM Learning located at Oregon State University. This undertaking should not be considered research, but an exercise intended to provide insights that may enhance the outcomes of the *CAISE Broader Impacts and Informal Science Education Year 7 Convening*.

Methods

A series of 21 face-to-face and phone interviews were conducted with volunteer researchers in Science, Technology, Engineering, and Mathematics (STEM) disciplines and with current or recent NSF support – all were referred by individuals involved with this CAISE BI initiative. This "sample of convenience" is described below.

Primary affiliation for all but one of the 21 participant was an academic department within an institution of higher education. Participants were geographically distributed throughout the U.S. with 10 residing in the Pacific Northwest including 6 from Oregon State University, 2 in the Southwest, one in the Midwest, and 8 in Eastern U.S.

Participants broadly represented the STEM disciplines with researchers from Physics, Chemistry, Biology, Ecology, Earth and Atmospheric Sciences, Agricultural Sciences, Environmental Sciences, Oceanography, Neuroscience, and Engineering.

Participants engaged in a variety of broader impacts (BI) activities associated with informal science education (ISE) such as working with museums and science centers, public outreach (e.g. science pubs), news and informational media (print, video, radio), diversity initiatives, afterschool and school supplemental programs, citizen science, stakeholder workshops, web and digital learning interfaces, engaging community partners or policy makers in the research process.

Approximately half of the researchers interviewed could be considered seasoned investigators in the later third of their careers. The rest were young investigators or investigators in their early-mid career. Participants valued anonymity and generally spoke very freely about their perceptions and practices.

The interview protocol was developed and approved prior to interviews and adapted as needed to solicit clear and relevant answers. Stated interview questions in this report refer to the way a question was asked most frequently.

Interview transcripts were broken into several sections: 1) Perceptions about BIs; 2) Planning and Processes; 3) Resources and Supports; and 4) Marketing and Communication. A qualitative analysis was conducted on each section of transcripts to glean the below subsections included in the report.

- Overall assessment of the section topic including a description of questions used.

- Dominant themes, those stated by 4 or more participants in response to a particular question or set of questions.
- Repeated themes, those stated by 2 or 3 participants (unless otherwise stated)
- Other themes or interesting quotes not necessarily repeated but potentially insightful (unless otherwise stated).
- Key language used by participants is embedded in theme statements presented as amalgamated participant quotes (with exception of Section 4 - Marketing). Care was taken to use language true to the transcripts. An additional discussion on language is included at the end of this report.

Section 1 - Perceptions about BI

Participants were asked to rank themselves and their colleagues on a BI continuum with a scale of one to ten where:

- A rank of one indicates, "I/my colleagues don't really understand the value of BIs. I/they wish BIs were not a factor in receiving research funding."
- A rank of 10 indicates, "I am/my colleagues are big believer(s) in the importance of BIs and always work to integrate BIs into my/their research and like to be deeply involved in the work personally or in partnership with others."

Figure 1 shows the distribution of ranks for both the self-assessment (Self) and the colleague assessment (Col). It is important to note that participants collectively tended towards the BI champion side of the spectrum. Colleagues were more difficult to assess because of the many possible scales one could interpret colleagues. Many participants provided 2 or 3 different designations for colleague groups and provided answers for each. Figure 1 is weighted to reflect this.

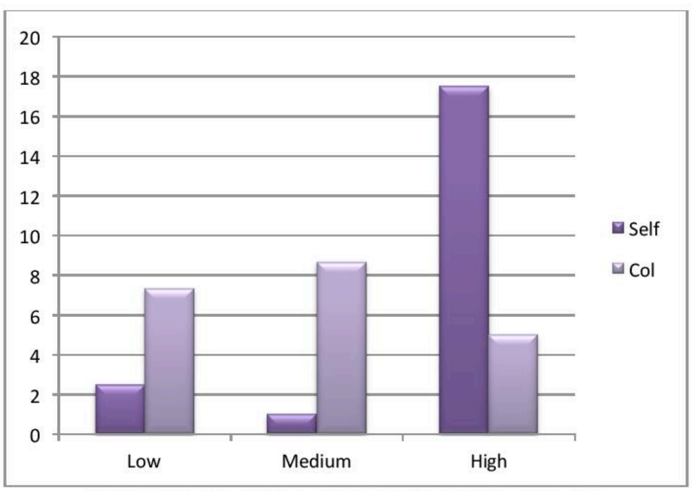

Figure 1 - X = section of the continuum and Y = number of selections

Dominant Themes – Self Assessment

1. BI and outreach are part of my personal mission, it is why I chose to become a scientist and if there is no clear impact I am probably not interested in doing the work. I enjoy doing outreach and working with kids/students/the public/partners; I've learned so much from working with educators and working to help the public understand science. I also see a place for "pure" science and think it is very important, but I am not interested in that.
2. I rank myself very high on BI/outreach, it is important, but only for projects in which such activities make sense and are natural. Many types of proposals and research should not be required to include BI or outreach; it just doesn't make sense for some types of work.

Repeated Themes – Self Assessment

1. I am a big believer in BI/outreach in concept, but in practice I am mediocre at outreach.
2. Outreach and other BI can be a burden and there is no reward at my institution.
3. Some BIs are unplanned, organic, and happen long after the science is completed.
4. It is difficult to know what is meant by BIs, it might mean something different to me than to NSF and something different still to my department chair or dean.

Dominant Themes - Colleague Assessment

1. Perceptions are changing over time. Young faculty members present a real opportunity; they are enthusiastic and looking to be more competitive. Older or "old school" faculty are also retiring, a few are changing their perceptions and beginning to place more value on outreach, but that is rare.
2. There is a perception that NSF has gone too far and should not require BI for all proposals. Even colleagues that enjoy BI don't feel it should be required for every proposal. Some even propose BI that they do not intend to complete or they do BI that is not useful, some of it could actually have a negative effect on the public's perception of science.
3. Perceptions are all over the map, those that tend to have an applied nature to their work generally see BI as more favorable. Those who focus on theoretical or esoteric work are not really interested in BIs.

Section 2 – Planning and Process

To assess process, specifically planning, participants were asked two questions these questions did not occur consecutively.

Question 1: We are interested in *your* description of your initial thought process when you conceptualize and design the BIs elements of your proposal. In other words, how do you come up with a plan of action?

Question 2: How do you plan on addressing the BIs requirement in your next proposal?

For reluctant participants the interviewer used a selection of follow-up questions that include:

- Do you find partners?
- What do you think about first, what is your first step and why?
- Do you think about outcomes or audience?
- How do you choose a strategy (or instrument, or mechanism)?

Some participants were asked to describe the planning process for a research project, and then asked to outline their process for BI. Overall a lot of energy was spent encouraging participants to unpack their process to provide insights. Still many were reluctant or stated that they don't really plan BI work. Figure 2 below shows the distribution of participant's responses. The three categories are described in more detail below.

- **don't plan** - I don't plan BIs they happen organically or sometimes accidentally.
- **semi-planned** - My BIs are semi-planned. I think it through, but not very much, I usually rely on colleagues or partners that I have worked with before.
- **pre-plan** - I pre-plan BIs in a stepwise fashion and tailor the work for each project and audience.

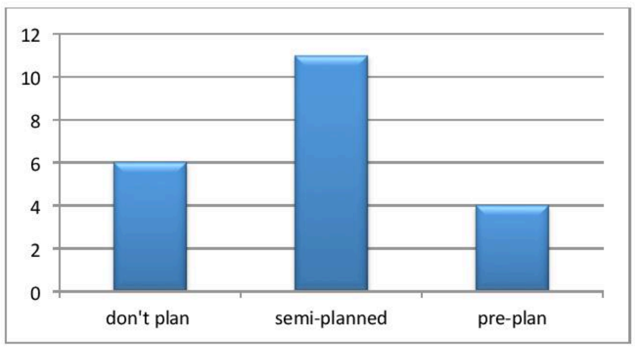

Figure 2
X = Type of planning for BI
Y = number of participants

Dominant Themes – Planning and Process

1. My BI (or outreach) work is part of my personal mission, I plan each project to meet my overall objective to help students or the public understand the work of scientists, the role of science in solving everyday problems, or basic scientific principles. I enjoy this work and I am satisfied knowing I am giving back [to society]. I feel I have a role in recruiting the next generation into STEM careers and diversity in science is particularly important to me.
2. I use my personal network. I don't really plan, I just call the people I know and we talk about what we want to do. If I do plan it out, I work with colleagues or friends that I am comfortable with because I believe we have a good chance of succeeding together.
3. Some science lends itself naturally to BI work. In those cases, the science comes first and the BI or outreach work follows easily. For some work, BIs are not natural. In those cases I end up scaling up for outreach; nobody is interested in what I do – it's too technical, but people care about earthquakes/climate change/farming/etc. which is sort of related to my work. I don't really think BIs should be required for all types of proposals.
4. BIs is an after-thought. It's the last thing to plan, the last thing to do, and the first thing to get dropped if there is not enough time or money. That's just the way it is. The science comes first.

5. Working with established partners who really know outreach or programs is a great help when you can make it work.
6. I do all the outreach work myself. I mean there really isn't any plan, there's no money for partners, so I just do it. Some of it I would do anyways.
7. Outreach work and other BIs are extremely time-intensive for the researcher, it's easy to get yourself in over your head, and that's a real problem if it distracts from the science.

Repeated Themes – Planning and Process

1. It's hard to maintain BI programs and outreach projects over time; it seems we keep reinventing the wheel.
2. When a BI is forced the outcome is not good; in fact, it can have the opposite effect of turning people off of science instead of inspiring them.
3. My focus for BIs is getting my research results into the hands of decision-makers and even involving them in the process, that's why I do this [science] so I can effect change.
4. My work is very locally and regionally relevant, so plugging into larger scale BIs efforts is a challenge.
5. My students do most of the BIs; they often plan it and almost always do the actual outreach. It's good training for them.
6. The human connection and face-to-face interaction is really important. You cannot have an impact without it.
7. A field work component is great for BIs, but the logistics can be very hard and liability is an issue. Often field work-based BI just doesn't work out.
8. I'm reluctant to put any budget towards BIs; I don't think my colleagues like to do it either. It will just be the first thing to get cut and I will have to do it myself anyways.
9. Many partner organizations ask for unreasonable sums to be involved in your BIs work, so I don't like to use them.

Section 3 - Resources and Supports

The fourth question in the protocol asked investigators to identify the specific resources and supports they use when planning and executing BIs work. Investigators were also asked, "are there resources or supports you would use to help with your BI work if only you knew about them or had access to them?" Resources and supports were clarified when needed as including people, programs, organizations such as professional groups or NGOs, places such as museums or science centers, information, expertise, students, networks, partners, or facilities and equipment.

Dominant Themes – Resources and Supports Used

1. I use my personal and professional network as my primary resource; there are people I always call to brainstorm and come up with ideas. There are people I like to partner with, I know them and I enjoy working with them (wife, sister, colleague, old friend, local educator, local community groups, teachers, people I meet in my community).
2. I use online tools such as databases of people, databases to share my work, www.compadre.org , social media, tumbler, project websites, backyard brains, and YouTube .

3. I use resources at my university such as science communications programs, the press office, video/media lab, STEM Center, student programs, extension, our campus leadership institute, pre-college programs, STEM learning researchers, outreach professionals, and STEM colleagues.
4. I rely on my personal bank account to pay for materials, supplies, travel, and to provide food at meetings related to my BIs and outreach work.
5. I work with museums and science centers. I like doing this, but sometimes it doesn't work out, the costs can be high and sometimes they do not have enough people or time to work with me. Also the project timelines often don't match up with the timeline of my grant.
6. I work with programs external to my university such as afterschool programs, citizen science groups, stakeholder workshop and engagement programs, and TOSA (teachers on special assignment). These are usually local or regional.

Repeated Themes – Resources and Supports Used

1. I work with my PBS television and/or local public radio station. They usually call me, but I will call them if I have something really interesting that I think will get the public excited about science and how it can affect them.
2. I sometimes use professional organizations that I belong to or my university administrators belong to. These can be good for learning about BIs work or connecting with outreach professionals (Ecological Society of America, American Association of Physics Teachers, Council of Colleges for Arts and Science, etc.).

Other Themes – Resources and Supports Used

1. Partnerships with the art community – painters, poets, other visual artists.
2. Webinars are not really useful
3. I use newsletters to get and give information.
4. Student travel funds and fellowships can be really useful.

Dominant Themes – Resources and Supports Desired

1. I would love it if there were a compendium of strategies for doing outreach. A sort of cohesive summary of the literature, the pros, cons and evidence for each approach. It would be nice to have elevated case studies that tell me the story and highlight the key points. I'd also like to know the cost and benefits for different outreach approaches; sometimes the cost outweighs the benefit. This type of resource could be organized by discipline (environmental science, chemistry, ocean sciences, climate science), geographic region, by type of resource or strategy (e.g. visualizations, curriculums, communicating with the public, art and language arts) or type of partner (e.g. museums, schools, the media).
2. It would be nice if there were money to conduct outreach. It costs to go to community meetings, to feed people, to drive there. It costs to make banners to let the public know about involvement of my university or NSF, to create pamphlets, and videos. No one is going to put that in their NSF budget, and my dean won't pay for that kind of thing.
3. Connections with the media, I would love a spot on a radio show, or to know how to get in touch with book publishers.
4. No, I can't think of any resources I wish for. We just make do with what we already have.

Repeated Themes – Resources and Supports Desired

1. A staff member at my university to connect me with BIs opportunities, I don't have time and I don't know what is good. I could really use someone who knows everyone in the region doing this kind of thing.
2. An entity or organization to sustain my BIs work after the grant is over. We put in so much effort to gain traction, then the grant is over and we can't afford to spend our time to sustain it. It would be great if there was some way to keep products up to date and relevant. Otherwise it's a waste of money and energy invested.
5. I wish my institution and my department valued this kind of work, but there is no reward for it and in fact it can be a big distraction prior to tenure.
6. Boiler plate language that I can paste into my proposal. I need to know what it costs too.

Other Themes – Resources and Supports Desired

1. I could really use help with graphics and visualization of our data. We are not very good at making graphics that the general public can understand.
2. Connections with minority-serving institutions.
3. Help with patent/publishing conflicts.
4. Regionally-based expertise in federal agencies like the National Parks Service.
5. A picture is really worth a thousand words, I say little cameras for everyone. We need to record ourselves doing science; we need to let our youth know what it is to be a scientist.

Section 4 - Marketing

The fifth question in our protocol addressed marketing directly. We asked investigators to, "help us think about effective and creative ways the informal science education community might be able to reach the science community. How could we let people know there are supports and resources available to help with their BIs needs?" Often the question was framed by stating, "Suppose there were a menu of resources and supports to help you with BIs, what would be a good way for us to let you (or the research community) know that it exists?"

Dominate Themes - Marketing

NSF - Nearly half of the participant specifically cited NSF as a reliable and credible source of information and identified program officers as a recognizable source from which to receive information directly.

Recommended vehicles/venues to market the availability of BIs resources:

- communications directly from program officers
- proposal guidelines
- solicitations for proposals
- proposal submission forms (Fastlane)
- NSF website

Recommended actions

- verbal acknowledgement from program officers (on the phone at project meetings or other gatherings such as professional meetings and conferences)
- endorse trainings or workshops that occur at professional meetings or are delivered by certain organizations
- deliver trainings or workshops at professional meetings
- provide a BI resource guide on the NSF website
- specifically address BI resources in panel review comments, even for unfunded proposals

Conferences and professional meetings – several participants cited conferences or professional meetings as a valid venue for marketing. Others cautioned against these venues citing the overwhelming nature of many meetings and a low likelihood of reaching investigators not already invested in ISE. Sessions and workshops focused on "outreach" were viewed as tending to "preach to the choir". Specific positive recommendations include poster sessions, take ten minutes of scheduled time during workshops focused on a science topic, use message boards, and collaborate with conference organizers to include information in conference emails. The importance of hallways conversations and lighthearted social events were also noted.

University-based efforts – several participants recommended marketing through their home institutions. The most frequent recommendation was to provide information during departmental faculty meetings, through the research office, and through individual grant programs and managers within departments. University-based workshops and webinars were also recommended.

Other Themes - Marketing

The below recommendations each reflect ideas shared by one to 3 participants.

- Create engaging stories and elevated case studies of successful ISE BIs that provide the context and highlight key points. Get these stories in the press and ultimately picked up by online news aggregators popular in the science community.
- Use professional society newsletters and websites, professional magazines and peer-reviewed journals to advertise resources and share success stories.
- Use listservs of existing organizations with an active following.
- Use online communities or existing portals and clearinghouses.
- Use established organizations like AAAS, COSEE, and AGU.
- Provide real assistance to investigators in drafting BIs language in proposals.
- Participants specifically advised against large-scale unfocused webinars and unsolicited emails as they are viewed as spam.

Key Language Notes

Although informal science education and it's broad nature was described in the invitation and the preamble to the interview, the term "informal science education", "informal education" or "ISE" were used by only a very few of the participants; each had successful partnerships with museums and/or science centers.

The terms "outreach" and "broader impacts" were used synonymously by most participants during interviews. In fact, "outreach" was used by the many participants as a catch all for any activities outside of the traditional academic job description and all activities that are not specifically research and take place away from one's university. "Reaching out" was used less frequently but similarly to outreach and specifically when speaking of the public audience in a generic sense. "Outreach" was most frequently used as a proxy for ISE, but it was also used to talk about K-12 classrooms, sharing science outside of one's own department, university or sub discipline. It was less frequently used to describe publishing in peer-reviewed journals and presenting and professional meetings.

"Communicating science" was also used and used in context of public lectures, mews media, print, and websites.

Appendix D: CAISE ISE Broader Impacts Interview Protocol

Center for Research on Lifelong STEM Learning

Questions

We're interested in *your* description of your initial thought process when you conceptualize and design the broader impacts elements of a proposal? In other words, how do you come up with a plan of action? (4 minutes)
How do you address the broader impacts criteria?

Do you find partners to design and execute BI?

Do you determine a desired outcome and plan accordingly?

Show continuum graphic or request interviewee looks at it
Where do you place yourself on this continuum of perceptions about broader impacts? Please tell me why you place yourself there. (4 minutes)

Where do the majority of your colleagues fall on this continuum or what are some of the dominant perceptions that exist?

Increasing emphasis (a, b, and c)
ONLY IF NEEDED
Are you aware of the January 2013 broader impacts criterion? (2 minutes)

Can you take a minute to tell me about the research involved in your next proposal? (not necessarily the broader impacts, but the investigation.

Reflect back on their process

How do plan on addressing the broader impacts requirements that proposal? (5minutes)
What would be your first step? Why?

What would be your next step? Why?

What types of resources or supports (such as partners, networks, programs, facilities, or information) have you used in the past, or do you imagine using in the future, to help you with developing and delivering broader impacts associated with your research? (3minutes)
Are there other resources you would you use if they were readily available to you?

How do you go about finding resources and/or partners for your broader impacts work?

Help us think about some effective and creative ways the informal science education community might be able to reach people like yourself within the research community. How could we let people know that there are supports and resources available that could help them with their broader impacts needs? (3 minutes)

Is there anything else you would like to share with us that might help us connect researchers with the informal/out-of-school science educational community to achieve broader impacts? (2-4 minutes)