Responsible Innovation and Sustainability: Interventions in Education and Training of Scientists and Engineers

by

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ABSTRACT

Three dilemmas plague governance of scientific research and technological innovation: the dilemma of orientation, the dilemma of legitimacy, and the dilemma of control. The dilemma of orientation risks innovation heedless of long-term implications. The dilemma of legitimacy grapples with delegation of authority in democracies, often at the expense of broader public interest. The dilemma of control poses that the undesirable implications of new technologies are hard to grasp, yet once grasped, all too difficult to remedy. That humanity has innovated itself into the sustainability crisis is a prime manifestation of these dilemmas.

Responsible innovation (RI), with foci on anticipation, inclusion, reflection, coordination, and adaptation, aims to mitigate dilemmas of orientation, legitimacy, and control. The aspiration of RI is to bend the processes of technology development toward more just, sustainable, and societally desirable outcomes. Despite the potential for fruitful interaction across RI's constitutive domains—sustainability science and social studies of science and technology—most sustainability scientists under-theorize the sociopolitical dimensions of technological systems and most science and technology scholars hesitate to take a normative, solutions-oriented stance. Efforts to advance RI, although notable, entail one-off projects that do not lend themselves to comparative analysis for learning

In this dissertation, I offer an intervention research framework to aid systematic study of intentional programs of change to advance responsible innovation. Two empirical studies demonstrate the framework in application. An evaluation of Science Outside the Lab presents a program to help early-career scientists and engineers understand the complexities of science policy. An evaluation of a Community Engagement Workshop presents a program to help engineers better look beyond technology, listen to and learn from people, and empower communities. Each program is efficacious in helping scientists and engineers more thoughtfully engage with mediators of science and technology governance dilemmas: Science Outside the Lab in revealing the dilemmas of orientation and legitimacy; Community Engagement Workshop in offering reflexive and inclusive approaches to control. As part of a larger intervention research portfolio, these and other projects hold promise for aiding governance of science and technology through responsible innovation.

DEDICATION

To those who have come before: Murray, Rita, Robin, Ira, Leonard, you are with me, always.

To those who are: my family, friends, and mentors for their love and support.

To those new and still to be: Addison, Alex, Annabel, Eleanor, Eliana, Fern, Finley, Franklin, Gabi, Hazel, Howard, Jonah, Mabel, Malina, Nathan, Odette, Ronan; your children's children's children, and beyond.

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TABLE OF CONTENTS

CHAPTER Page

APPENDIX

LIST OF TABLES

LIST OF FIGURES

PREFACE

With the exception of the introduction and conclusion in this work, each chapter has been co-authored, and co-authors have granted permission to include the text in this dissertation. One of the manuscripts has been submitted for peer-review; two are in revision for resubmission. Co-authors for each manuscript, and target journal where appropriate, are listed below:

Chapter 2: An intervention research framework for responsible innovation. Authorship: **Michael J. Bernstein**, Rider W. Foley, Arnim Wiek, John M. Anderies.

Chapter 3: Science Outside the Lab: Helping Graduate Students in Science and Engineering Understand the Complexities of Science Policy. Journal: *Science and Engineering Ethics.* Authorship: **Michael J. Bernstein**, Kiera Reifschneider, Ira Bennett, Jameson Wetmore.

Chapter 4: Preparing engineers for the challenges of community engagement. Journal: *Engineering Studies*. Authorship: Matthew Harsh, **Michael J. Bernstein**, Jameson Wetmore, Susan Cozzens, Thomas Woodson, Rafael Castillo.

CHAPTER 1

INTRODUCTION

Problem Statement

Despite good intentions, human invention and adoption of new technologies to solve problems (Nelson 2004) often means human creation of new social and environmental problems (Westley et al., 2012). One example of this seemingly infinite loop of problem solving / creating is the way seemingly innocuous, utopian visions of a technologically magical future—flying cars, cities of steel, chrome, microchips, robotic pets, etc.—leads to human and environmental degradation the world over. My iPhone is a wondrous testament to human innovation and know how. Still, it is also testament to an uncanny ability for shrugging-off disastrous human health impacts on workers in China, ore miners in Africa, smelting facilities in South America or Southeast Asia—locations home to the top ten most toxic pollution sites exist (Biello 2011); locations also deriving the least economic and social value from production (Clift and Wright 2000).

In this dissertation, I argue that a key link in the chain of events between utopian future visions and dystopian realities is the way scientists and engineers are taught to think about science, engineering, and society relationships (Figure 1). To address this kinked link, I propose a way to systematically influence science-society interactions generally, and science and engineering graduate education specifically (Figure 1). The educational interventions I discuss occur upstream in a suite of efforts that, together, comprise innovation processes (Figure 1). These educational interventions represent one of many different options to influence innovation process; other examples outside the scope of this work include policy action, standards revision, legal reform, etc. I define innovation after Robinson (2009) and Wiek and Foley (2013) as a the combination of people, ideas, knowledge, resources and other things in discrete phases that progress sometimes forward, sometimes backward, always geared to produce something for a reason. The suite of phases involved in innovation processes include initiating research through funding and discovery; experimentation to refine ideas; demonstration of ideas at greater scale and for market niches; compliance with regulatory and business needs; commercialization; and end of intended life/repurposing (Robinson 2009; Wiek and Foley 2013).[1] The interventions in education and training I discuss occur in the initiation phase; the types of interventions presented vary from a two-week discussion-based policy immersion program (Chapter 3) to a two-day hands-on communication, listening, and problem-framing workshop (Chapter 4).

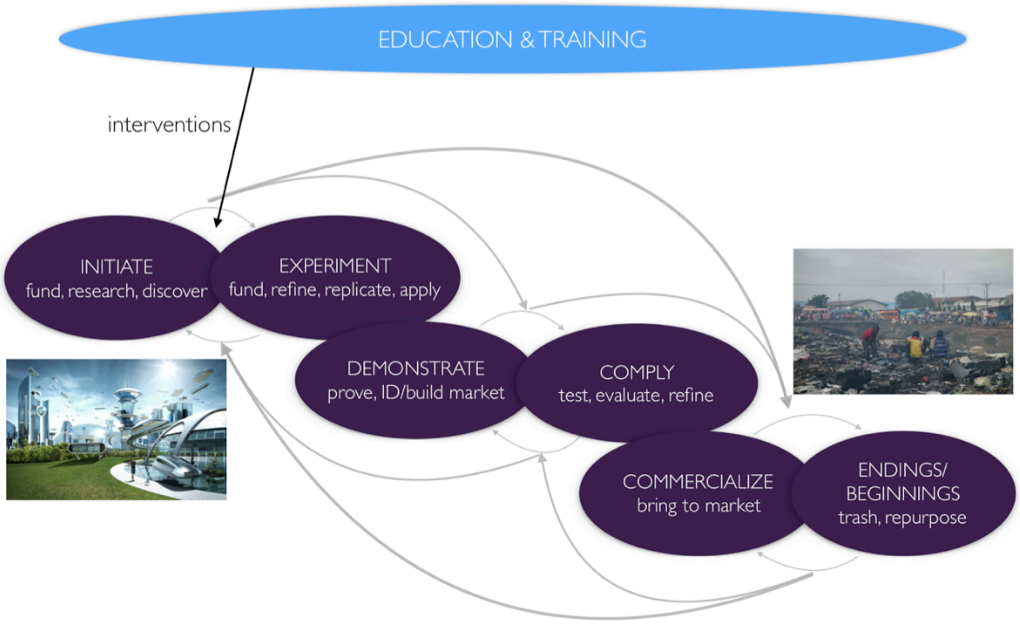

Figure 1: Schematic presentation setting up this dissertation: focusing on changing the way scientists and engineers are educated to think about science and society relationships, such that utopian visions (image source: http://afflictor.com/wp-content/uploads/2013/10/techutopia1.jpg) cease to create dystopian realities (image source: http://motherboard-images.vice.com/content-images/contentimage/no-id/1433876853025882.jpg)

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[1] Fisher et al., (2006) have offered a riverine metaphor of innovation as unfolding ‘upstream’, ‘midstream’, and ‘downstream.’ Stepping back from the river to the larger water cycle, as it were, in Chapter 2, I adopt a worldview of robust control to better represent the feedbacks and non-linear dynamics inherent to large-scale sociotechnical systems (Anderies et al., 2007).

Before presenting the empirical work of interventions, I propose an overarching research framework to inform how such interventions could be designed to advance the goals of sustainability through responsible innovation. In the remainder of this introduction I go into greater detail about responsible innovation and interventions to aid in governance of science and technology for sustainability. Throughout the manuscript I use the following terms and definitions:

- **Innovation**: putting people and things together to do stuff for a reason.
- **Sustainability**: helping people, other living things, and the world; today and tomorrow.
- **Responsible**: having to care for people and things when it's important and when you have to.
- **Responsible innovation**: putting people and things together to care for people and the world, when it's important and when you have to.
- **Intervention**: change something to make the thing(s) better.

The above definitions are simplified, using only the most common ten-hundred words in the English language (http://splasho.com/upgoer5/); more formal technical definitions follow.

Dilemmas of science and technology governance

There are many reasons why it is difficult to intentionally influence the direction and course of (i.e. govern) science and technology. Broadly, such challenges are associated with *why* pursue a research and development trajectory (begging also the *what*, which I fold into the question of "why" for this work); *who* should be involved in this process; and *how* this process should be controlled. These questions of *why*, *who*, and *how*, can be formally presented as dilemmas of orientation, legitimacy, and control.

The *dilemma of orientation* deals with the challenge of keeping a publicly supported research and development enterprise oriented to benefiting broad public interests, rather than the interests of a select few. When private market or scientific interests are served exclusively or disproportionately by publicly funded initiatives, public value that should accrue from public funding does not, creating "public value failure" (Bozeman and Sarewitz 2011). Such orientation challenges with public funding are a dilemma because people and well organized groups with money, access to decision makers, and resource advantages—groups well positioned to advance solutions to societal challenges—use their positions of privilege to instead gain more advantages; they divert and cannibalize public funds to benefit at the expense of public interest (Jsokow and Rose 1989; Bozeman 2007; Benessia and Funtowicz 2015).

Two phenomena make the dilemma of orientation possible: interpretive flexibility, and pluralism in democracy. The interpretative flexibility of social and technical artifacts—the ways in which the same objects can be perceived as serving multiple, sometimes conflicting purposes (Pinch and Bijker 1987)—makes it impossible to singularly define the role of any given technology for advancing public interest through research and development. The old aphorism "one man's trash is another man's treasure" can be a helpful way to think about how different objects get used to advance the agendas of different groups of individuals (Pinch and Bijker 1987). While such flexibility is the small-scale reality that makes interpretation of objects problematic, having such objects researched and developed with the resources of a pluralistic democratic society of 300+ million people makes everything even messier. The difficulty of making choices in a democratic government for a diverse public is known as a challenge of "public choice" (Ostrom and Ostrom 1971; Simon 1990). Because so many voices are able to get involved, but only so many voices can be heard, the crowding out and public value capture/failure described above ends up as an all too common result.

The dilemma of orientation is problematic because it risks short-sighted innovation. While there is great potential in technology, social, political, and economic interests trade on peoples' dreams of a better future to accrue private benefits in the present. In other words, special interests are able to subvert the promises of publicly funded research and development, on the one hand advocating for a potentially beneficial project, and with other stacking the political deck to ensure that the maximum amount of benefits from a project benefit the smallest numbers of individuals. Such short-sighted innovation plunges ahead all to eager for near-term gains at the expense of long-term negative implications.

Beneath, but also contributing to the dilemma of orientation is the dilemma of legitimacy. The *dilemma of legitimacy* deals with the way individuals and groups in a democracy claim to have the expertise and authority to govern innovation activities. Grappling with the question of who is or should be involved in research and development (Collins and Evans 2002; Wynne 2003; Rip 2003) has major implications for an endeavor's relevance and usefulness to people with a stake in management and outcomes (Cash et al., 2003). An important consideration associated with *who* is involved in designing social-technical systems and *why* is tied to the idea of compatibility between inputs to and expected outputs of a process (Cherns 1976). If a process aspires to involve people, "a necessary condition for this to occur is that people are given the opportunity to participate in the design" of the process (Cherns 1976, p. 785).

A central factor contributing to the dilemma of legitimacy is the challenge of picking competent, talented, and trustworthy people to do the work. Guston (2000), drawing from the field of insurance, expressed this phenomena as a principal–agent dilemma.[2] In this dilemma, the "principal," a person with resources seeking to get something done, lacks in expertise. To get his or her project done, the principal turns to an "agent" with the expertise to do the desired action (the agent likely having few of the necessary resources).

The dilemma of legitimacy is problematic because of asymmetries inherent in the relationship between principals and agents. One outcome of the asymmetry is "adverse selection," in which a principal lacks the expertise sufficient to hire an appropriate agent (Guston 2000). Increased specialization in scientific expertise, for example, makes it more and more difficult for Congressional staffers to identify experts to learn from about topics and thus inform policy development. Another outcome of the asymmetry is "moral hazard," in which a principal may have picked the right expertise, but is completely unable to vet or ensure that the "right action" is being carried out by experts (Guston 2000). A crude example: I trust the expertise of my preferred auto mechanic, but have no capacity to verify when he tells me that my front-right upper control arm bushing has been successfully replaced. Combined, adverse selection and moral hazard make governing science and technology—even when oriented in a societally desirable direction—difficult to assure.

Finally even if the rock and hard place of orientation and legitimacy are avoided, the *dilemma of control* lies in wait. Where orientation questions "why" and legitimacy questions "who," the dilemma of control concerns issues of "how." Articulated by Collingridge (1980),

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[2] In future work to integrate political science and public administration in science policy, I will argue that not only is the delegation to expertise problematic, but the larger principal-agent dilemma between publics and elected representatives (Moe 1990) may also be partly responsible for the dilemma of legitimacy.

the dilemma of control suggests that the implications of technologies are hard to grasp, especially when new; yet once undesirable implications of a technology are grasped, it is often too late to act due to the social and physical inertias of vested, entrenched interests.

The dilemma of control exists in part as a result of the way social, economic, and political aspects of these systems "harden" and resist change as the technical components stabilize (for example in the way, discussed above, that private interests capture public investments for private value at the expense of public interest). The dilemma also exists because of ignorance about the operation of technical components in the future. Ignorance makes it difficult to identify the social and other costs of mistakes. Collingridge (1980) speaks about four aspects of social-technical systems that one should consider in advance: how long it takes to detect an error in the system (detection time); how much the error costs the system (error cost); how long it takes to fix an error in the system (response time); how much it costs to correct the error (correction cost). Often times, there are difficult tradeoffs to be made in the design of social-technical systems to account for these parameters: the ability to rapidly detect errors coming at the expense of fixing the error; the ability to make systems error resistant with long time signals making errors costly once they occur but go undetected.

Dilemmas of orientation, legitimacy, and control are interrelated, making their isolation difficult. Fortunately, this interrelation also means that attempts to address one dilemma can provide benefits for resolving another. The evolving science policy concept of responsible innovation sets forth activities to resolve different aspects of orientation, legitimacy, and orientation dilemmas facing science and technology governance.

Labors in Responsible Innovation

Responsible innovation, with foci on anticipation, inclusion, reflection, coordination, and adaptation[3], aims to beat back the trio of dilemmas plaguing science and technology governance. The motivation behind responsible innovation is to bend the processes of technology development toward more just, sustainable, and societally desirable outcomes. Responsible innovation seeks a commitment from science to be more explicitly conducted with and for society (Owen et al., 2012; Guston 2013; von Schomberg 2013). Beyond this expression, the normative (as in explicitly value-laden) goals of responsible innovation are often nebulous. To strengthen the normative commitment of responsible innovation, Foley et al. (under review) integrated normative dimensions of sustainability science. Throughout this dissertation, I invoke responsible innovation as inclusive of this normatively rich paradigm; alternatively framed as "responsible innovation for sustainability." In the following sections, I introduce the foundations of responsible innovation from social studies of science and technology; propose additions to responsible innovation from sustainability science; and offer a synthesis of responsible innovation for sustainability.

Responsible Innovation Inputs from Social Studies of Science and Technology

Social studies of science and technology constitute responsible innovation's critical lenses and concrete approaches for avoiding Pollyannaish faith in technological solutions to challenges at the intersections of environment, technology, politics, and society (Marx 1987; Pinch and Bijker 1987; Latour 1992; Jasanoff 2004; Woodhouse and Sarewitz 2007; Sarewitz and Nelson 2008). Scholars of history, philosophy, and politics of science and technology

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[3] Please see below section, *Responsible innovation: a synthesis*, for definitions.

draw insights from studying the ways technology has been relied upon but insufficient to address, alone, many societal challenges (c.f., Noble 1979; Collingridge 1980; Boserup 1981; Winner 1986; Marx 1987). Social studies of science and technology increasingly emphasize a significant disconnect in dominant narratives about technological change in society (Dennis 2004; Douglas 2009; 2014; Rommetveit et al., 2013). Research from social studies of science and technology highlights that links among science, technology, and society are not as straightforward as often believed (Polanyi 1967) or marketed (Bush 1945). Social studies of science and technology have broken-down the black box of technology to illustrate the socially contested aspects of technological change (Bijker et al., 1984; Winner 1993; Latour 1992; Bijker 1997). Examples here range from the political and organizational arrangements necessitated by large-scale destructive technology (e.g., nuclear weapons Winner 1986), to male domination of females in a contraception-delivery-medical-industrial-complexes that treats childbirth as an illness and develops contraception to enhance men's experience and burden women, to great profit (Wajcman 1991). Recognizing that engineers influence society through the choices constrained by technology decisions (Hughes 1987; Law 1987; Callon 1987), social studies of science and technology have advanced the notion that knowledge and social orders are not independent but, in fact, produce each other iteratively and through nuanced feedbacks (Jasanoff 2004). Further, realizations that technology is not value free (Douglas 2009) and that status-quos in scientific research and technology development may exacerbate social inequity (Woodhouse and Sarewitz 2007; Cozzens et al., 2013; Wiek et al., 2016) mark fundamental concerns in social studies in science and technology discourse, often asking who benefits form technology development and how? Answers to this and other questions are highly contested (Marx 1987; Benessia and Funtowicz 2016).

Contestation over sociotechnical systems speaks to an inescapable conclusion of social studies of science and technology: reality is fractured by as many points of view as there are individuals. Such a fracturing means that that technology development often may not lead to broad social progress, benefiting instead the interests of the most effectively resourced and organized (Kreuger 1974; Melman 1975; Joskow and Rose 1989). This conclusion has led some in the social studies in science and technology community to adopt a solution orientation akin to that found in sustainability (Guston and Sarewitz 2002; Guston 2008; Stirling 2010; Lin 2011; Stilgoe et al., 2013; von Schomberg 2013; see below). Examples of turns toward solutions in social studies in science and technology include assessing and deliberating over the place and impact of technology (Schot and Rip 1997; Guston and Sarewitz 2002); developing capacity for anticipatory governance (Guston 2008); reconciling the supply and demand for science (Sarewitz and Pielke 2007); and calling for means of enhancing public value from science (Woodhouse and Sarewitz 2007; Bozeman and Sarewitz 2011).

Sustainability Science Additions to Responsible Innovation

Sustainability science offers responsible innovation normative and analytical approaches to solution development in inter- and trans-disciplinary contexts (Kates et al., 2001; Clark 2007; Miller et al., 2013). A hallmark of sustainability science is the normative stance that humanity's dominant mode of interacting with local and global environments is exploitative, destructive, undesirable, and untenable (Clark 1973a; 1973b; WCED 1987; Fischer-Kowalski & Swilling 2011; Rockström et al., 2009). Such a normative stance is not only critical, but also aspirational, offering that humanity's relationship should, instead, steward social and environmental systems with greater concern for equity for present and future generations, commitments to human flourishing, and social-ecological system integrity (c.f. the U.S. National Environmental Policy Act[4]; WCED 1987; Kates et al., 2001; Gibson 2006; Chapin et al., 2011; DeFries et al., 2012; Miller et al., 2013). Concurrent with such normative critiques and aspirations, sustainability scientists have advocated a fundamentally different[5] approach to scientific inquiry; a post-normal approach that shifts focus from quality of research products only to include also the people, process, and purpose of inquiry (Funtowicz & Ravetz 1993). The post-normal approach opens up conventional qualifications of knowledge and directly address problems rendered intractable by (often) unrecognized values conflicts and uncertainty (Rittel and Webber 1973; Metlay and Sarewitz 2012).

Articulation of sustainability solution agendas is the constructive response from some in the sustainability science community for systematically addressing wicked, ambiguous, inherently normative challenges (Matson 2009; Sarewitz et al., 2012; Seager et al., 2012; Wiek et al., 2011; 2012; Miller et al., 2013). Key attributes of the sustainability approach include a commitment to working across disciplines, epistemic communities, and societal sectors to solve place-based issues with global implications (Matson et al., 2005; Lang et al., 2012; Wickson et al., 2006; Brundiers et al., 2013). Despite the urgency of sustainability rhetoric (van der Leeuw et al., 2012), efforts to integrate and apply science and technology for sustainability problem-solving have proven complicated, complex, troublesome, and incomplete (Westley et al., 2013; Miller et al., 2013; Benessia and Funtowicz 2015).

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[4] [1] Pub. L. 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended by Pub. L. 94-52, July 3, 1975, Pub. L. 94-83, August 9, 1975, and Pub. L. 97-258, § 4(b), Sept. 13, 1982. Sec. 101 [42 USC § 4331]. "to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."

[5] Different in the sense of complementary, not calling for absolute replacement.

Responsible Innovation for Sustainability: a Synthesis

Insights from social studies in science and technology and sustainability science to augment responsible innovation for sustainability can be synthesized as five activities and three normative aspirations. Foley, Wiek, and I have articulated these activities and aspirations elsewhere.[6] In brief, the five RI activities have been expressed as:

- **Anticipation**: adopting a disposition toward the future in the present, considering potential, systemic, plausible effects of one's knowledge, intuitions, beliefs, judgments, and actions (Guston 2008; 2014);
- **Engagement**: intentionally and appropriately including individuals of diverse knowledge, experience, and profession (Chilvers 2008; Guston 2008; Stilgoe et al., 2013);
- **Coordination**: supporting coordinated, decentralized networks to enable participation, accountability, and production of relevant knowledge (Ostrom and Ostrom 1971; Guston 2001; Cash et al., 2003; Ostrom 2010);
- **Reflexivity**: considerately examining one's knowledge, intuitions, beliefs, judgments, and actions (Schön 1983; Pinch and Pinch 1988; Pinch 1993; Fisher et al., 2006);
- **Adaptation**: using the insight and lessons from other RI activities to systematically and strategically respond with modifications to practice (Walters and Holling 1990; Norton 2005; Stilgoe et al., 2013)

RI aspirations draw from sustainability and have a temporal dimension: a focus on both the present (intragenerational) and the future (intergenerational) (WCED 1987; Norton 2005;

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[6] Please see Foley et al., *under review*.

Gibson 2006; Miller 2011). Each of these temporal foci entails concerns for the viability and function of social ecological systems (Kates et al., 2001; Clark and Dickson 2003; Gibson 2006; Clark 2007), and the safety, rights, and equity in opportunity for people to thrive (WCED 1987; Gibson 2006; Stiglitz 2002; Piketty 2014).

Current State and Gaps in Efforts Toward Responsible Innovation

Progress to advance responsible can be found in various pockets of social studies in science and technology, particularly in the early phases of innovation processes. Cozzens (2011) sought to help research managers account for concerns about the equitable distribution of benefits from funding decisions. Cozzens' (2011) funding decision protocol counters the dilemma of orientation by urging funders to listen to diverse groups of stakeholders when setting priorities; create incentives for open-source work; avoid undue burden of risk for technology development; and track inequality data while also setting up a funding criterion that demonstrates commitment to reversing some aspects of inequality. Researchers have organized citizen panels to inform national research policies, attending to the dilemma of legitimacy (Decker and Fleisher 2012). The original addition and subsequent modifications of the broader impacts criterion at the US National Science Foundation, a requirement that proposers include activities that "contribute to the achievement of societally relevant outcomes" [7] fall into this category as well (Holbrook 2005) (an attempt to

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[7] National Science Foundation 2016 Grant Proposal Guide. OMB Control Number 3145-0058. available at: http://www.nsf.gov/pubs/policydocs/pappguide/nsf16001/gpg_print.pdf

remedy the dilemma of control by having researchers anticipate the potential positive implications of their work[8]).

Current efforts in responsible innovation also draw on antecedent attempts to navigate the dilemmas of orientation, legitimacy, and control (Figure 2). The dilemma of orientation can be disrupted in part by recognizing the contestability of technological promises and assumptions that societal progress inevitably results from scientific advances (Marx 1987; Woodhouse and Sarewitz 2007). Turns in social studies in science and technology for reconciling the supply and demand for science (Sarewitz and Pielke 2007) attempt to offer an open and actionable approach to resolving this orientation dilemma. Activities of engagement with knowledge producers and users; anticipation of potential benefits and risks of pursuits; reflexivity on whether such pursuits offer prudent tradeoffs; and adaptation in response to these insights comprise the responsible innovation response to this dilemma.

The dilemma of legitimacy is often met with boundary work to enable collaborative assurance between principals and agents (Guston 2000; Guston 2001) and participation in science policy and technology assessment (Rowe and Frewer 2000; Lin 2011). In responsible innovation, activities of reflexivity on limits of expertise; engagement with diverse experts and coordination across disparate groups to cover blind spots; and adaptation in response to insights offer responses to the dilemma of legitimacy.

To resolve the dilemma of control, Collingridge focuses on issues surrounding decisions, including ambiguity, uncertainty, and limited information environments (March

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[8] Bozeman and Boardman (2009) rightly critique the broader impacts criterion for assuming that scientists and engineers have a privileged position from which to arbitrate what constitutes research of broader import to society (i.e., falls victim to the dilemma of legitimacy). Being considerate of potential negative implications is missing entirely from the proposal process.

1978; 1982). Collingridge (1980) offered heuristics for decision-making under conditions of technological ignorance to reduce the costs of the dilemma of control.[9] Collingridge (1980) suggested making decisions that are easy to correct (corrigibility); choosing systems that are easily controlled (controllability); keeping future options open (flexibility); and making decisions that are insensitive to error (robustness).

Together, the disposition of these heuristics towards the future makes them similar to precursors of anticipatory approaches to governance of science technology. Work by Guston (2008) on anticipatory governance has also been instrumental in hedging against dilemmas of control by offering ways of acting in the present with stronger regard for the future. Similar intentions toward flexibility can be found in literatures on adaptive governance of social-ecological systems (Walters and Holling 1990; Folke et al., 2005).

Dilemma	Issue explained	Exemplary response(s)	RI activities	Sources
Orientation	interest capture and goal displacement	supply & demand for science	engagement, reflexivity, anticipation, adaptation	Joskow and Rose 1989; Rayner 2012; Woodhouse and Sarewitz 2007; Holbrook 2005
Legitimacy	principle-agent issues	boundary spanning; participatory technology assessment	engagement, reflexivity, anticipation, coordination	Guston 2000; Guston 2001; Sclove 2010
Control	correction and response	anticipatory governance; real-time technology assessment	engagement, reflexivity, anticipation, adaptation, coordination	Collingridge 1980; Guston 2008; Guston and Sarewitz 2002

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[9] Much can be said about the dilemma of control, including insufficiency in recognizing the decentralization of control in technological choice (i.e., there is no central technology lever, especially not in the U.S.); the social determinants and negotiability of "acceptable cost"; and the political economy exerting influence on whatever levers do exist. A full treatment of the dilemma is beyond the scope of this dissertation.

Figure 2: Summary figure of science and technology governance dilemmas, responses from responsible innovation, and exemplary sources. RI stands for 'responsible innovation.'

Although important as individual steps, none of these efforts have yet offered an approach commensurate to the challenge at hand. In particular, current efforts to advance responsible innovation lack clarity on normative aspirations, do not account for research in the behavioral sciences, and are under-theorized in terms of accounting for mechanisms of efficacious and effective change (see Chapter 1). As I argue in Chapter 1, the field lacks a means of comparing from and learning across efforts to advance responsible innovation in a way that would allow such gaps to be addressed. Despite the potential for fruitful interaction across social studies in science and technology and sustainability in responsible innovation, social studies in science and technology scholars often hesitate to take a normative stance (c.f. Stilgoe et al., 2013; Fisher and Rip 2013). Further, sustainability science scholars often under-theorize the sociopolitical dimensions of technology and technological solutions (Miller et al., 2013; Benessia and Funtowicz 2015).

Research Objective and Question

In this dissertation, I build off of work to integrate sustainability and social studies of science and technology (Miller 2011 and Foley 2013), as well as work on intentional change management (Kay 2012), to develop a framework for supporting knowledge generation about efficacious and effective means to advance responsible innovation.[10] My aim is to help researchers in sustainability science and social studies of science and technology aggregate

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[10] Throughout this work, I will refer to "efficacy" and "effectiveness." The difference between these terms is significant. *Efficacy* refers to conclusions of how well a treatment causes change in a target in a given context; *effectiveness* refers to comparisons of how different treatments affect the same target in a given context (Shadish et al., 2002). The goal of intervention research is to build knowledge about the efficacy of individual programs and, through comparison, the effectiveness of different programs to advance a given normative aspiration.

the benefits of their individual works and so better rise to the challenges of influencing sociotechnical change for intra- and inter-generational justice. I propose a framework for systematically designing, assessing, and comparing across solution-oriented social studies in science and technology research for sustainability. I illustrate the usefulness of the framework by offering two empirical cases of interventions in science and engineering education for responsible innovation.

The main research question I ask is *how do upstream interventions in the capacity, motivation, or opportunities available to people involved in science and engineering advance responsible innovation?* I approached this question through a theoretically informed, empirical agenda. Although I present my conceptual framework in Chapter 2, with empirical studies in Chapters 3 and 4, the intervention research framework was in fact developed in dialogue with my empirical research. The initial chapter offers a conceptual grounding and intellectual foundation for research to advance responsible innovation. A first study (Chapter 3) offers a case in which the framework aids evaluation; a second study (Chapter 4) offers a case in which the framework aids design and evaluation. Concluding remarks discuss benefits and limitations of the intervention research approach; implications for theory, policy, and practice; and include preliminary ideas for a research agenda based on a portfolio approach to responsible inovation for sustainability.

Summary of Individual Studies

Intervention Research for Responsible Innovation

Chapter 2 sets out the intellectual and conceptual framing of and an approach to intervention research for responsible innovation. To account for the important intersections of sustainability and social studies of science and technology, the framework is anchored in a normative perspective and tailored to problem-based and solution-oriented work. The core of the framework is a focus on the feedbacks among the social and material factors affecting innovation processes; the behaviors and activities of innovation processes; the outcomes of innovation processes; and the assessment of these outcomes (Figure 3). A reflection on the UK Engineering and Physical Sciences Research Council pilot study from the responsible innovation literature is used to highlight the usability of the framework. Subsequently I offer a procedural approach to intervention design and research. The procedure presented is intended to support researchers as they develop and implement interventions by encouraging collaboration with stakeholders and taking pragmatic accounts of barriers, assets, and linkages to leverage in the process.

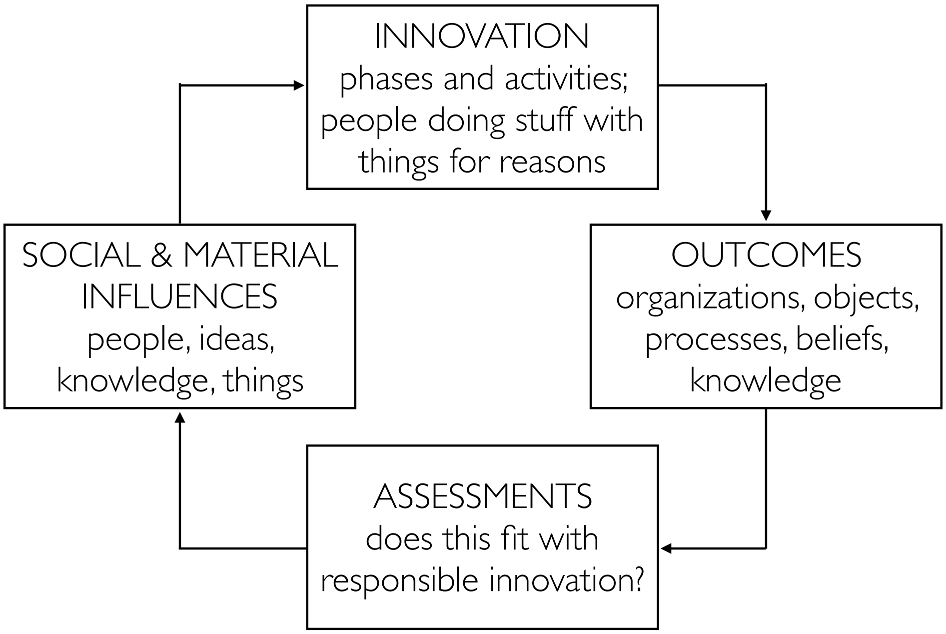


Figure 3: Core feedbacks invoked in the intervention research for responsible innovation chapter.

Study 1: Science Outside the Lab

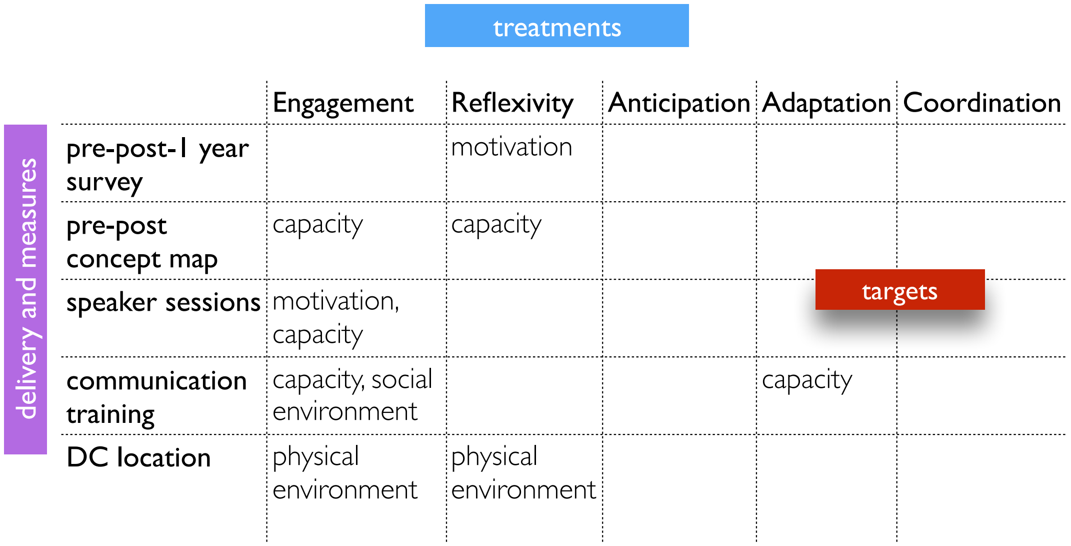
Chapter 3 explores an intervention to enhance Ph.D. science and engineering students' understanding of the complexities of science and engineering policy processes. The treatment, evaluated for efficacy is Science Outside the Lab, a Washington, DC-based policy-immersion program. A summary of the program can be found in Figure 4. The two-week Science Outside the Lab program invites ideologically diverse policy analysts, lobbyists, business people, and decision makers to discuss their work with participants. Students are challenged to reconcile the conflicting realities presented by these different interests jockeying for the future of science and technology policy.

Learning objectives	help science & engineering PhD students understand science policy; reflect on beliefs about science and society relationships
Structure	two weeks, based in DC 30 + speakers representing diverse interests off-the-record, dynamic conversations
RI Treatment	primary: reflexivity and engagement secondary: adaptation
Measures	pre-post-1 year perspective surveys; pre-post concept map; burst reflection
Dilemma(s) addressed	reveal dilemmas of orientation and legitimacy

Figure 4: Summary of Science Outside the Lab program and study.

To investigate the effects of the Science Outside the Lab program and how these effects align with capacity building for responsible innovation, my co-authors and I developed a series of assessment techniques, including a long-form survey and a concept map diagnostic tool, each deployed before and after the program. The survey was designed to assess participant perspectives on the role of trained scientists and engineers in science-policy processes, and the role of scientific information and values in science-policy decisions. The concept map was designed to measure changes in participant understanding of science policy. These assessments were deployed with the Science Outside the Lab 2014 cohort (n=9).

As an intervention, the program targets participants' awareness and appreciation of the nuances of science policy as it shapes the interaction between science and society (Figure 5). These are concerns central to the dilemmas of orientation and legitimacy. The program advances participants' capacities of engagement and reflexivity. Evidence of increases in engagement capacity can be found in changes to concept maps. Before the program, "research," "the executive branch," and "academia" are the dominant ideas students associate with science policy. After the program, "the legislative branch," "the executive branch," and "special interest groups" dominate the scene, as does a focus on issues pertaining to "budget." These changes indicate participants' deeper understanding of the groups involved in shaping research and innovation. Evidence of participants' greater reflexivity can be found in survey results and concept maps. In the survey, participants demonstrate leaving with greater humility about the roles of scientific experts in policy and greater skepticism of simple relationships scientific advances benefiting society. Finally, students departing the program with a greater understanding of the ontological status of science policy—as a socially constructed enterprise—further demonstrates increases in capacity for reflexivity.



	Engagement	Reflexivity	Anticipation	Adaptation	Coordination
pre-post-1 year survey		motivation			
pre-post concept map	capacity	capacity			
speaker sessions	motivation, capacity				
communication training	capacity, social environment			capacity	
DC location	physical environment	physical environment			

Figure 5: Alignment between study 1 activities and assessment methods and responsible innovation treatments.

Study 2: Community Engagement for Scientists and Engineers

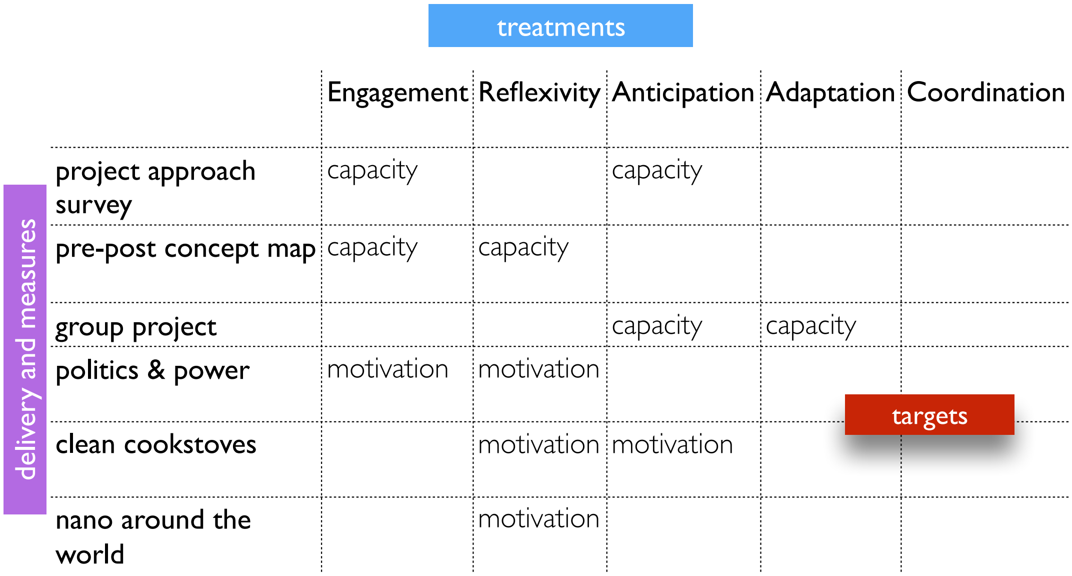
Chapter 4 explores an intervention to equip science and engineering graduate students to consider normative and societal concerns of research and professional practice. The intervention designed and evaluated is the Community Engagement Workshop. The program goals are for participants to be better able to: (a) look beyond technology to see how people, values, and other factors influence and are embedded in technologies; (b) listen to and learn from people about these non-technical aspects; (c) empower communities through a greater understanding of how technology relates to decision-making, managing, planning, and resource use in community and practitioner interactions. Facilitated over the course of two days, Community Engagement Workshop activities are designed to help participants systematically consider the societal dimensions of engineered systems and develop a toolkit of questions and methods for engaging with stakeholders. My colleagues and I ran two Community Engagement Workshops in fall 2014, one in Montreal at Concordia University, one in Tempe at ASU. We ran a total of 12 activities at each event, ranging from group discussions to role-play to card games to case-study reviews. In addition, three non-facilitator faculty partners (from the host institution), experienced in working with communities, were invited to each event to share their work and provide examples of community-engaged research and practice (see Figure 6 for a program and study summary).

Learning objectives	help science & engineering graduate students increase capacity to look beyond technology; listen to and empower communities
Structure	two 8-hour days; 12 activities + guest faculty with community experience group project
RI Treatment	primary: reflexivity and engagement; secondary: anticipation and adaptation
Measures	group project content; pre-post concept map content and structure; project approach survey
Dilemma(s) addressed	engaged, reflexive, and anticipatory approaches to control

Figure 6: Community Engagement Workshop program and study summary

In the Community Engagement Workshop study, participant learning is evaluated primarily through two pre–post instruments, a short questionnaire and a concept map. The project approach questionnaire asks participants to share the actions they would take and questions they would ask when starting a new project. The concept maps capture participants' mental model of technological systems and whether and how respondents look beyond technology when thinking about such systems.

The Community Engagement Workshop program is an intervention that targets participants' capacity to embrace the multiple normative perspectives shaping engineering projects, as well as engage in productive collaborations. These are concerns central to addressing dilemmas of legitimacy and control. The program advances participants' capacities of engagement, anticipation, adaptation, and reflexivity (Figure 7). Engagement is enhanced through interaction with community, practitioners, and researchers at various points in the workshop. Anticipation and reflexivity are enhanced and demonstrated in questionnaire results, revealing that participants came away better able to ask questions more broadly inclusive of non-technological dimensions of engineering projects. Reflexivity is also demonstrated in concept map results indicating participants' increased conceptualization of how social factors shape complex material systems. Finally, adaptation is increased as students have the chance to iteratively develop their group project over the course of the workshop and lay out ways of engaging with different groups of people relevant to their project.



	Engagement	Reflexivity	Anticipation	Adaptation	Coordination
project approach survey	capacity		capacity		
pre-post concept map	capacity	capacity			
group project			capacity	capacity	
politics & power	motivation	motivation			
clean cookstoves		motivation	motivation		
nano around the world		motivation			

Figure 7: Alignment between study 2 activities and assessment methods and responsible innovation Treatments.

Value Proposition

Value of the intervention research framework can be identified in its design for dynamic feedbacks, allowing iterative and incremental advances in knowledge about complex and ambiguous problems (Anderies et al., 2013). Additionally, the approach is solution-oriented with a focus not on reducing uncertainty about a problem or describing the problem in greater detail, but rather building confidence in the efficacy and effectiveness of potential solutions (Sarewitz et al., 2012). Finally, by integrating insights from sustainability and social studies in science and technology in a hybrid model of responsible innovation, I account for integration of broader sets of knowledge and expertise in the research process, enhancing the legitimacy and relevance of activities (Cash et al., 2003).

The case studies offered address specific gaps in the training of early career and graduate students in science and engineering in two ways. Students increase their understanding the complexities of science policy processes, and they develop the capacities needed to engage systemically and considerately in collaborations with communities in development work. Over the long term, these attempts set the stage for transformation through other upstream interventions in the way future scientists and engineers may meet dilemmas in orientation, legitimacy, and control. Still, the scale of the challenge in science and engineering education dwarfs the ability of reported or any individual solutions from education and training to yet make a difference. For perspective, “scale” would mean reaching all 139,550 first-time, full-time science and engineering graduate students in the U.S., based on 2013 data from the most recent National Science Foundation statistics[11]

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[11] National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 2013 Survey of Graduate Students and Post doctorates in Science and Engineering. *Science and Engineering Indicators 2016*.

(alternatively even the mere 41,563 with earned doctorate degrees in 2013[12]). Given this challenge, I see the value of the intervention research framework as helping to develop and collate a body of knowledge about intentional changes to advance RI and better meet the dilemmas of orientation, legitimacy, and control facing science and technology governance.

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[12] NCES, Integrated Postsecondary Education Data System, Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov. *Science and Engineering Indicators 2016*.

CHAPTER 2
AN INTERVENTION RESEARCH FRAMEWORK FOR RESPONSIBLE INNOVATION

'Faced with a variety of social and environmental ills, there is growing recognition that what is needed is a process of redirecting our technological systems and projects in ways inspired by democratic and ecological principles. How that reconstruction might occur is an open question, one ripe for widespread study, debate, and action. I believe it to be the great challenge for cross-disciplinary thinking during the next several decades.'
- Langdon Winner, 1993, p. 377

Theoretical Foundations of Responsible Innovation and Intervention Research

Responsible innovation is a concept for guiding technology development to better realize 'the (ethical) acceptability, sustainability, and societal desirability of the innovation process and its marketable products' (von Schomberg 2013, p.63). Owen et al., (2012) asserted that people and organizations can engage in a collective endeavor to shape technology development with and in service of society by altering the social processes of innovation. Drawing on ideas from anticipatory governance (Guston 2008), Stilgoe, Owen, and Macnaghten (2013) proposed four capabilities for responsible innovation:

- Anticipation: (re)considering actions today based on regard for myriad future consequences.
- Reflection: thinking through the actions taken by people involved in innovation and whether those actions align with broad societal values.
- Inclusive deliberation: 'opening up' proposed courses of action to account for the diverse knowledge and values of people involved in or possibly affected by scientific knowledge production and technological advances.
- Responsiveness: integrating knowledge from anticipation, reflection, and inclusive deliberation to modify processes of technology development.

Arguments for responsible innovation are based on mounting evidence that technological outcomes currently contribute to or exacerbate many of the challenges and inequities plaguing societies (c.f., Cozzens et al., 2005; Woodhouse and Sarewitz 2007). Dominant social paradigms for innovation, such as triple-helix arrangements of industry, government, and research organizations (Leydesdorff and Etzkowitz 1998), perpetuate these shortfalls and exclude broader social groups and organizations (Foley and Wiek 2013). A recent example of the broken promises of technology can be seen in the failure of nanotechnology to address development and sustainability challenges (Cozzens et al., 2013; Wiek et al., 2012a), applications for which it is often hyped (Salamanca-Buentello et al., 2005). A longer-lived example can be found in the unintended consequences of fossil fuel dependence on environmental, health, and social outcomes (Tainter and Taylor 2014).

Efforts to advance responsible innovation have been made in conjunction with research into science and technology and science policy. Researchers, such as Cozzens (2011), have developed decision protocols to help program managers better consider distributional equity in research funding decisions. Fisher (2007) and others have inserted themselves into science and engineering laboratories to enhance reflexivity in laboratory decision-making processes. Similarly, Shilton (2014) reported on acting as the 'resident ethicist' in an information and communication technology group to influence a design process through explicit consideration of privacy values. Citizen panels have been orchestrated to inform research policies at the level of national governments (Kearnes and Stilgoe 2007; Decker and Fleisher 2012). Holbrook (2005) studied how broader impact criteria at the US National Science Foundation embody an attempt to better align research outcomes with the interests of society. Also in the US, federal science managers have formalized a program to study the science of science policy to gain understanding of how policies change the outcomes of science and innovation (Jaffe 2006).

While notable, these efforts have been one-off projects that do not readily lend themselves to comparative analysis and learning. In part, difficulty in comparing studies of responsible innovation arises from a dearth of process-based innovation research frameworks to organize and elaborate the elements, relationships, and dynamics among elements (Ostrom 2011, p. 8). The Multi-level Dynamics Approach to Socio-technical Systems is an example of one such framework that integrates research on institutions (rules) and actors (users of technology) to tackle innovation challenges (Geels 2004). In particular, Geels (2004) argues the approach is well suited to addressing the 'structure-agency dilemma' (p. 907; Giddens 1984), which pertains to unpacking how the actions of an individual are determined by the structure of his/her environment versus his/her own individual ability to exert influence and effect change in his/her life. The multi-level perspective—focusing on laboratory level to business, municipal and regional levels, to national and international levels—presents a dynamic view of the evolution of innovation systems. While the multi-level perspective has proven useful to describe historical transitions, it remains untested as a framework for guiding intentional attempts to alter innovation processes; i.e., to enable intervention research.

Interventions involve the design, implementation, evaluation, and refinement of intentional changes to a social practice in order to advance alternative outcomes (Fraser and Galinsky 2010). Intervention research is the study of intervention design and delivery. Pertaining directly to scientific and technological endeavors, the framework we propose entails the study of interventions for responsible innovation. We seek to augment existing innovation research frameworks by:

- broadening normative frames to explicitly encompass societal challenges (Weber and Rohracher 2012);
- integrating an experimental, rather than descriptive approach to examining interventions in innovation processes (Banerjee and Duflo 2009); and
- accounting for individual-level drivers of human behavioral (Michie et al., 2011).

Intervention research is conducted in many fields. In public health and medicine, examples include vaccination efforts for disease eradication, and uses of graphic labelling on cigarette cartons to render the harms from smoking more compelling and thus encourage smoking cessation (West et al., 2010). Other instances of intervention research exist in public policy and public administration (Jung and Lee 2014; Pedersen 2015); psychology (Ben Zeev et al., 2014) and behavioral science (Hekler et al., 2013); social work (Fraser and Galinsky 2010); development and resource economics (Alcott and Rogers 2014; Banerjee et al., 2010; Duflo et al., 2013); environmental studies (Hobbs et al., 2011; Glenn et al., 2015); and education studies (Fuchs et al., 2013; Hooper et al., 2013).

In STS, modulation research (Fisher, Mahajan, and Mitcham, 2006) sets a precedent for intervention research. Modulations are conceptualized as occurring across three phases of innovation: upstream, midstream, and downstream. The stated goal of modulation is to 'conduct and implement R&D with an eye toward subtly and creatively shifting on-going, nested interactions among techno-scientific actors and networks' (Fisher et al., 2006, p. 492).

Despite an action orientation and efficacious protocol, modulation researchers tend to distance themselves from explicit normative framing, even while embracing ideas of 'doing better' with 'soft intervention' to diffuse responsibility for the impacts of research and innovation (Fisher and Rip 2013).

The proposed intervention research framework, initially hinted at by Wiek et al., (in press), builds on the precedent of modulation by introducing clear normative framing from responsible innovation studies and sustainability science. Sustainability scientists (Kates et al., 2001) attempt to conduct problem-based and solution-oriented research (Sarewitz et al., 2012; Wiek et al., 2012b; Miller et al., 2014) with clear normative frames. Normative, solution-oriented approaches to responsible innovation that draw on sustainability can be found in research on nanotechnology governance (Wiek et al., 2013), community-based technology development (Foley, Wiek, and Kay, 2015), and engineering education (Harsh et al., submitted).

The second way in which we hope to augment existing innovation research frameworks draws from research on the governance of social-ecological systems (SES). SES researchers, not unlike Geels (2004), adopt an institutional perspective, focusing on how formal rules and informal social norms, cultural attributes of communities, and biophysical environment interact dynamically over time to affect the capacity of a resource system to continue to generate stocks and flows of resources (Ostrom 1990; Anderies and Janssen 2013). Incorporating SES research on institutions and dynamics into our framework offers two advantages. First, the seven types of rules Ostrom (1990) identified as operating in resource governance regimes—boundary, position, choice, scope, information, aggregation, and payoff—offer greater analytical specificity than the three—regulative, normative, cognitive—proposed by Geels (2004). Second, the legacy of studying adaptive, experimental approaches to resource management and governance in SES research (Walters and Holling 1990; Folke 2005) provides powerful analogues for attempts to alter innovation processes to better account for societal responsibility and sustainability in addition to economic growth.

Finally, we seek to include advances from behavioral science to balance institutional perspectives in STS. Research on individual-level influences of behavioral is important to include because interventions are meant to effect change in human activities. One won't usefully inform responsible innovation by saying 'change laboratory research'—there is no laboratory research 'lever'; however, there are the 'knobs' and 'dials' of research norms, researcher skills and training, PI motivations, the design of physical space, etc.—all malleable through intentional experimentation. This reality raises the need to explicitly account for the conscious and unconscious mental and emotional processes that subtly influence human actions (Kahneman and Tversky 1979; Michie et al., 2011) in a way that, as Giddens (1984) pioneered and Geels (2004) adapted to innovation studies, can help bridge the structure-agency divide in responsible innovation scholarship.

Descriptive studies of science and technology often explore how current innovation practices and processes fall short of responsible innovation aspirations. Intervention research for responsible innovation would build upon descriptive insights to investigate questions such as: What alternative activities could remedy these shortfalls? What is the theoretical basis for suggesting such alternatives? If designed and implemented, how might the success of an alternative activity be assessed? How can these changes be studied over time? What can be done to integrate findings from other research (or translate findings to other contexts)? How do different combinations of activities complement, augment, or obstruct each other? In the remainder of the manuscript, we elaborate the conceptual foundations of the proposed framework, illustrate the usability of the framework through a case study, and present a procedure for intervention research design.

Conceptual Foundations of the Intervention Research Framework

The core of the intervention research framework involves two components: first, the innovation activities (Figure 1, center box, black loop); and second, the interventions designed to alter innovation activities in support of responsible innovation (Figure 1, center box, red loop). Innovation phases consist of suites of activities and stakeholders, shaped by particular aspirations (Foley, Bernstein, and Wiek? submitted). Innovation activities, stakeholders, and their aspirations are the targets of interventions.

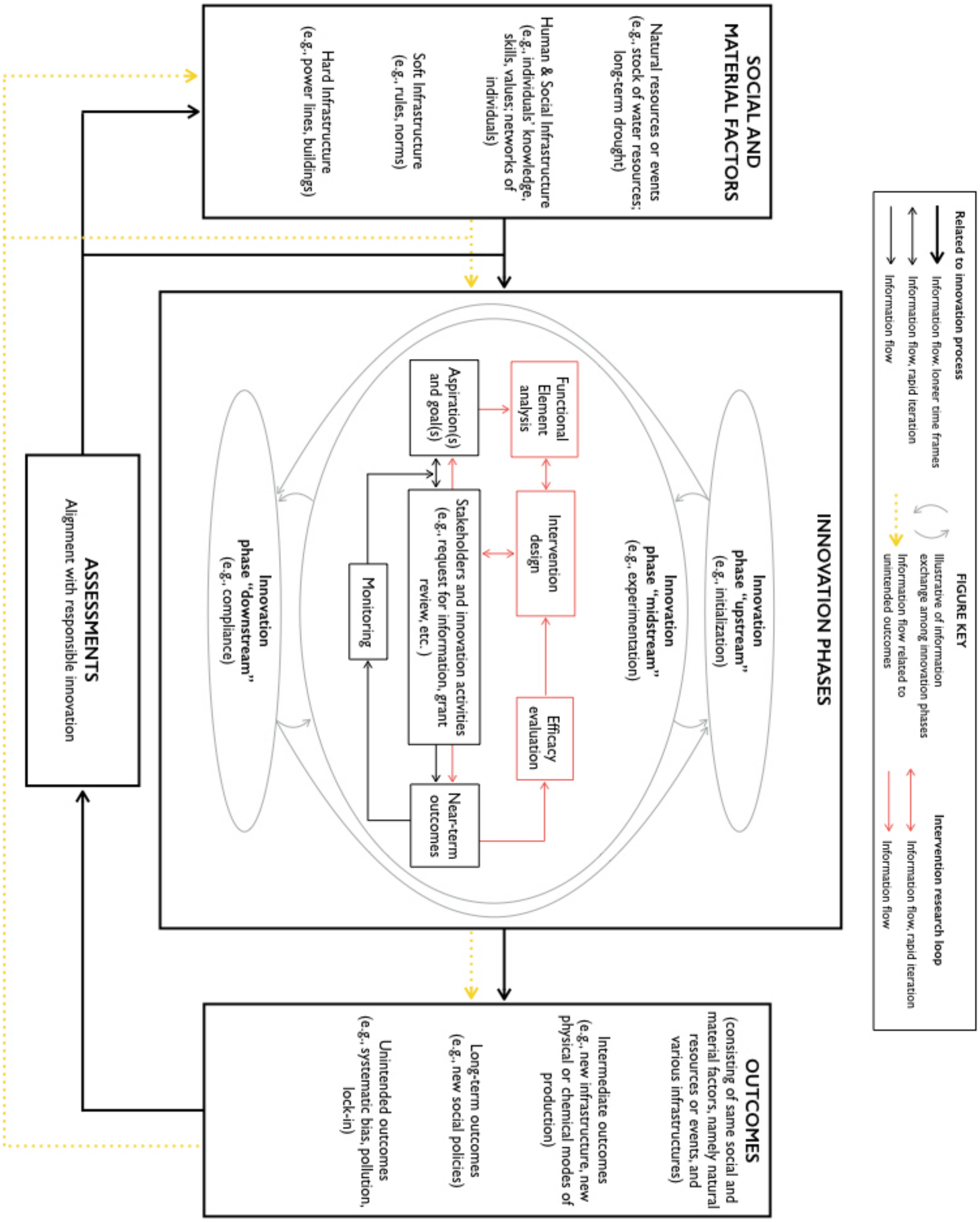

Figure 1: Schematic of innovation processes as a nested, dual-loop feedback system embedded within larger social and material factors; interventions presented as alterations to support responsible innovation.

Innovation Activities

Innovation phases and constituent activities are delineated temporally with the language of ‘upstream’, ‘midstream’, and ‘downstream’ (Fisher et al., 2006) (Figure 1, center box, upstream oval, midstream oval, downstream oval). Innovation phases have been described as non-linear, yet necessarily sequential groups of activities associated with research initialization, experimentation, proof of concept, compliance, commercialization, etc. (Robinson, 2009). The schema of robust control feedback systems (Anderies et al., 2007) proved most useful here to conceptualize the complex interrelationships among innovation phases and activities. Feedbacks through monitoring and assessment can promote learning loops. We focus on innovation activities first since, as Foley and Wiek (2013, p. 234) argued: ‘if innovation ought to happen somewhat differently (with somewhat different decisions and actions), namely in more anticipatory and responsible ways, we first need to know who is doing what (and why) within the innovation process’.

An example of an upstream research initialization activity ripe for intervention research is grant solicitation development. One can answer ‘who is doing what’ by generating a list of prominent stakeholders involved in this activity: program managers and directors, researchers, entrepreneurs, and lobbyists. Stakeholders pursuing any given activity in an innovation phase will have multiple goals or aspirations (the, ‘and why’). We consider three general types of aspirations at play in innovation processes (Foley and Bernstein et al.,, submitted): advance livelihood opportunity (e.g., enhance economic opportunity (Stiglitz 2002)); support human flourishing (e.g., improve human health (Cozzens et al., 2013)); and safeguard socio-ecological integrity (e.g., remediate environmental contamination

(Rockström et al., 2009)). Each aspiration entails a variety of more specific goals, which can be tracked and assessed through indicators (Gibson 2006).

More slowly changing social and material factors (figure 1, left-hand box) shape and, through outcomes, are shaped by innovation processes (Pinch and Bijker 1987; Geels 2004). Such factors include natural resources or events (e.g., water supplies; long-term drought) as well as infrastructure. The *Oxford Dictionaries* defines infrastructure as, 'basic physical and organizational structures and facilities needed for the operation of a society'[13]. After Anderies and Janssen (2012), we differentiate infrastructure into: (1) human and social infrastructures, including an individuals' knowledge, skills, values; the networks of individuals; and organizational structures). (2) Soft infrastructure, including rules and norms. (3) Hard infrastructure, including power lines and wastewater systems. These different infrastructure types almost always combine to influence innovation processes. For example, Reardon (2001) showed how the process and outcomes of the human genome diversity project were shaped by a combination of physical infrastructure, social interactions among scientists and funders, and mobilized social opposition.

Near-term outcomes of innovation (figure 1, center box, right) are those most immediately related to the outputs of a particular innovation activity—for example the knowledge gained immediately after instituting an alternative practice. Intermediate, longer-term outcomes, and unintended outcomes (figure 1, right-hand box) unfold over time, and are observed in the forms of altered physical infrastructure, artifacts and products; revised or

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[13] infrastructure. Oxford Dictionaries. Oxford University Press, n.d. Web. 05 November 2015. <http://www.oxforddictionaries.com/us/definition/american_english/infrastructure>.

new chemical or mechanical modes of production; modified social process such as revised or new interactions among individuals and organizations; or changes in cultural norms. These changes overtime become part of larger feedbacks among social and material factors, innovation processes, innovation outcomes, and assessments (Introduction, Figure 3). Unintended outcomes are particularly important to attend to for refining theories about innovation processes and better accounting for undesirable effects of innovation.

In the context of intervention research, a process theory conveys how innovation stakeholders, aspirations, activities, and outcomes are interrelated. Process theories should be informed by best-available evidence so they can, in turn, orient research questions about how (and why) interventions might effect responsible innovation. Process theories in intervention research should be testable, intended to be refined in the course of intervention research and thus augment understanding of science, technology, and innovation processes. Critically, process theories provide intervention researchers with key components to consider in intervention design.

Interventions

Interventions (figure 1, center box, red-coloured components) rely on analysis of the functional elements of stakeholders involved in innovation phases. Functional elements consist of stakeholders' capacity and motivation and social and physical environments (Michie et al., 2011; Ostrom 1990). Capacity refers to what a stakeholder is capable of, including knowledge, skills, and cognitive abilities (Michie et al., 2011). Capacity is affected by cognitive biases and heuristics. Cognitive biases reflect tics of human decision-making, such as how people evaluate relative to reference points and how possible losses often loom larger than possible gains (Kahneman and Tversky 1979). Heuristics are the mental shortcuts we take to reduce the cognitive strain of decision-making (Gigerenzer and Goldstein 1996). Motivation refers to why a stakeholder might act, based on individual goals, desires, values, and habits (Michie et al., 2011). Motivation too is a function of conscious and unconscious processes. Conscious motivation deals with how an individual weighs the costs and benefits of an action (i.e., utility function (Ostrom 1990)). Unconscious motivations encompass the habitual and instinctual, for example ways in which people seek to act consistently across situations (Cialdini 2009). Social environment pertains to the formal rules and informal norms affecting stakeholder interactions, and the social capital available to stakeholders though networks or group composition. A formal rule codifies and proscribes what individuals may or may not do and stipulates consequences for non-conformance (Ostrom 2011); informal norms (like waiting in lines in some countries) guide individual actions without officially documented consequences, but with undeniably real social effects (Kinzig et al., 2013). The physical environment refers to conditions that affect how and why a stakeholder might act, and depends on infrastructure (Anderies and Janssen 2013), the nature of a resource (Ostrom 2007), or the attributes of a technological artefact (Latour 1992). The above literatures offer rich theories that can support hypotheses on how changing functional elements might affect innovation activities through interventions.

Intervention research design considers responsible innovation aspirations, targets, treatments, and near-term outcomes (Shadish, Cook, and Campbell 2002; Cronbach and Shapiro 1982). The aspiration for an intervention relates directly to the motivations for study *qua* the responsible innovation aspirations of livelihood opportunity, human flourishing, and socio-ecological integrity (from above). A target is a specified stakeholder group central to an innovation process. Intervention targets are not nameless, faceless persons or organizations, but rather critical partners for the implementation of an intervention research effort (as reflected by the double-headed arrows for iteration in the center box of figure 1) (Banerjee and Duflo 2009). Relationships between stakeholders and researchers take various forms, from extractive and distanced, to engaged and interdependent partnerships anchored by shared visions, depending on the nature of an intervention (Talwar et al., 2011). The treatment refers to what the researchers and stakeholders agree to do to effect change. Near-term outcomes are determined by systematic study and evaluation. The rationale for how a specific treatment ought to affect target(s) and lead to outcomes is a theory of change (Fraser and Galinsky 2010). Intervention researchers evaluate the efficacy, or internal validity, of an intervention to ascertain how well a treatment causes change in a target in a given context (Shadish et al., 2002). The results of efficacy evaluations can be fed back to intervention design until a treatment is calibrated to result in the intended outcomes. A well-articulated, evidence-based theory of change advances the study of responsible innovation through empirical validation and contributes to theory building.

Assessments (figure 1, bottom box) of innovation processes offer an opportunity for second-order reflection. Assessment allows researchers and practitioners to ascertain whether observed intermediate and longer-term outcomes of innovation processes align with the aspirations of responsible innovation. Assessments must be tuned to specific indicators of the goals associated with different aspirations, yet must also be flexible enough to account for subtle or less easily quantifiable outcomes (Sunstein 2014). A quest for perfect indicators should not supersede the rationale for assessment: improving innovation processes to better serve society.

Demonstration of Use: Responsible Innovation Case Study

Owen and Goldberg (2010) reported on a pilot study to advance responsible innovation with the UK Engineering and Physical Science Research Council (EPSRC). Re-casting this pilot study as an intervention illustrates how our intervention research framework facilitates efforts to communicate about interventions for responsible innovation that more easily lend themselves to comparison. We overlay the language of intervention in parenthesis and italics, where appropriate.

Owen and Goldberg (2010) studied the lag between when technologies are developed, and when the impacts of these technologies become well understood. The research investigated potential changes that could make the initialization (*upstream phase*) of research more anticipatory and responsive, thus reducing the 'understood-impact lag' (*responsible innovation goal*). Underlying this lag is a *process theory* about the 'fragmented and often loosely coordinated nature of actors involved in funding innovation itself, those investing in understanding of wider impacts and associated risks, and those with a role in technological governance' (*ibid*, p. 1700). The authors chose to study the UK EPSRC (*stakeholder group*), the largest public funder of basic to proof-of-concept research in the UK (*activity*) to 'begin to understand how it [the EPSRC] could embed approaches that promote responsible science and innovation research within its funding activities' (*ibid*, p.1700). The funding solicitation used for the pilot study was a call for nanoscale science and engineering to contribute to carbon capture and storage (*aspiration, advancing social-ecological system integrity*).

The *treatment* in the EPSRC case was a request (*social environment*) that scientists and engineers (*target stakeholders*) submit proposals augmented with a 'risk register' that 'identifies wider potential impacts and risks of proposed research' (Owen and Goldberg 2010, p. 1699).

The risk register was chosen for its ease of implementation and potential to help proposal submitters reflect on managing risk and uncertainties (*target capacity*) associated with the project (*ibid*, p. 1703). Combined, these project elements express a *theory of change*. Each risk register was externally peer reviewed (additional *stakeholders*, *activity*), and considered by the review panel (*stakeholder*) as a secondary criterion (*social environment*) in the evaluation process (*social environment*). The researchers evaluated the 'use' and 'value' of the risk register through a series of one-on-one interviews with researchers, peer reviewers, funding panel reviewers, and a workshop with representatives from each group to discuss the strengths and weaknesses of the risk register *(monitoring and efficacy evaluation)*. The authors observed that while researchers seemed able to reflect on the immediate health and exposure risks from handling nanomaterials, they gave little consideration to environmental risks, and no consideration of possible future societal impacts (*observed outcomes*) (*ibid,* p. 1702)—the risk register was thus deemed a useful tool for delineating impacts about which researchers were 'certain', but not for impacts unknown to or unpredictable for researchers. This highlights a *limited capacity* and a potential focus for additional intervention studies on motivations for scientists and engineers to avoid considering unknown and uncertain risks. Two *unintended outcomes* were the findings that some investigators built interdisciplinary teams to augment their risk register, and other teams consulted publics and stakeholders (*social environment functional element*) to help characterize risk and impacts (*ibid*, p. 1702).

Owen and Goldberg (2010) presented a series of questions about how to use risk registers: when should they be deployed: for all calls for proposals, or only for large project solicitations? What resources are needed to administer such calls in particular? The authors further point out how the observed outcomes (lack of consideration of future impact across-the-board, and sparse use of interdisciplinary teams or public engagement) could each prompt further study *(assessment)*. The authors highlighted the need for a cultural change (*social and material factor)* around considering and embedding risk perspectives in innovation, especially in the face of fear that consideration of risk might lead to liability. Their conclusions illustrate how specific interventions in innovation activities nest within innovation processes.

The intervention research framework helps translate this singular (exceptional *and* unique) upstream intervention study for comparison with other responsible innovation projects. For example, holding constant the *target stakeholder* (researchers) and *functional element* (*capacity* to manage risk and uncertainty), one could compare the results of the upstream risk register intervention and, say, a midstream intervention in-laboratory training *a la* Shilton (2014). Using the framework also reveals project strengths, lessons to transfer to other contexts, and findings to explore in further research, intervention or otherwise.

A Procedure for Intervention Design and Research

We turn now to the question of intervention design and research. The steps below are extended and adapted from similar efforts in transformational sustainability research (Wiek and Lang, in press) and social work (Fraser and Galinsky 2010). The design process can support researchers in developing possible interventions, filtering these according to a series of pragmatic criteria, and refining intervention designs in collaboration with stakeholders. Steps 1 through 5 are intended for rapidly generating intervention ideas; step 6 details intervention selection; steps 7 and 8 detail the lengthier processes of intervention implementation, monitoring, and evaluation. After completing an initial pass of steps 1 through 5, we recommend that researchers connect with potential collaborators—i.e., the stakeholders needed as partners to conduct the interventions—to refine the intervention ideas. Co-refinement of interventions is an important way to build trust, align expectations, and enhance the usability of research (e.g., Pielke et al., 2010). In addition, co-development helps establish clear roles for researchers and practitioners with regard to implementation, monitoring, and evaluation, further augmenting a pragmatic approach to intervention design and research. Figure 2 presents an abbreviated schematic of the steps detailed below.

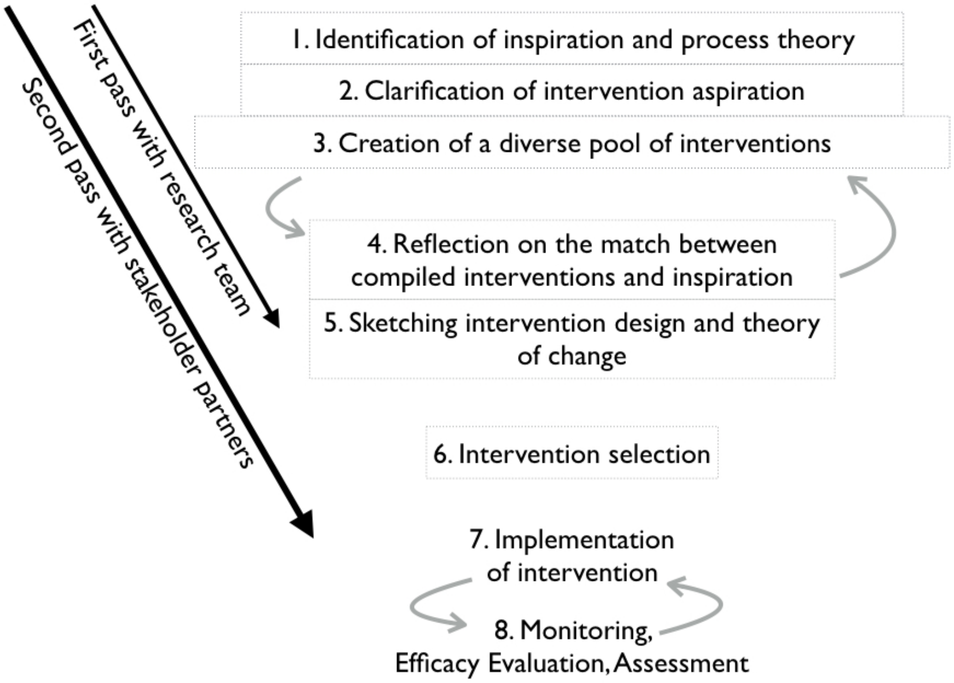

Figure 2: Schematic of intervention design and research process. The funnel-like shape of the schematic reflects the pragmatic and systematic filtering from a broad pool of ideas to a single intervention.

Step 1: Identification of project inspiration and process theory

Why is the research team proposing an intervention? How do current arrangements of stakeholders, activities, and aspirations perpetuate deficits in responsible innovation? A research team might begin by exploring the inspiration for conducting intervention research. Are there unjust or inequitable processes or outcomes that inspire the research? Researchers here elaborate the specifics of the innovation phase and activities involved, as well as identify the stakeholders perpetuating, complicit in, or burdened by these activities. Which stakeholders may be absent, but *should* be involved? How does the combination of stakeholders and activities lead to the outcomes inspiring the team's intervention? Answers to these questions will help the team form a process theory for the research and a foundation from which to propose interventions. As an example, Owen and Goldberg (2010) worked with specific stakeholders (researchers, funders, peers) on funding activities (revised call for proposal). Their process theory related the requirements in a call for proposals (initialization phase) to subsequent research trajectories and, ultimately, the risks associated with nanotechnology development.

Step 2: Clarification of intervention aspiration

What is the goal of the research team's intervention? How might aspirations of responsible innovation help specify the goal? The team uses the activities and outcomes associated with responsible innovation to think through aspiration and goals for intervention research (Foley and Bernstein et al.,, submitted). Owen and Goldberg (2010) aspired to reduce negative 'wider impacts and associated risks' (Owen and Goldberg 2010, p. 1700), an aspiration aligned with advancing social-ecological system integrity. The subordinate goal associated with this aspiration was to lessen the "understood-lag" associated with nanotechnology development. Owen and Goldberg (2010) tested responsible innovation activities of anticipation and responsiveness (Stilgoe et al., 2013) to try to achieve their goal. Note that this case is an example of collaboration between a researcher (Owen) and a manager within the EPSRC (Goldberg).

Step 3: Creation of a diverse pool of interventions

What current or alternative combinations of stakeholders, activities, and aspirations might advance responsible innovation in the innovation phase identified? This question explores possible solutions to the ‘irresponsible innovation’ the team identified in step 1 and aspired to improve upon in step 2. When brainstorming, a researcher team should set aside critical reflection to allow for unencumbered consideration of alternatives and possibilities. How might different stakeholders, activities, or aspirations alter the innovation phase to facilitate responsible innovation? Owen and Goldberg (2010) focused on prominent stakeholders involved in solicitation (program managers and researchers), but observed in closing that a public engagement component might have been an alternative treatment to affect the target. Looking to other fields for inspiration is often helpful at this step. As a team’s list of ideas expands, it is important to consider whether the pool of interventions accounts for a diversity of responsible innovation activities and stakeholders. Helpful here are a portfolio approach and questions such as: are we over-attentive to one particular activity (e.g., 10 ideas for citizen involvement)? Are we attuned to only one capacity for responsible innovation (e.g., reflexivity)? Are all of our aspirations aligned with socio-ecological integrity without consideration of livelihood opportunities? Identifying imbalances in the portfolio, modifying, or generating additional ideas associated with the above considerations helps round out the intervention pool.

Step 4: Reflection on the match between compiled interventions and inspiration

After generating a diverse pool of interventions for responsible innovation, the next critical step is reflecting on the match between proposed interventions and the initial inspiration. Completing this step with the aid of a table (Table 1) can help keep track of the team's main ideas. The point of reflection here is to save effort with intervention design by pragmatically winnowing out interventions that would not plausibly influence the innovation deficits identified in step 1. Going back again to Owen and Goldberg (2010), had the authors tried to enhance reflexivity and responsiveness of researchers by providing slides about nanotechnology risks with the solicitation announcement, it is unlike that any effects would have been noted in submission outcomes. More hyperbolically, if an intention is to advance responsible innovation in policy, and the main intervention is to conduct a researcher-only workshop without connection to policy makers, it may be implausible to expect uptake of outcomes. We propose a trio of external criteria (outside the control of researcher team), informed by considerations of change and transition management literatures (Kay et al., 2014) to help research teams reflect on the match between compiled interventions and initial inspirations:

- *Barriers:* conditions that obstruct interventions from plausibly achieving aspiration(s). Barriers include the presence or absence of formal rules, infrastructure, or organizational connections. For example, the defunding of the US Office of Technology Assessment (OTA) has made it impossible to conduct a present-day intervention with that office (although historical lessons from the OTA may still be useful for a baseline comparison with another intervention).

- *Assets:* conditions that support interventions. Assets include existing behaviorals to leverage, organizational structures, and material or financial resources. For example, a Dear Colleague Letter for a future solicitation on public forums in healthcare might present an opportunity to pursue an intervention around engagement, reflexivity, and anticipation in solicitation design.
- *System linkages:* individual and organizational connections endemic to innovation activities. Factors to consider here are whether organizations are related, how, and if these are positive and functional connections. For example, there is a direct relationship between funding agencies and researchers seeking funding, yet in the U.S. there is an indirect link between the voting public and funding agencies, mediated by legislative and bureaucratic processes. Such lack of connection suggests that a public engagement effort to inform research directions might, on its own, gain little traction.

Assessing the match between inspiration and intervention of each entry in a research team's idea pool (table 1) need not require extensive investigation. A basic score can be tallied for each intervention idea: -2 for interventions with major barriers, and no supportive assets or system linkages; -1 for interventions with moderate barriers, and limited assets or linkages; 1 for interventions with minor barriers, and general assets or linkages; 2 for interventions with few if any barriers, and supportive assets and linkages. Tallying the external match scores for each intervention in the pool should leave a team with a pragmatically filtered set of interventions to further develop in step 5.

Table 1: Table to summarize intervention projects elements (left), and reflect on projects in light of external feasibility criteria (right), using two example interventions from the literature.

Project Elements				**External Criteria**			
Project Name	**Inspiration**	**Phase & Activity**	**Aspiration(s) & RI Goal(s)**	**Barriers**	**Assets**	**System linkages**	**Total Score**
EPSRC (Owen and Goldberg, 2010)	Poor attention to technological risk in funded solicitations	Initialization; requests for proposal (RFP)	Socio-ecological integrity; enhance reflexivity and responsiveness through a 'risk-register'	1	1	2	4
Socio-technical integration research (STIR) (Fisher, 2007)	Limited awareness of ethical implications in laboratory research	Experimentation; laboratory decision-making	Human flourishing; Enhance reflexive capacity in laboratory groups	-1	2	1	2

Step 5: Sketching intervention design and theory of change

With a handful of well-matched interventions, a research team can more efficiently spend time specifying targets, treatments, and outcomes for each intervention. This is the point at which the research team would refine a theory of change using functional elements (capacity, motivation, social and physical environment) to link intervention target, treatment, and expected outcome. Each linkage between functional element(s) and target(s), and treatment(s) and expected outcome(s) should be justified with evidence or theoretical backing from the literature. To assist monitoring and evaluation, it is useful here to identify indicators that will be associated with the outcomes of intervention. In the event that intervention designs become overly complicated, we recommend stepping back to see if alternative, simpler treatments could generate the same intended outcomes.

Step 6: Intervention selection

The research team has by this point developed a pragmatic pool of interventions tuned to responsible innovation and supported each intervention with a process theory and a theory of change. We strongly encourage researchers to use this set of interventions to identify possible implementing partners. Researchers should recruit and work with these partners to further refine the set of ideas in light of practitioner experience and expertise. Once the research team and implementing partners have co-refined the intervention pool (revisiting steps 1 through 5), the group can select an intervention with which to proceed. To strategically select an intervention, we encourage the research and practitioner group to reflect on shared experiences, team strengths, and networks in light of three internal criteria (drawing again from (Kay et al., 2014)):

- *Barriers* include: project location (travel costs, access to stakeholders, etc.); project timeframe (consider that results may not manifest for years); access to data; project costs; lack of analytical tools; and lack of background knowledge or research.
- *Assets* include: resources (knowledge, funding opportunities, etc.); project location (nearby or critical site for case study); project type (e.g., collaboration with key decision-makers); and access to data and analytical tools.
- *Relationships* can help the group overcome key barriers or leverage key assets. Relationships include research team members and home organizations, implementing partners and organizations, and possible informal advisors.

Estimate the group's capacity to undertake each intervention in light of the above internal criteria (Table 2). A basic score can be tallied for each intervention idea: -2 for interventions with major barriers, and no supportive assets or relationships; -1 for interventions with moderate barriers, and limited assets or relationships; 1 for interventions with minor barriers, and general assets or relationships; 2 for interventions with few if any barriers, and supportive assets and relationships. The research team and practitioner group should agree on and select the intervention that best leverages the group's capabilities.

Table 2. Table to summarize intervention project elements (left), and further reflect on projects in light of internal feasibility criteria (right), using two example interventions from the literature.

Project Elements				**Internal Criteria**			
Project Name	**Target & Treatment**	**Functional element(s)**	**Outcome (O) & Indicator (I)**	**Barriers**	**Assets**	**Relationships**	**Rank**
EPSRC (Owen and Goldberg, 2010)	Researchers writing proposal; Modify solicitation and review processes	Researcher reflexive and anticipatory capacities; physical environment in form of additional solicitation activity	O: Earlier consideration of health and safety risk I: Proposal language	1	2	2	5
STIR (Fisher, 2007)	Laboratory research group; Insert 'humanist' into laboratory to ask probing questions	Researcher reflexive capacity; social environment from including humanist in laboratory	O: Enhanced ethical capacity in laboratory groups I: Direct references in documents and verbal statements	1	1	2	4

Step 7: Implementation of intervention

One of the most vital steps in implementation is ensuring that researchers and practitioners have shared and clearly defined roles and expectations for the project. In our experience, an informal memorandum or code of conduct can help establish and serve as a future reference for researchers and practitioners. Although beyond the scope of this paper to detail a typology, we recognize that different interventions will require different commitments from researchers and practitioner partners. An intervention focused on education is more likely to be conducted by a researcher, with partners involved in planning to ensure that the program is relevant and legitimate. Professional training workshops might require equal involvement of researchers and partners in recruitment, design, and facilitation. A research policy intervention is likely to be implemented by the partner (e.g., a program manager), with the researcher available for general support, as well as efficacy evaluation. Obviously, roles depend on context; for example, in the EU a Directorate-General for Research and Innovation Science with and for Society is integrated in the policy landscape, and staffed by practitioners who may also serve as university researcher (c.f., European Commission 2015).

The duration of implementation is contingent on a number of factors, including whether funding is in-hand, treatment duration, a need for Institutional Review Board exemption or approval, and logistical concerns. Intervention implementation revolves around research practice and project management; conducting necessary literature reviews; recruiting people to participate, as appropriate; securing additional approval and partnerships for activities; meeting to discuss progress and necessary changes to treatments; collecting quantitative and qualitative data to study innovation activities and evaluate interventions, etc. Although we separate steps 7 and 8, implementation should be designed and executed with monitoring and evaluation in mind to enable substantive learning.

Step 8: Monitoring, Efficacy Evaluation, and Assessment

A research team and practitioner partners rely on experience and on quantitative and qualitative data collected during implementation to monitor, evaluate, and assess the intervention. Monitoring (figure 1, center box, black-coloured components) allows practitioners to assess whether innovation activities are still functioning as needed. Efficacy evaluation (figure 1, center box, red-coloured components) allows researchers to assess whether the treatment is causing changes in the target, in a given context. The results of monitoring and evaluation can be used to refine the intervention, as well as the innovation activity, as desired. Over time, assessments can be conducted to ascertain relationships among innovation phases, interventions, and more distant outcomes. Assessments help answer the research team's larger question of whether altered processes and outcomes of responsible innovation do indeed guide technology development to better realize 'the (ethical) acceptability, sustainability, and societal desirability of the innovation process and its marketable products' (von Schomberg 2013, p.63).

5. Discussion

We proposed an intervention research framework to make diverse studies of responsible innovation easier to compare. Our hope is that the framework's normative framing, inclusion of problem-based and solution-oriented approaches, and leveraging of behavioral and SES institutional perspectives will provide scholars and practitioners a means to systematically investigate efforts to advance responsible innovation.

The research framework presented is suited to current challenges in innovation governance. First, our framework is designed around dynamic feedbacks, allowing for iteration and incremental advance on complex and ambiguous, or ‘wicked problems’ (Rittel and Webber 1973). The use of feedbacks and iteration to incrementally address wicked problems builds on insights into the value of disaggregating more resolvable components of wicked problems (Metlay and Sarewitz 2012). Second, an intervention approach to responsible innovation is solution-oriented; the focus of the research is not on reducing uncertainty about a problem or describing the problem in greater detail, but rather building confidence in possible solutions (Sarewitz et al., 2012). Third, by actively including practitioners as partners in a problem-solving, transdisciplinary process (Wickson, Carew, and Russell 2006; Lang et al., 2012), interventions stand to enhance the legitimacy and relevance (Cash et al., 2003) of scientific research involving high-stakes, value-laden (Funtowicz and Ravetz 1993) challenges such as those endemic to technology development.

We readily acknowledge that our framework is not without deficiencies. Studying processes is hard. System boundaries are leaky and relationships are dynamic; studying changes to processes nested in systems that you yourself are embedded within can prove even more vexing. Intervention in innovation processes may yield cascading feedbacks, presenting major obstacles to evaluation. Intervention researchers will need to distinguish between efficacy of a specific treatment, and external validity when treatments are adapted to different settings. Still, theorizing and testing alternatives through intervention research need not be a quixotic quest for causal relationships (Shadish et al., 2002). As recognition of interdependence becomes increasingly common in studies of complex processes, causal claims may be impractical to pursue (c.f., Ioannidis 2005). Such complexity advantages iterative and learning-based attempts to build evidence, as we have proposed.

There remains a dearth of theories on the mechanisms by which innovation governance efforts effect change. Studies critical of innovation processes often highlight deficits in innovation practices, positing how innovation *should* be conducted (e.g., Grunwald 2004; Kemp et al., 2005), but offering limited evidence for the viability of such recommendations. We assert that such recommendations offer valuable starting points for intervention research. As Sarewitz (2013) noted in a testimony to the US House of Representatives committee on Science, Space, and Technology, *'There will be no single policy intervention that can productively address all of these issues together, yet it is important to recognize that neither can they be considered or addressed separately … there are many possible intervention points where relatively modest changes in policy or priorities might move things in the direction of stronger accountability and greater public value'* (p. 11). We offer our initial attempt at a research framework to advance such efforts and to better hold science and innovation accountable to promises for realizing broader societal benefit.

6. Conclusions

The intervention research framework for responsible innovation complements and builds on contemporary modes of inquiry in science and technology studies. The framework accounts for dynamics and system feedbacks to capture innovation process complexity; equips people to think through change on multiple timescales through feedbacks; and focuses on human behavioral to calibrate interventions and align actions with intended outcomes. The mode of empirical inquiry in this framework can aid in the creation of portfolios of solution-oriented evidence to advance responsible innovation. As Winner (1993, p. 377) noted, what has remained a challenge for the field has been a way to intentionally redirect 'our technological systems and projects in ways inspired by democratic and ecological principals'. Intervention research offers a way to respond to this challenge. The black box of technology development has been cast open; by exploring its contents, researchers have learned how it is a box created by humans, for humans, but not necessarily vested with human well-being. An intervention research approach offers a way to shape technology development in a more versatile, flexible, and responsive process of scientific research and innovation.

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CHAPTER 3

SCIENCE OUTSIDE THE LAB: HELPING GRADUATE STUDENTS IN SCIENCE AND ENGINEERING UNDERSTAND THE COMPLEXITIES OF SCIENCE POLICY

Introduction

Macroethics education can challenge scientists' and engineers' received assumptions about how science, engineering, and society relate (Ladd 1980; Herkert 2001, 2005). Assumptions of such a 'received view' (Rommetveit et al., 2013) hold that science is an unpredictable, value-free pursuit (Douglas 2009) imbued with a right to autonomy best adjudicated by experts (Polyani 1967). Autonomy is held as important because science is also viewed as a pursuit whose fruits inevitably benefit society (Bush 1945).[14] Social studies of science and assessments of scientific and engineering research speak to the need for a more critical approach to the good intentions underlying these assumptions (Cozzens et al., 2005; Woodhouse and Sarewitz 2007; Sarewitz and Pielke 2007; Douglas 2014). This task for macroethics education in science and engineering grows ever more important as scientists and engineers are enrolled in global quests to solve 'grand challenges' (NRC 2008).

Efforts to integrate macroethics education into science and engineering curricula vary (Herkert 2005). Stand-alone courses, ethics-embedded content, hybrid online-in-person courses, and lab-based ethics courses each present viable options, but with mixed results (Lincourt and Johnson 2004; Canary et al., 2012). The challenges faced by individuals offering macroethics education include content development, delivery, and assessment.

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[14] Alternatively referred to as a "linear model" perspective.

Content for macroethics education spans from introducing notions of plurality and ambiguity in decision-making (Murphy 2004; Metlay and Sarewitz 2012); engaging in conversations about sets of responsibilities (Pimple 2002; Weil 2002; Foley et al., 2012); and grappling with notions of what constitutes progress and for whom (Marx 1986; Son 2008). To avoid becoming box-checking exercise,[15] macroethics education must draw students emotionally and break the strong pull of traditional science and engineering curricula (Newberry 2004; McCormick et al., 2012). Instructors must also deal with assessing the efficacy of their initiatives immediately and over time (Borenstein et al., 2010; Canary et al., 2012; Keefer et al., 2014). The importance of scientific and technological endeavors and the challenges associated with implementing macroethics education leave the field open to innovations in programming and evaluation.

One such innovation is Science Outside the Lab *(*Science Outside the Lab), a two-week program that immerses students in Washington, DC, the heart of US science policy. The primary goal of Science Outside the Lab is to enhance Ph.D. science and engineering students' understanding of the complexities of the policy process. This is pursued by introducing students to a wide array of decision makers who both use science in their decision making and make decisions that may ultimately affect science.

Science Outside the Lab: Program History and Development

Science Outside the Lab was created by Drs. Dan Sarewitz and Neal Woodbury in 2002 as a partnership between Arizona State University and Columbia University's Center

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[15] To say nothing of the obstacle of being an ethical engineer or scientists in a workplace where ethical practice may not be the norm (Herkert 2001).

for Science, Policy & Outcomes. The program ran every other year between 2002 and 2009. Since 2009 Dr. Ira Bennett has directed the program, versions of which are now offered up to seven times a year, supported through a mixture of grant and fee-based programing. The aspiration of Science Outside the Lab has consistently been to increase the ability of young scientists and engineers to understand the sense of ambiguity and attendant issues of contested responsibilities and values associated with science policy.

Sarewitz and Woodbury, and now Bennett, each have strived to ensure program design and implementation respond to the challenges of macroethics education. First, to convey content on plurality of values, the program is designed around 90 minute, open conversations with drivers and constituents of science policy including policy analysts, lobbyists, industry executives, lawyers, regulators, and scientists who work for NGOs. Throughout the program, students are challenged to reconcile the conflicting realities presented by the diverse interests jockeying for the future of science policy. Instructed on ways to ask guest speakers questions that probe an individual's values, goals, beliefs, and expertise, students find that most of their interlocutors are intelligent and have a very good command of the science involved, but hold values that conflict not only with another speaker's but also with the students' themselves. Further, such values will often seem and may indeed be incommensurable; yet, by learning about these in immediate juxtaposition, students have the opportunity to see values coexist in a single science-policy landscape.

Second, and critical to the viability of having more than two dozen guest speakers visit with students over the course of ten days, the program is based in Washington, DC. As part of this stand-alone, immersion experience, students are separated from traditional laboratory contexts. Such separation encourages reflection on laboratory practice without the social pressures invariably generated by peers or advisors. This intentional act of separation proves critical for enabling student inquiry into what is, essentially, a contested narrative about how science, engineering, and society relate.

Third, and central to creating an exciting and engaging experience, individual sessions are designed to be active and interactive. Speakers are instructed only to share a brief biography and job description before opening the floor to questions. This interactive approach is commensurate with growing empirical insight into the importance of active learning pedagogies in STEM education (Freeman et al., 2014). Sessions are held under Chatham House Rule to ensure that while students can use the information received, "neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed."[16] Confidentiality of sessions is critical to helping speakers feel comfortable to freely share insights, and instills in participants a sense of responsibility and import—that matters discussed are not to be taken lightly. Vesting participants with such trust, the program organizers seek to make students shareholders in the emotional journey of questioning received norms about science, engineering, and society.

Several additional attributes of program design and delivery are also worth noting. Focusing on Ph.D. science and engineering students is done in the hope that participants, despite being acculturated to the dominant paradigm of their science and engineering education, still have opportunity to question some of the fundamental assumptions of their

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[16] Chatham House Rule. Chatham House: The Royal Institute of International Affairs. Accessed on 18 February 2016. Available at: https://www.chathamhouse.org/about/chatham-house-rule

discipline. The program is voluntary, avoiding contentions of being a box-checking exercise and helping to ensure that participating students believe there is something to learn in the area. Related, the program is not free, requiring participants (or the home institutions that fund them) to have “skin in the game” for attending. Finally, the program honors that practical matters of employment are also of interest to students and so several sessions are designed to offer students concrete lessons about the Federal budget process, science communication, policy communication, and career development.

Science Outside the Lab: From Informal to Formal Assessment

Anecdotally, the program has been well received by participants and their sponsoring research organizations. Such feedback has been used to help the program improve over time: students’ favorite speakers get invited back again and again; reflections on past groups’ experiences have helped the organizers converge on a program size of 12-16 students; the intellectual curiosity and capacity for self-directed learning of Ph.D. students make them particularly attuned to this form of educational experience. Despite these insights, over its first decade, a formal evaluation of the program’s impacts on students had not been attempted.

This paper offers a formal evaluation of Science Outside the Lab and examines: whether participants learn the macroethical lessons embedded in the program; if so, what lessons they retain; and how we might know. Our assessment focuses on the specific learning objectives of the program, namely that after the participating, science and engineering Ph.D. students should be able to:

- describe and appreciate the complex array of people and organizations involved in shaping science policy
- reflect on the role of science and engineering expertise in science policy
- articulate the limitations of information in resolving values-based policy debates

In science education, there has been much attention to assessing individuals' views about the nature of scientific inquiry (Ledermen 1992), but not to the "metascience" of why scientists pursue what they do (Ziman 2001). Dating in some instances as far back as 1907, studies in science education have been concerned primarily with student understandings of aspects such as how scientific hypothesis and theory relate or the nature of experimentation and discovery (Ledermen 1992). Little attention in these studies has been paid to the implicit narrative about science and society relationships (one exception being Behnke (1961), who, as part of a study to compare scientists and science teacher's views on the nature of science, explored views of relationships between society and science and scientists). This macroethics gap in science education persists to this day (Lederman et al., 2013).

In engineering ethics education, assessment methods generally focus on students' moral judgment and reasoning associated with microethical concerns. Mumford et al., (2008) reported on their evaluation of ethical decision making on responsible conduct of research, a strongly microethical program. Similarly, Brock et al., (2008) reported on the evaluation of a program to increase graduate students' reflexivity about ethical dilemmas in complex situations—again a microethical agenda. Borenstein et al., (2010) developed the Engineering and Science and Issues Test (ESIT) to ascertain students' responses when confronted with "moral dilemmas" (p. 390). In the ESIT, and its antecedent Defining Issues Test (DIT; Rest and Narvaez 1998), students are presented with cases to which they are supposed to relate and assume the role of a decision-maker facing a microethical quandary. Designed in this way, such tests actually end up being incompatible with assessments of macroethical sensitivity, which, in theory, should instead inquire after a respondent's perspectives on the larger, systemic interplay of information, values, and societal aspirations rolled up in science and engineering decisions. Further, the ESIT and DITs seek explicitly to *filter out* political bias from measurement (Borenstein et al., 2010), a step that assumes a divisibility of beliefs from values, which also stands contrary to a central tenet of macroethical education (Herkert 2001; Douglas 2009).

In response to this dearth of methods for assessing the efficacy of macroethical education initiatives, we developed two complementary instruments, a survey and a concept map, to explore changes in students' macroethcial sensitivity. These instruments were deployed to better understand the impact of the Science Outside the Lab program on a 2014 cohort of participants. Each assessment instrument was given before and after the program. The survey was developed, validated, and used to gauge student perspectives on relationships between science and society and the roles of scientists and engineers in science policy. To track not just the nature of students' shifts in perspective but also the changes in associated knowledge, we also used a conceptual mapping activity (Novak 1990). Whereas the survey sought to uncover student perspectives, the concept map sought to elicit student conceptualizations of science policy before and after the program.

Methods

The learning goals of the program--to increase understanding of the complexities of science and technology policy decision-making, and appreciate the role of expertise in science and engineering policy—relate directly to Herkert's (2001) synthesis of socially focused macroethics. Our task in evaluating Science Outside the Lab was thus to determine the efficacy of the program in increasing student's macroethical sensitivity. Consistent with advances in moral psychology, we recognized that macroethical sensitivity consisted of "intuition" and "reasoning" components (Haidt 2001). The notion of intuition is sympathetic to an individual's beliefs about a topic; the notion of reasoning to the knowledge an individual might employ to elaborate or rationalize his or her intuition (Haidt 2001; 2007). Conceptualizing macroethical learning outcomes through a social intuitionist model of morality and ethical sensitivity allowed us to determine two separate objects of study: student's beliefs about science and society relationships and student's knowledge about science policy. We developed a survey to capture insights on the former and adapted concept mapping for the latter.

Survey of Participant Perspectives

We developed the survey to assess changes in participant perspectives on the relationships between science and society and the role of science and engineering expertise in science policy. Survey development began with a literature review to identify appropriate concepts for assessment. We assembled 44 ideas about how science and society "should" relate from literatures of scholarship on science and society (Berlin 1953; Polyani 1967; Hughes 1984; Pinch and Bijker 1987; Jasanoff 2004; Lindblom 1959; Schot and Rip 1997; Guston 2000; Guston and Sarewitz 2002; Pielke 2007; Sarewitz & Pielke 2007; Bozeman and

Sarewitz 2011). Next, ideas were crafted as statements that we subsequently arranged into groups of related concepts about science—society relationships (scales; Table 1). Each statement was constructed with a positive and a negative framing to mitigate response bias. People taking the survey were prompted, “Please rank the extent to which you agree or disagree with the following statements,” with response options on a 5-point Likert scale (1, strongly disagree; 2, disagree; 3, ambivalent; 4, agree; 5 strongly agree). We expected that statements in the positive would elicit lower scores (more disagreement) from scientists and engineers without prior exposure to macroethical issues. To keep scores consistent, statements framed as negatives were therefore scored inversely (e.g., a 5, strongly agree, scored as a 1; 4, agree, as 2, etc.). Based on this set of expectations, we anticipated that changes in Science Outside the Lab participant responses would provide proxies of changes in participant beliefs (intuitions) about macroethical issues of science and society relationships. Early iterations of the survey were validated with different groups of natural scientists, engineers, science policy, and science and technology studies researchers.

We grouped statements into 15 scales of the constructs identified. Aspects of macroethical education content were broken out into different scales. The general categories of macroethical content covered: relationship between scientific progress and societal benefit; the role of experts and expert knowledge in policy; the relationship between science and policy; role of information in policy choice. A reliability analysis was conducted to confirm the internal consistency (correlation of responses) among scale items that we theorized were related (Carmines and Zeller 1979; DeCoster 2005). A Chronbach’s alpha of greater than 0.6, indicative of reliability, was observed for 11 of the 15 scales (table 1), based on analysis of 55 respondents. We briefly describe and present an exemplary statement from each reliable scale in table 1.

Table 1: summary of science and society relationship scales used in perspective survey.

Scale	Macroethical content	Exemplary item
Linear model	relationship between scientific progress and societal benefit	"Basic scientific research informs technical design and engineering applications, which yield societal benefits."
Social impact*	role of experts and expert knowledge in policy	"The knowledge I provide should be used to help solve societal challenges."
Value of science**	relationship between scientific progress and societal benefit	"The generation of knowledge or engineered systems alone is not enough to justify the value of science and engineering research."
Specific Policies*	relationship between science and policy	"Science and engineering research clearly demonstrates the need for certain policy decisions."
Primacy of science**	relationship between science and policy	"Science and engineering research is not the most important factor for shaping science and engineering policy."
Technical information**	role of information in policy choice	"Providing a policy maker with more technical information will not equip him or her to make a better decision."
Necessary versus sufficient**	relationship between science and policy	"Scientific and technological advances are necessary but not sufficient for resolving science and engineering policy debates."
Policy justification**	relationship between science and policy	"Science and engineering research cannot alone be used to justify one policy over another."
Personal involvement*	role of experts and expert knowledge in policy	"I should engage with policymakers to ensure that political debate is informed by the best available knowledge."
Policy priorities	role of experts and expert knowledge in policy	"Scientists and engineers should not define the priorities for science and engineering policy."
Research use*	relationship between scientific progress and societal benefit	"My research findings could be used as justification for a variety of political interests and I should be concerned about those outcomes."

* indicates a 4 item scale with two pairs of positive-negative statements.

** indicates a 2 item scale with one pair of positive-negative statements.

The 17 Ph.D. participants in the 2014 Science Outside the Lab cohort were sent the survey electronically one week before, one week after, and one year after the program. A total of 14 Ph.D. students completed pre and post surveys and concept maps, however only 9 students also completed a follow up survey one-year later (an effective response rate of 43%).

Concept Mapping

Whereas the survey was designed to elicit participant beliefs about science-society relationships before and after the program, we adapted a conceptual mapping activity (Novak 1990) to illuminate student knowledge about key actors and organizations involved in (shaping) science policy. A "concept map" refers to a two-dimensional portrayal of interrelated ideas. Ideas, terms, or concepts are "nodes" on the map; directionality among "links" between nodes indicates the relationships among ideas; a pair of nodes connected by a line is known as a "proposition" (Yin et al., 2005). The concept map has become appreciated not only for its value in assessment, reviewed below, but also for its use as an educational aid (Regis et al., 1996).

Concept maps were initially developed and deployed by education researchers interested in studying student learning of science concepts (Novak 1990). A variety of adaptations in science and engineering education have emerged since 1990 (Nesbit and Adesope 2006). Focusing on changes in the structure and complexity of student knowledge, Markham et al., (1994) used concept maps to compare differences among freshman non-majors, upper division majors and graduate students in biological science. Concept maps have been similarly applied to study knowledge structures of people ranging from high-school physics students (Austin and Shore 1995) to medical school applicants (Slotte and Lonka 1999), to pre-service sustainability teachers (Foley et al., 2015). Beyond traditional science and engineering education, concept mapping has also been used in ethics components of curricula. Hirsch et al., (2005) reported on using concept mapping to evaluate effectiveness of a stand-alone, non-credit ethics course focused on microethcial areas including research integrity and responsible conduct of research.

The aspects of a concept map that must be adjusted for an assessment are: the task asked of respondents and the way the invitation to share knowledge is presented; the format and materials respondents may use; and the scoring mechanism researchers use to analyze data (Ruiz-Primo et al., 1996). We designed a minimally directed approach. Students were provided with a topical prompt, a central "science policy" node and, without any further content (aside from knowing the context of the program as a science policy workshop), given 10 minutes to construct a concept map from scratch using a provided piece of paper and a pen (c.f. Yin et al., 2005 on the range of choices available in concept map design). In our instructions we asked students to note the people, organizations, things, or factors that they saw as related to the central node "science policy." Mappings were completed at the beginning and end of the two-week program. We selected this form of minimally directed approach because it has been shown as the more effective option for having students convey the content and structure of topical knowledge (Ruiz-Primo et al., 2001).

We used the adapted concept map to assess students' knowledge about science policy through several variables. Complexity of participant understanding was measured by comparing the number and degree of connections before and after the program. Content of participant understanding of the key actors involved in or implicated by science policy was assessed through a qualitative analysis of pre versus post node text, first by grouping the nodes into themes, then coding these themes into a smaller set (axial coding) (Bernard 2011). Finally, participants' view on the nature of science policy —as an independent, objective entity versus a socially constructed phenomenon—was assessed by comparing the number of links pointing into versus branching out from the "science policy" center node before and after the program. We analyzed only those concept maps made by the 9 Ph.D. students from the 2014 cohort who also completed all three rounds of surveys.

Results

We set out to determine the Science Outside the Lab program's efficacy as a mode of increasing science and engineering students' macroethical sensitivity. Science Outside the Lab program learning objectives have consistently been to help students appreciate the complex of people and organizations involved in shaping science policy, challenge received notions of how scientific advances and societal progress relate, and grapple with the role of science and engineering expertise in science policy. To assess attainment of these learning objectives, we used complementary tools to better understand changes in student perspectives on science and society relationships, and to better understand changes in the content and structure of knowledge about science policy. Results from analyses of the compete data sets produced by Ph.D. student participants in the 2014 Science Outside the Lab cohort (n=9) provide initial insights into the efficacy of the program. Specifically, students left Washington, DC with greater humility about the role for science and engineering experts in arbitrating policy and greater skepticism about whether scientific progress necessarily entails societal benefit.

Survey Results

As demonstrated by the surveys, Science Outside the Lab participants begin the program generally agreeing with the notion that science discovers, technology applies, and society benefits—a perspective encapsulated by a linear model orientation for how science and society relate (Douglas 2014). This linear view, imbued with notions of faith in inevitability of social progress with scientific advances, implicitly denies[17] the possibility of macroethical concerns—the social discourse where value is negotiated. Related, students start the program with the perspective that, generally, more information leads to better decisions and that scientific and technical information are the more important factors in science and engineering policy decisions. There is strong agreement among students that knowledge produced by science and engineering research is valuable in-and-of-itself, and yet that such research should also be used to benefit society.[18] Finally, students seem initially confident that scientists and engineers are best positioned to arbitrate how knowledge should be used in policy debates. These insights into students' initial beliefs related to critical social dimensions of macroethical sensitivity come from participants' mean scores on a variety of scales before the program (table 2).

Table 2: Descriptive statistics for each survey scale from one week before the Science Outside the Lab intervention, one week after the Science Outside the Lab intervention, and one year later.

	Pre		**Post**		**Post-Post**	
Survey Scales	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Linear Model*	3.81	0.56	3.39	0.61	3.17	0.53
Social Impact	4.47	0.44	4.31	0.35	4.22	0.46
Value of Science	2.94	0.88	3.33	0.90	3.11	0.99
Specific Policies*	3.92	0.56	3.75	0.56	3.47	0.70
Primacy of Science*	2.94	0.95	3.28	0.71	3.67	0.75
Technical Information	2.50	1.25	2.67	0.87	3.17	0.79
Scientific Method	2.33	0.97	2.89	0.74	2.78	0.83
Necessary Versus Sufficient	3.22	1.03	3.39	0.78	3.72	0.57
Policy Justification	3.67	0.56	3.56	0.92	3.89	0.78
Personal Involvement*	4.48	0.47	4.26	0.52	4.11	0.60
Policy Priorities	2.53	0.85	2.86	0.59	2.69	0.62
Research Use	3.86	0.57	3.58	0.57	4.03	0.51

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[17] The logic being that if science automatically leads to social benefits, then anything a scientist does in the name of science will undoubtedly and inevitably make the world a better place for everyone.

[18] Pielke (2007) described a similar contradiction in the way some scientists will assert that the value of their work rests in knowledge production for knowledge's sake, yet lobby for funding because of the value of their work to policy.

* indicates significant or moderately significant result in a test for significance (see Table 3)

Both soon after the program and over time, we expected changes in participant perspectives to persist and reflect increased sensitivity to macroethical issues of science and society relationships. We analyzed variance of the 11 survey-scale means over three time points (pre, post, post-post) to ascertain changes in participant perspectives. Owing to the small sample size of the study, we also calculated effect sizes (eta squared), a scale-independent measure of the magnitude of variance observed when comparing changes over time (Table 3). Our point in presenting these results is not to claim discovery of generalizable knowledge but rather to speak to the efficacy of this specific macroethics education program.

After the program and one year later, students became increasingly skeptical about ideas associated with a linear relationship between science and society. The change in participant perspectives on this received linear model accounted for the greatest share of variance in the data, indicative of the large size of the effect (table 3; "linear model"). After the program and one year later, students also became increasingly ambivalent about the notion that science and engineering research clearly demonstrate the need for different policy choices (table 3; "specific policies"). It seems reasonable that students become ambivalent both about the inevitability of research leading to progress and about the role information generated by research plays in making policy decisions, such information being what would connect research to progress in the first place.

In addition to the above significant results, we observed marginally significant changes in how students came to perceive the primacy of science and the role of scientists and engineers in policy. After the program and one year later, students were more favorably inclined toward the notion that information is not the most important factor shaping science and engineering policy (table 3; "primacy of science"). Students also came away from the program with more tempered enthusiasm about the notion that they should engage with policymakers to inform political debates (table 3; "personal involvement"). We offer two interrelated interpretations of these results. One aspect is that this change in perspective is a sign of increased humility, consistent with changes in students' perspectives on relationships between scientific progress and societal benefit and on the roles for information in policy. A second aspect of this change in perspective is as a sign of participants' increased appreciation of the people involved in policy processes based, we would expect, on new-found understanding of and respect for these people's work (as imparted through each Science Outside the Lab session).

Table 3: Inferential statistics for survey scales.

Survey Scales	**F**	**Sig ANOVA (p)**	**Eta squared**	**Effect size cutoffs (0.01, 0.06, 0.14)**	**Sig t1 to t2**	**Sig t2 to t3**
Linear Model**	10.225	**0.001**	0.20	large	0.013	0.212
Social Impact	1.143	0.344	0.06	small		
Value of Science	1.1	0.357	0.03	medium		
Specific Policies**	7.502	**0.005**	0.09	medium	0.195	0.03
Primacy of Science*	3.236	0.066	0.13	medium	0.242	0.154
Technical Information	1.465	0.261	0.08	medium		
Scientific Method	2.218	0.141	0.08	medium		
Necessary Versus Sufficient	1.6	0.233	0.07	medium		
Policy Justification	0.445	0.648	0.04	medium		

Personal Involvement*	3.134	0.071	0.08	medium	0.141	0.312
Policy Priorities	0.662	0.529	0.04	small		
Research Use	1.738	0.207	0.11	medium		

One finding we also deem of note is the absence of significant change in “social impact” and “value of science scales.” After the program and overtime, Science Outside the Lab participants maintain their agreement with perspectives that science and engineering research have value for society and should be used to benefit society. Continued belief in the value of science to society points to an important point about macroethics education in science and engineering—the point of our work is *not* to devalue the contributions of science and engineering to society; rather, the point of our work is to *reframe* the ways in which scientists and engineers think about values of science and engineering in society.

Concept Map Results

To better understand changes in Science Outside the Lab participants’ knowledge about science policy we had students complete a concept mapping exercise at the beginning and end of the two-week Science Outside the Lab program. The following data points were compared to determine changes in the structure of student knowledge about science policy: total number of nodes; number of nodes at different degrees out from the central “science policy” node; and number of links into versus out of the central “science policy” node. We conducted a qualitative analysis of what students wrote in each node to determine changes to the content of student knowledge. Students departed Science Outside the Lab with a greater understanding of who is involved in shaping science policy and how these groups interact.

At the start of the program, students presented a narrow view of science policy, dependent largely on a small set of factors structured close to the central "science policy" node. Students presented a far more complex understanding of science policy after the program (Figure 1). Total number of nodes and links conveyed in concept maps increased by 60%, and the density of nodes at different degrees out of the center node also increased. After the program, students included more nodes at second and third degrees in their maps, indicating greater ability to connect among actors related to science policy. Qualitative analysis of node content helped us see that student conceptualization of these actors also changed. Before the program, "research," "the executive branch," and "academia" were the dominant groups associated with science policy. After the program, "the legislative branch," "the executive branch," and "special interest groups" dominated the scene, as did a focus on issues pertaining to "budget."

An increase in the proportion of in-linkages to the "science policy" center node indicated another key impact of the Science Outside the Lab program. As indicated by the increase in proportion of links in-to the "science policy" center node after the program, participants increasingly recognize that science policy is the product of many people, with different interests, jockeying for control of different policy processes. We interpret this recognition as an appreciation of the socially constructed nature of science policy. This change in understanding of the ontological status of science policy is highly commensurate with the more general learning objectives of macroethical education initiatives.

	Pre count	Post count	Percent change
Total nodes	241	386	60%
1st degree	144	133	-8%
2nd degree	53	107	102%
3rd degree	7	40	471%
Unlinked	26	98	172%

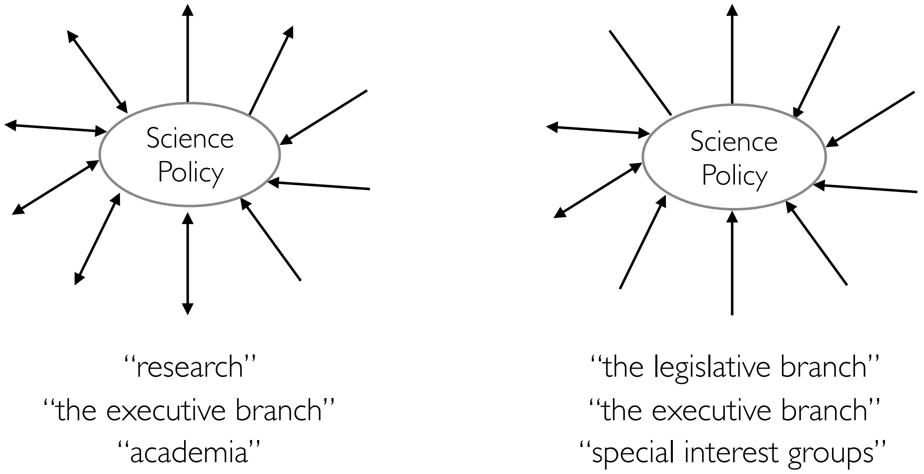

Figure 1: Changes in concept map content, structure, and direction into and out of "science policy" center node

Discussion

Macroethics education in science and engineering plays a critical role in helping Ph.D. science and engineering students appreciate the greater social context in which their work is embedded and from which it derives meaning. Despite the importance of this aspect of STEM education, implementation and assessment have been difficult for the field. We have presented a stand-alone, experiential, immersive policy program, Science Outside the Lab, as a promising macroethics program. We assessed its efficacy using two novel assessment methods; a survey to gauge changes in respondents' beliefs about science and society relationships and a concept map to gauge changes in respondents' knowledge about science policy. Results of our assessment suggest that Science Outside the Lab offers an efficacious means of enhancing students' macroethical sensitivity. Specifically, students leave Science Outside the Lab with greater humility about the role of scientific expertise in science and engineering policy; greater skepticism toward linear notions of progress from scientific advances; and a deeper, more nuanced understanding of the actors involved in shaping science policy. Below, we discuss advantages, limitations, and ways to improve upon the Science Outside the Lab model as well as limitations of the assessment and directions for continued evaluation.

Reflection on the Program

Science Outside the Lab resulted from recognition by Sarewtiz, a science-policy practitioner and scholar, and Woodbury, a biochemist, that conventional science and engineering education approaches were failing to prepare students to engage with deep ambiguities and social dimensions of science and engineering issues in society. Unfortunately, the very attributes that contribute to the program's efficaciousness as a macroethical education intervention—location in DC, access to diverse interest groups associated with science policy, to name just two—make it challenging to scale. For perspective, when we say "scale" we mean reaching all 139,550 first-time, full-time science and engineering graduate students in the U.S., based on 2013 data from the most recent National Science Foundation statistics[19] (note, we would also settle for the 83,542 with U.S. citizen or permanent resident

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[19] National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 2013 Survey of Graduate Students and Post doctorates in Science and Engineering. *Science and Engineering Indicators 2016*.

status…or even just the 41,563 with earned doctorate degrees in 2013[20], really). Even running the program seven times a summer cannot possibly offer a viable means of implementing macroethical education at scale.

Despite this difficulty with program replication at scale, we believe that the Science Outside the Lab model suggests several viable avenues for transfer and adaptation. First, educators can still seek to create programs in which students interact in and experience forums for critically engaging with ambiguous and contested social issues intimately related to science and engineering. Universities operate in larger social systems. Whether as a rural hubs of extension services or urban centers for innovation—all of these contexts implicate local governments, business, nonprofits, and other entities with a stake in the social and political context inextricable from science and engineering. A Science Outside the Lab model can convene other sets of plural interest together and offer a venue to grapple with macroethical issues.

Second, organizations should commit to keeping these programs outside of the lab and concentrated over a specific period of time. Separating participants from atmospheres of traditional science and engineering education and culture is critical to building a cohort in which students can critically reflect on said culture. The value of a cohort model reflects research insights on the importance of social ties for individual's well-being (Brownell and Shumaker 1984), of social networks for preventing undesirable behavior in organizations

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[20] NCES, Integrated Postsecondary Education Data System, Completions Survey; National Science Foundation, National Center for Science and Engineering Statistics, Integrated Science and Engineering Resources Data System (WebCASPAR), http://webcaspar.nsf.gov. *Science and Engineering Indicators 2016.*

(Brass et al., 1998), and even of peer networks in inter-organizational learning and transformation (Kraatz 1998). Forging such cohorts in a foreign (not international, necessarily, just different) location may help build a further sense of camaraderie, offering participants a shared experience of novelty with which to build cohort.

Third, those desirous of this format must value, train, and retain the human capital central to the experience. This means program directors who can maintain the social networks needed to fill a program reliant on external expertise. This means cultivating individual session educators—the faculty who run individual instances of the program and can model constructive modes of inquiry, dialogue, and conflict resolution. This means building relationships with science and engineering programs that recognize the value in offering their students opportunities for macroethical education.

Regardless of programmatic replication or adaptation, an issue any such macroethics program must face—and we still grapple with this—is how to continue to support participants as they engage with macroethical issues long after program is over. Science Outside the Lab alumni who come from ASU have a much easer time seeking out Wetmore or Bennett (both based at ASU) to talk through additional questions as desired. Most students do not have this opportunity and struggle to find outlets at home institutions. A significant challenge to macro- and microethics educators alike thus becomes one of how to maintain communities of science and engineering ethics in practice.

Reflection on Program Assessment

Our assessment of the efficacy of Science Outside the Lab suggests the promise of using complementary qualitative approaches to ascertaining macroethics educational outcomes. Capturing participants' beliefs and knowledge offers insight into emotional and intellectual domains of macroethics (Newberry 2004). Future assessment work would benefit from establishing control populations for comparison. Analysis of the perspectives and knowledge of control groups would help distinguish the extent to which Science Outside the Lab participants are "different" from the larger Ph.D. STEM pool (i.e., self-selecting). Distinguishing this factor would help refine the way in which the program is advertised and students recruited. Future assessment work would benefit as well from larger sample sizes to allow for broader claims than the more narrow-bore conclusions about program efficacy we determined from our analyses.

Science and engineering ethics programs are intended to have long-term impacts on STEM students. Another important direction for future work—not necessarily specific to Science Outside the Lab evaluation—is thus to assess the impact of macroethics education programs on the career choices of Ph.D. scientists and engineers. We have begun this inquiry with an initial open-ended survey of Science Outside the Lab alumni. Preliminary results indicate that alumni continue to express an appreciation of the wider perspectives they obtain through the program and the pragmatic ways the program prepares them for careers. For several alumni, the program spurred career change, for example one responded: "My science policy training steered me away from a tenure track academic position. I took a job for a state government agency to contribute my scientific training to the management of [state, *removed to preserve anonymity*] water resources." In the 2014 Science Outside the Lab cohort alone, program graduates received three Mirzayan fellowships through the National Academies of Science, two Science and Technology Policy fellowships from the American Association for the Advancement of Science, and one Presidential Management Fellowship. This is not to say that a goal of Science Outside the Lab or any macroethical education program is to compel students to leave the laboratory; rather, the goal is to equip participants with a broader understanding of the variety of ways that science is important for and contributes to society outside the lab. Longitudinal follow-ups with these and other participants in macroethics education programs also seem worth while given one of the underlying rationales for Science Outside the Lab: that scientists and engineers with greater appreciation of societal context are better positioned to successfully navigate policy arenas and work constructively with policy makers.

Conclusion

Appreciating the full range of ways that science and society can and do relate should make scientists and engineers more effective at honestly engaging with policy debates and political processes. Preparation to do so stands to benefit scientists and engineers in their careers; policy makers desirous of more evidence-informed approaches to policy making; citizens concerned with and interested in engaging with science and technology issues; and general National interests. Educating scientists and engineers outside the lab can help mend rifts between science and society perpetuated by received, narrow ideologies about these relationships. Our effort to create and evaluate Science Outside the Lab demonstrated that macroethics education programs can help scientists and engineers better understand the complexities and nuance of science policy, and that these efforts—and their rewards—are within our grasp.

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CHAPTER 4

PREPARING ENGINEERS FOR THE CHALLENGES OF COMMUNITY ENGAGEMENT

Introduction

There is growing recognition of the need for engineers to engage with communities in order to address pressing global issues. For instance, many of the Grand Challenges identified by the US National Academy of Engineering, such as providing access to clean water and improving urban infrastructure (National Academy of Engineering, 2008), are difficult to meaningfully address unless engineers engage with the communities who, for example, would end up drinking the water or using the infrastructure (Lucena, 2013). Despite this recognition, there is often little explicit focus on teaching engineers about community engagement as part of engineering programs (Schneider, Leydens and Lucena, 2008). Only a small number of specialized degree programs, minors, and optional classes on humanitarian engineering or engineering and community development address community engagement, and only a small number of organizations, like Engineers Without Borders or the Peace Corps, offer specialized training for select students in similar areas (see Lucena et al., 2010, pages 8-9 for a list). The majority of engineering students do not have access to any such programs, classes, organizations or trainings in the course of their engineering studies. Further, for programs that do exist, there is little research on the efficacy or effectiveness of different training formats. We observed this 'engagement education gap' in engineering education firsthand when conducting technology policy research about the distribution of social and economic benefits arising from the interdisciplinary field of nanotechnology in the United States and South Africa (Cozzens and Wetmore, 2011).

After witnessing how engineering and technical students in each country were encouraged by advisors or government organizations to engage with communities, yet rarely prepared to do so, we investigated key lessons that an engagement training program might deliver, as well as efficacious means of training. Our study began with the initial design of a two-day Community Engagement Workshop for engineers based on key lessons from the literature, such as "critically reflect on motivations for projects," and "act with the community." Formative, qualitative evaluations of initial pilot projects allowed for continuous program improvement toward increased interactivity. Once we settled on a stable workshop format, we worked to evaluate workshop efficacy. We developed and deployed a short questionnaire and a concept map activity to assess pre-post differences in participants' ability to consider non-technological dimensions of engineering projects and conceptualize social factors in complex engineered systems. Our findings indicate that an interactive and experiential short-course approach represents one potential way to address the engagement education gap. In discussing the efficacy of the workshop, research limitations, and efforts to build upon workshop outcomes, we offer a way forward for engineering educators working to bridge the community engagement gap.

Literature Review

As many countries have moved to an outcomes-based mode of accrediting engineering education (including Australia, Canada, Ireland and the United States), they have stipulated that graduating engineers possess capabilities related to communication, ethics and equity, and impact of technology on society that involve 'engaging stakeholders' and understanding users of technology (Chan & Fishbein, 2009; International Engineering Alliance 2013). Helping engineers learn to effectively work with communities not only assists in career development, but also has major implications for the health and well-being of communities where engineers work. Indeed, failure to understand community context has been documented as a main barrier to creating engineering projects that provide lasting benefits to communities (Lewis, 2012). To explore how to better prepare early-career engineers to work with communities, we reviewed literatures at the intersection of science and technology studies (STS) (Hackett et al., 2008; Sismondo, 2004) and development studies (Peet & Hartwick, 2009) in search of practicable lessons and methods. Within these fields, we focused specifically on engineering for development, applied participatory development, and local and grassroots innovation.

The engineering for development literature offered perspectives on connecting with professionals through service learning (c.f., Brower, 2011) as well as with nongovernmental organizations (NGOs), such as Engineers Without Borders (c.f., Passino, 2009). Also referred to as 'Engineering to Help,' 'Humanitarian Engineering,' 'Engineering and Sustainable Community Development' or 'Global Engineering', these areas of study detail interactions between engineers and communities often described as 'poor,' 'developing,' 'underdeveloped,' 'third world,' 'marginalized,' 'disadvantaged,' or 'underserved' (Lucena et al., 2010; Pritchard & Baillie, 2006). Applied participatory development studies investigate modes of empowering communities to advance development and to exercise control over decisions that affect their livelihoods (c.f., Chambers, 1983; 1993). Literatures on local and grassroots innovation were selected for a focus on technology development in local community contexts and included works from the appropriate technology movement (see Willoughby, 1990) based on the economic principles of Schumacher (Schumacher, 1974), the alternative and sustainable technology movement (e.g. Seyfang & Smith, 2007), the social technologies movement in Latin America (Fressoli, et al., 2011), and local innovation systems (Clark, Yoganand, & Hall, 2002; Hall, Clark, & Naik, 2007; Hall et al., 2001).

Overall, readings from STS were more theoretical; those from development studies more applied. Academic literatures were supplemented with non-academic (gray) literature, produced by NGOs or governmental agencies, to add insight into more practical and normative concerns. From these literatures, we distilled a series of lessons that we sought to impart through the Community Engagement Workshop. Ten main lessons derived from the above literatures are presented in Table 1 and explored further in the next section on workshop learning outcomes.

Table 1: List of ten main lessons, and key references, derived from literature review for the Community Engagement Workshop.

Lesson derived from literature	**Key references**
Reflect on your motivation, existing knowledge and training	Easterly, 2006; Lucena, 2008; Lydens & Lucena 2009; Vandersteen et al., 2009
Strive to understand community context before starting any technical work	Chambers, 1993; Clark et al., 2003; Lucena, 2008; Lydens and Lucena, 2006; Schneider et al., 2008; Robbins, 2007
Act with the community	Cornwall and Gaventa, 2001; Downey, 2005; Hall et al., 2007; Mathie and Cunningham, 2003; Robbins, 2007
Build capacities and empower community members	Fressoli et al., 2011; Schneider et al., 2008
‘De-center technology’	Nieusma and Riley, 2010
Keep power differentials in mind	Nieusma and Riley, 2010
Strive for equitable process and outcomes	Cozzens and Wetmore, 2011; Fressoli et al., 2011; Nieusema and Riley, 2008

Think about structural issues surrounding your work	Lucena et al., 2010; Nieusema and Riley, 2010
Assess often	Robbins, 2007
Effective engagement takes time	Lucena et al., 2010

Workshop Design and Structure

Translating the nuanced and complex lessons from the literature into an agenda for a two-day workshop involved making challenging choices about program design. The roots of these challenges extend beyond logistical and even conceptual considerations. A large amount of new material had to be covered in a short time frame. In addition, much academic literature tends to be descriptive, theory-laden and jargon rich, which makes translation into normative lessons for engineers difficult. Our literature review and our own experience led us to acknowledge that effectively engaging with communities involves drawing on certain intangible, human qualities such as humility, empathy, sense of humor, and patience. These are emotional dimensions not present in typical engineering subjects, and difficult to teach even in a semester-long course. Similar to Goldberg's view of engineering education in general, we were specifically committed to addressing these emotional aspects of community engagement at the outset (Goldberg & Somerville, 2014).

Given these parameters, all of the workshop content needed to be engaging, clear, and easily retained. We began by distilling three main learning outcomes from the list of ten lessons (see Table 1). We determined that engineers and scientists interested in community development should be able to: look beyond technology, listen to and learn from people, and empower communities. We then developed an overarching structure of original or adapted exercises, some from Lucena et al., (2010) and others from Engineers Without Borders Canada and Australia, to could convey the three main learning goals. In the remainder of this section, we present these key learning outcomes in detail, describe workshop design, and subsequently present our research on the efficacy of the short-course format for education on community engagement.

Learning Outcomes

Look Beyond Technology

Technical students who wish to engage with communities are often excited and enthusiastic about putting their technical knowledge to use. Such eagerness, however, can obscure important factors affecting communities. To balance this eagerness, engineers engaging with communities are well served by stepping away from technology at the beginning of their engagement and reflecting on three other areas that will have a critical impact on the success of the project: history (Lucena, 2008), community context (Schneider et al., 2008), and larger structural considerations in society (Lucena et al., 2010).

Reflecting on history and current context are vital for 'de-centering' technology (Nieusma & Riley, 2010:31)—helping the engineer or scientist move away from technology-centered approaches to projects. Knowing this history is also crucial for learning from past community development efforts (Clark, et al., 2003) and ameliorating legacies of injustice (c.f., Golub et al., 2013). Historical lessons also help illustrate the various dimensions of present-day community context, appreciating a community as an interdependent web of systems 'economic, technological, social, cultural' and more (Schneider et al., 2008:313).

Such broad reflection can help engineers look beyond technology by examining the material in the context of 'the social practices and social relationships that make the material objects possible and useful' (Johnson and Wetmore, 2008: xiii). A key perspective from these reflections is that while technology may be an important part of a community engagement project, a technological fix alone will rarely be sufficient (Sarewitz & Nelson 2008). Technologies must be coupled with social and political changes to have a positive effect.

In addition to these temporal considerations, students can benefit from considering geographically nested political and economic forces (Lucena et al., 2010). At more regional (e.g., county or province) levels, relevant political and economic factors may be considered. Structural policies related to land ownership and education, for example, may drastically affect the livelihoods of community members, but often are determined at the national level. Therefore, consideration of such spheres of influence can help one more thoughtfully design and scope collaborations. An example of a specific lesson here is that if students help communities design any sort of product, they should be careful to investigate how the economic exchanges for that product might be affected by the structure of the national economy, national politics and even international trade (Nieusma & Riley, 2010).

Listen to and Learn from Communities

The second skill for engineers seeking to work with communities is to listen and learn from community partners. Many engineers are not afforded the experience of working with communities, and, as a result, overlook the biases they bring to communities by nature of their different culture, life histories, and values. Listening to local communities, however, can help engineers reflect on the perspectives they bring to the project and help them to learn from, rather than impose upon, the community partner (Lucena, 2008). By listening openly, one can engage in the community with less bias.

Listening, however, is not as simple as it might seem. The dominant problem-solving paradigm in engineering education involves a six-step approach (Given, Find, Diagram, Make Assumptions, Equations, Solve) and strongly influences how engineers think, act (Lucena et al., 2010:135), and hear as they listen to community members. In community engaged work, presuming a 'given' based solely on a technical mindset often leads to severe discounting of the cultural, social, and behavioral factors enmeshed in a complex web of technical and non-technical components. Such discounting results in narrowly defined problems often amenable to resolution with the technical knowledge of the scientist or engineer, but in a way that does not at all, or only minimally, addresses the problem at hand. Critical to this reflection is a realization that technical students act not only as 'problem solvers' but also as 'problem definers' (Downey, 2005). Reflection on personal motivation can further help technical students listen by circumventing motivations fueled by a sense of superiority that comes with having strong formal technical knowledge (Easterly, 2006:368 in Lucena et al., 2010:108).

Reflecting on practice and motivation can also help engineers move from a mindset of community-as-deficient to one of community-as-asset-and-partner (Vandersteen et al.,, 2009). As a true partner, a community must be deeply and continuously involved throughout the process of community development. Students thus can benefit from viewing community members as 'makers and shapers' of solutions to their own problems (Cornwall & Gaventa, 2001; Mathie & Cunningham, 2003; Lucena et al., 2010). From this perspective, all aspects of problem definition, planning, and implementation need to involve the community (c.f., Hall et al., 2007) and consider community values, perspectives, capabilities, and knowledge (Lucena, 2008; Leydens & Lucena, 2006). Understanding a community as an asset and a partner helps technical students see themselves as people who come to a community to learn as much as to teach (Schneider et al., 2008:313). This increased humility can improve relationships with community partners and facilitate listening to and learning from people.

Empower Communities

Once engineers have established that they are working with a community, they must find ways to empower the community. Empowered communities have increased capabilities and competences. They will thus benefit more from any project, and will be better able to address future problems (Fressoli et al., 2011). There are three essential aspects necessary to empower the community: accounting for issues of justice, incorporating plans for building skills and social capital, and planning for long-term relationships.

Community engagement processes must be designed with aspects of social justice in mind to address power imbalances among the community, technical experts and other outsiders, as well as inequalities within a community (Nieusma & Riley, 2010; Riley, 2008; Fressoli et al., 2011). Such consideration is especially important when common notions of what social justice means in practice may not be shared between engineers and community members, or may even be in opposition. While equal partnerships may be nearly impossible because of differences in culture or access to resources, the way these imbalances translate into social power is important to consider and counter when working with communities (for instance community members might be biased towards agreeing with visiting engineers out of a cultural deference towards outsiders, or those who bring greater or different resources).

Within a community, inequalities in distributions of things people value (e.g., money, water, land or other intangible resources such as education) likely vary along horizontal and vertical dimensions (Cozzens and Wetmore, 2011). The horizontal dimension refers to unequal distributions between community members or groups who are delineated by culturally defined categories like gender, ethnicity, nationality, religion, or age. The vertical dimension refers to unequal distributions based on relative wealth or lack thereof (rich versus poor) (Cozzens and Wetmore, 2011). In working with communities to remedy vertical or horizontal inequities, it is also useful to note that the engagement process should be designed commensurate with the intended outcomes (Cherns, 1976). For example, a project seeking horizontal equity in water access may not do well if designed by just one unrepresentative segment of a population.

Another critical aspect of working with a community is a commitment to continuously build capabilities and empower community members over the long term (Fressoli et al., 2011). These capabilities, meant to outlast any single project, can take the form of new skills and knowledge, but also the form of social networks and relationships within the community and with other groups (Fressoli et al., 2010). Popularly known in community development literature as ‘social capital’ (Putnam, 2000), creation of social networks with and within communities can support future interactions with state, regional, national, and non-state actors (Woolcock 1998:168). For example, Bernstein et al., (2014) reported on a collaboratively defined community development project to mitigate the effects of urban sprawl in an underserved community in Phoenix, Arizona, and noted how the formation of social networks was one of the most impactful outcomes of the project. In light of the importance of building community capability, community engagement best resembles a process that creates 'community ownership' instead of being about 'community charity' (Schneider et al., 2008:313). Finally, strong collaborative relationships and trust vital to social capital can take years to nurture, and this expectation is important to internalize and plan for at the outset of engaged work.

Workshop Structure

The workshop was piloted at a public university in the southern United States and then again at a public university in South Africa. In table 1 below, we present a summary of workshop activities, intentions, and learning outcomes from the most recent iteration of the workshop. In the remainder of this section, we delve into the particular evolution of three aspects of the program: one activity, the community partner element, and the group project. This evolutionary perspective provides an appreciation not only of the workshop content but also of the process of workshop design—a process critical to understand as the workshop continues to be deployed in new contexts.

Table 2: Summary of Community Engagement Workshop activities, with brief descriptions of each activity and its associated learning goals. The * indicates an element whose evolution is discussed in this manuscript.

	Activity	Brief Description	Intended Learning Outcome(s)
Day 1	Introduction and icebreaking activity	Students are introduced to each other and facilitators. Expectations are set.	
	Images of community development	Students begin to encounter their perceptions of	Listening to people

		‘development.’	
	Light switch game	Students actively work through the systems involved in illuminating a room.	Looking beyond technology
	Nano Around the World card game	Students role-play to encounter the diversity of social, cultural and environmental barriers that shape or are shaped by global inequities in the context of nanotechnology.	Looking beyond technology
	El Cajon Dam case study*	Students role-play the parties involved in a large international development project to experience the dynamics of power involved.	Empowering communities
	Ghanaian village case study	Students engage with a case of well-intended engineering project that led to some unintended outcomes.	Listening to people; Looking beyond technology
	Asking questions	Students explore different types and ways of asking questions to help with community engagement.	Listening to people
	Listening, biases, and communication	Students practice active listening and looking beyond personal biases in communication.	Listening to people
	Guest speakers*	Students hear from faculty about best practices and pitfalls of community engaged work.	Variable
Day 2	Re-introduction and icebreaking activity		
	Politics, advocacy, and power	Students discuss politics and power relationships in community development contexts.	Empowering communities
	Powerful and powerless	Students reflect on and share personal experiences with power dynamics.	Empowering communities; Listening to people

Group project work*	Students apply lessons learned from the workshop.	Integrative
Group project presentations	Students apply lessons learned from the workshop.	Integrative
Group reflection	Students share and reflect on lessons learned from the workshop.	Integrative

El Cajon Dam Case Study Element

Our commitment to experiential learning and program iteration can be seen in the evolution of exercises related to our lesson on listening and learning from communities. We begin the lesson on listening and learning from communities with an activity about the construction of the El Cajon Dam in Honduras. This was a major technological undertaking in the 1980s in which local officials in charge of the project listened to rural villagers, local engineers, and development donors (Jackson, 2005 in Lucena et al., 2010). For this exercise, we originally had participants read a short case description and then we discussed how different voices were heard in the project, facilitated through PowerPoint slides.

After our pilot workshops, we felt that the exercises would have a greater impact if they were more interactive and experiential. The El Cajon Dam exercise was one that we significantly revised. The current version involves no reading. Instead, participants play the role of villagers, engineers, development donors and local officials (facilitators split-up the responsibility of breaking-out and briefing groups of students in each role) and students debate the case of the dam in a mock town meeting. We still discuss how different voices are heard in development projects, but now the students actually experienced being heard (or not heard) firsthand. Furthermore, we follow this exercise with another where students are paired and repeatedly take turns listening and re-voicing what they hear in a dialogic exercise. After each iteration of listening and re-voicing, students experience how listening biases impact their interactions and gain some insights into how to overcome them.

Guest Speakers Element

In addition to the facilitator-led activities, we brought in partners working with communities, to speak with participants. This was one of the most significant aspects of the workshop, but it was also the most challenging to organize. From the outset of this project, we were committed to bringing local issues into the workshop. However, after our pilot workshops, we made a pragmatic shift from working directly with community partners in the workshop to working with local faculty members and graduate students who have deep partnerships with local community groups. Initially, drawing in a community partner relied heavily on the relationship and trust that a faculty member had built with partners, and faculty were rightly very protective of their partners. Scheduling direct interactions with community partners, who tend to be extremely busy, also proved challenging. In addition, it was hard to clearly articulate to a community partner the benefit of participating in a workshop with us, and we quickly and un-ironically realized we risked falling victim to some common pitfalls we were trying to remedy with the workshop: presuming community interests and needs. The pivot to engaging the faculty with the partnership rather than the communities themselves has not been detrimental. Such faculty and graduate students have deep understanding of community issues and have been able to share firsthand accounts of community engagement best practices and pitfalls. Faculty presentations on these issues were kept short to allow for focus on a dialogue between faculty partners, workshop participants and facilitators.

Group Project Work Element

The work of the community partners initially served as a launch pad for the group projects. We charged students with developing a plan for addressing a problem flagged by the partners. However, in pivoting from community to faculty partners, we also had to re-scope the group project, already a challenge given the short duration of the workshop. We realized that the desire to have participants experientially learn by working with a community in the span of our workshop clashed with one of our main lessons: that community engagement takes time. Similarly, by too narrowly scoping a project to a pre-specified problem, participants focused too much on technological fixes, again going against one of the lessons we were trying to help students learn: not to take as given a set of community problems without actually engaging the community. Finally, we rapidly learned that if the guidance was too general, participants presented projects that converged at a very high-level. In trying to find the balance, we settled in on giving the participants the following guidance the latest iterations of the workshop:

In a small group, develop a plan to work through the early stages of a community engagement project related to one of the workshop's faculty partner work areas. You are describing the process you would undertake to work with a community to collaboratively define the project, as well as specific questions you would ask in the process. At the end of the workshop you will present your plan to the group and receive feedback.

In a similarly spirited programmatic change, we facilitated group project formation in the latest iteration of the workshop (previously a self-organized process) by holding a short vote that allowed students to select groups based on shared interest. Facilitators then met with groups several times during the project preparation so that the groups had a chance to focus and re-focus their projects with constructive feedback. As participants prepared their presentations, we helped them operationalize workshop lessons and encouraged them to think about their community engagement plans in terms of asking questions: what specific questions will be asked? To whom? By whom? When? Why might these questions be difficult to ask? How will you overcome these difficulties?

Research Methods

To assess workshop efficacy, we conducted pre–post assessments of the iterations at a public university in Canada and at a public university in the southwestern United States. Each workshop was attended by an average of 14 early-career technical students (mostly graduate students in engineering, but some in the sciences). We developed two rapid learning assessment tools to deploy at the Canadian and Southwestern US iterations (henceforth iteration 3 and iteration 4), a 10-minute project approach questionnaire and a 10-minute concept map. The short time burden of the assessment tools reflects our attempt to balance the research burden placed on participants given the constraints of a short-format workshop. The project approach questionnaire asked participants to share the actions they would take and questions they would ask when embarking on a new engineering project. The concept maps captured participants' mental model of social and material systems and whether and how respondents look beyond material aspects of technology when thinking about such systems. Each instrument is intended to assess transferable knowledge developed rather than direct recall of topical information.

Project Approach Questionnaire

The project approach questionnaire presented participants with an open-ended engineering project scenario, and then asked two questions. The scenario that we used dealt with a relevant local issue, but also was a neutral topic not covered in the workshop. By choosing a neutral topic we expected to be able to better determine differences that reflected the participant's approach to tackling technical projects generally, rather than of workshop-relevant system specifically. As a result, we asked the participants to discuss local transportation problems. Participants were given the questionnaire when they first came to workshop and at the end of the workshop. Below is the questionnaire prompt and questions:

Scenario
You have just joined a team working with the City of [_______] on a new transportation system project. Your team is tasked with developing recommendations for actions that the City can take to reduce traffic congestion and related issues.

Questions
1. What are the first three things you propose to do to get started on the project?
2. What are initial questions you would ask to help get started on these things?

The team analyzed participant responses through a content analysis (Krippendorff, 1980; Stemler 2001) of statements based on *a priori* codes reflecting the workshop learning outcomes. All participant responses (pre and post) to question 1 were assigned a random number between 1-499, for question 2 between 500-999. These steps were taken to keep the coder unaware of which responses were pre, which post, and which linked to a single respondent to reduce the possibility of confirmatory bias in coding. The three codes used were: 'looking beyond technology' (looking), 'listening to people' (listening), and 'empowering communities' (empowering). Codes were viewed as mutually exclusively, thus only one code was allowed for a given response: if a respondent had three responses to question 1, then each of those responses could receive only one code. In order to ensure that we had a robust pre-post analysis, we coded only data for participants who attended both days of the seminar (n=21; n=10 at iteration 3 and n=11 at iteration 4).

Concept Map

Across each of the three learning goals, we wanted to assess whether a student could understand the breadth of the idea as well as the interconnections among different aspects of it. To carry out this assessment for the 'looking beyond technology lesson,' we had students develop concept maps, two-dimensional representations of the respondent's ideas on a topic and of how these ideas are related. Ideas, terms, or concepts are drawn as 'nodes' in the map, the lines linking these nodes as 'connections' and linking phrases as words labeling the lines connecting nodes; a pair of nodes connected by a line is known as a proposition (Novak, 1990; Yin et al., 2005). Concept maps can be used for quantitative as well as qualitative analyses. Markham et al., (1994) used concept mapping to assess differences in structure and complexity of student thinking about biology, finding significant differences in the content and organization of maps of freshman non-majors and upper division biology majors and graduate students. Concept mapping has also demonstrated its use in engineering education generally, and on development-related topics specifically (Segalàs, Ferrer-Balas, and Mulder 2008). Murdy et al., (2011) used concept maps and found a positive correlation in the completeness and quality of a concept map and a student's overall performance in an engineering biology course. Going beyond traditional engineering education, Hirsch et al., (2005) used concept mapping to evaluate effectiveness of a stand-alone, non-credit ethics and communication course in a bioengineering research center.

For use of the concept map in the Community Engagement Workshop, participants received minimal direction; a topical prompt, without any seeding concepts, linking phrases, or prior structure (Yin et al., 2005). The request was for students to construct a concept map from scratch: '*Please take 10 minutes to fill out this concept map of people, organizations, things, or factors that compose, influence or are influenced by food supply and distribution systems. Put as much on paper as possible in the given time—and don't worry about creating a perfect map.*' Similar to the project approach survey, the request was made at the beginning and end of the two-day workshop. This low-directed, open approach has been shown to better elicit the content and structure of student's knowledge (Ruiz-Primo et al., 2001). We selected the 'food supply and distribution system' as the prompt because it is a system we do not cover in the workshop. Like the Project Approach Questionnaire, we designed the prompt to be a topic neutral so that, if differences emerged, they would be more likely to reflect changes in participant thinking about social-technical systems generally rather than in topical knowledge of the system of inquiry.

To analyze the concept maps, each pre and post entry of participants was transcribed into Microsoft Excel. Data were recorded according to the following protocol: 1) pick one node on the map, 2) record the starting node in the 'Node 1' column, 3) record the direction of each link going out of the starting node in the 'Direction' column and, 4) record the nodes connected by those links in the 'Node 2' column. A complete dataset for any given concept map could then be read as a series of Node 1 – Link – Node 2 propositions. A total of 311 unique words were found across the 40 maps transcribed (10 pre and 10 post for iteration 3; 10 pre and 10 post for iteration 4). Rather than analyze the combination of all unique words, we 'cleaned' each node to reduce differences from plurality (e.g., 'farm' to 'farms'), parts of speech (e.g., 'farming equipment' to 'farm equipment'), or phrasing (e.g., 'generate profits' to 'profits'); wherever possible, we sought to balance parsimony with fidelity to the data set, and thus some data cleaning changes were made for synonyms already within the dataset (e.g., ‘equipment corporation’ to ‘equipment manufacturers’). Next, we took the resulting 182 unique cleaned words and deductively coded each as being of or related to a ‘social,’ (S) ‘material,’ (M) or ‘social-material’ (SM) aspect of the food supply and distribution system (as with analysis of the questionnaire, the coded words were divorced of source, relationship, and pre/post indicators to reduce potential for bias in analysis). For example, ‘people’ was coded as social, ‘food’ was coded as material and ‘transportation’ was coded as social-material. The three codes (social, material, and social-material) were theory-driven, based on workshop lesson content that ‘the social practices and social relationships that make the material objects possible and useful’ (Author, 2008: xiii) are important to reflect on. Original Node 1 words, cleaned Node 1 words, and cleaned Node 1 codes were compiled into a database that could be referenced to facilitate consistent coding across all concept maps. A variety of analyses were possible with transcribed, cleaned, and coded concept maps that represent how engineering and science students think about complex, social and material systems. We felt the most appropriate indicator of a workshop effect would be changes in the propositions presented in the pre- and post-workshop data.

Results

Project Approach Questionnaire

Measure 1: Incidence of Outcome Codes

The first measure that we hypothesized would demonstrate participant learning was a change in the incidence of the codes ‘looking,’ ‘listening,’ and ‘empowering’ after the workshop in question 1 (prompting for ‘*first three things you propose to do*’), and in question 2 (prompting for ‘*initial questions you would ask*’). These data are presented in tables 3 and 4 respectively.

Table 3: Incidence of learning outcome codes in project approach survey question 1 from workshop iteration 3, iteration 4, and combined iterations 3 and 4.

		Incidence of code 'listening'	**Incidence of code 'looking'**	**Incidence of code 'empowering'**
Iteration 3	pre	23% (7/30)	17% (5/30)	0% (0/30)
	post	29% (9/31)	39% (12/31)	16% (5/31)
Iteration 4	pre	9% (3/33)	21% (7/33)	6% (2/33)
	post	33% (11/33)	18% (6/33)	6% (2/33)
Iterations 3 + 4	pre	16% (10/63)	19% (12/63)	3% (2/63)
	post	31% (20/64)	28% (18/64)	11% (7/64)

Table 4: Incidence of learning outcome codes in project approach survey question 2 from workshop iteration 3, iteration 4, and combined iterations 3 and 4.

		Incidence of code 'listening'	**Incidence of code 'looking'**	**Incidence of code 'empowering'**
Iteration 3	pre	18% (7/39)	28% (11/39)	10% (4/39)
	post	19% (10/53)	34% (18/53)	9% (5/53)
Iteration 4	pre	19% (6/31)	35% (11/31)	0% (0/31)
	post	11% (5/44)	64% (28/44)	9% (4/44)
Iterations 3 + 4	pre	19% (13/70)	31% (22/70)	6% (4/70)
	post	15% (15/97)	47% (46/97)	9% (6/97)

For question 1 responses from iteration 3, the incidence of all three learning outcome codes increased at the end of the workshop. The incidence of the code for *looking beyond technology* increased the most. For question 1 responses from iteration 4, the incidence of the code *listening to people* increased after the workshop; the incidence of the code *empowering communities* remained unchanged; the incidence of the code *looking beyond technology* decreased.

For question 2 responses from iteration 3, the number of total responses increased by 36% after the workshop. The incidence of the code *looking beyond technology* had the greatest increase, followed by a slight increase in the incidence of the code *listening to people*. The incidence of the code for *empowering communities* decreased. For question 2 responses from iteration 4, the number of total responses increased by 39% after the workshop. The incidence of the code *looking beyond technology* had the greatest increase, followed by an increase in the incidence of the code *empowering communities*. The incidence of the code for *listening to people* decreased.

Measure 2: Proportions of Participants

The second measure that we hypothesized would demonstrate how participants retained workshop lessons was the proportion of participants with increased incidence of learning outcome codes after the workshop (table 5 for question 1; table 6 for question 2).

Table 5: Percent of students for whom number of responses, and incidence of learning outcome codes either increased, remained the same, or decreased after the Community Engagement Workshop for question 1 in the Project Approach Questionnaire.

	Percent of students…	**Number of questions asked**	**'Listening' code**	**'Looking' code**	**'Empower-ing' code**
Iteration 3 (n=10)	Increase	10%	30%	70%	40%
	No change	90%	60%	20%	60%
	Decrease	0%	10%	10%	0%
Iteration 4 (n=11)	Increase	0%	64%	18%	18%
	No change	100%	36%	45%	73%
	Decrease	0%	0%	36%	9%
Iterations 3 + 4 (n=21)	Increase	5%	48%	43%	29%
	No change	95%	48%	29%	67%

	Decrease	0%	5%	29%	5%

Table 6: Percent of students for whom number of responses, and incidence of learning outcome codes either increased, remained the same, or decreased after the Community Engagement Workshop for question 2 in the Project Approach Questionnaire

	Percent of students…	**Number of questions asked**	**'Listening' code**	**'Looking' code**	**'Empower-ing' code**
Iteration 3 (n=10)	Increase	60%	40%	50%	20%
	No change	20%	30%	10%	50%
	Decrease	20%	30%	40%	30%
Iteration 4 (n=11)	Increase	64%	27%	82%	36%
	No change	27%	36%	9%	64%
	Decrease	9%	36%	9%	0%
Iterations 3 + 4 (n=21)	Increase	62%	33%	67%	29%
	No change	24%	33%	10%	57%
	Decrease	14%	33%	24%	14%

For question 1, after the workshop, almost half of Community Engagement Workshop participants (iterations 3 + 4) proposed more actions that involved *listening to people* and *looking beyond technology* lesson codes; just under a third of participants proposed more actions that involved the *empowering communities* code, with the majority of participant responses unchanged for this code. For question 2, the majority of Community Engagement Workshop (iterations 3 + 4) participants had a greater number of initial questions they would ask after the workshop. The majority of participants (67%) asked more questions that involved the code for *looking beyond technology*. Approximately one third of participants asked more questions that involved the code for *listening to people* code. Just under a third of participants asked more actions that involved the code for *empowering communities*.

Concept Map

Our hypotheses in coding concept map propositions were: 1) that propositions in which social or social-material nodes that 'shape' (S→, SM-->), or 'shape and are shaped by' (S<-->, SM-->) would increase as a proportion of relationships after the workshop, and 2) that material nodes that 'shape' (social or social material nodes would decrease as a proportion of propositions after the workshop. Our theoretical foundation for these hypotheses is the notion that technological artifacts simultaneously shape and are shaped by social forces (Bijker and Law 1992), rather than more basic material determinism (as described in Heilbroner 1967).

With all link relationships interpretable as either outward (represented as '-->'), inward (represented as '<--'), bidirectional (represented as '<-->'), or unspecified (no arrow head, represented as '--'), and all nodes coded as either social 'social,' (S) 'material,' (M) or 'social-material' (SM), each node-link-node proposition could be reduced to a string code: for example, M-->M translates as material shaping material; S<-->S translates as social shaping and shaped by social. We compared pre- and post- node-link-node propositions across the combined iterations 3 and 4 (table 7) to examine the overall effects of the workshop on participant conceptualization of complex social-material systems.

Table 7: Table of the frequency of node 1 (N1) – link – node 2 (N2) propositions in concept maps. Pre-workshop data are presented in the left-hand columns, post-workshop data in the right. The proportion of a given proposition out of all propositions is presented in the 'proportion' columns, and data are listed in decreasing order of proportion in both the pre and the post sections of the table. The color reference is to whether the first ten relationships lost (red), gained (green), or stayed the same (yellow) in terms of share of all propositions after the workshop.

	Pre Workshop			**Post Workshop**	
N1 link N2	Relationship Freq	Proportion	N1 link N2	Relationship Freq	Proportion
M-->M	36	6%	S<-->S	46	6%
M<--M	35	6%	SM<--S	40	6%
M-->SM	30	5%	SM<--SM	39	5%
S<--S	29	5%	S-->SM	36	5%
S<--SM	29	5%	SM-->SM	36	5%
SM-->S	29	5%	SM<--M	33	5%
SM<--SM	28	5%	M-->M	31	4%
S-->S	27	5%	M-->SM	31	4%
SM<--M	26	5%	S-->M	30	4%
SM-->SM	25	4%	M<--M	29	4%
M-->S	22	4%	S<--S	29	4%
M<--S	22	4%	M<--S	28	4%
S-->M	21	4%	S-->S	27	4%
SM<--S	21	4%	SM<-->SM	26	4%
S-->SM	20	4%	SM-->S	25	3%
S<--M	19	3%	S<--SM	24	3%
S<-->S	18	3%	S<-->SM	23	3%
S<-->SM	18	3%	SM<-->S	22	3%
SM<-->S	18	3%	SM-->M	21	3%
SM<-->SM	15	3%	M<--SM	19	3%
M<--SM	14	3%	M-->S	17	2%
SM-->M	14	3%	S<--M	17	2%
S<-->M	9	2%	M<-->S	15	2%
M<-->S	8	1%	S<-->M	15	2%
M<-->SM	5	1%	M<-->M	12	2%
SM<-->M	5	1%	S--SM	9	1%
M--M	4	1%	M--M	8	1%

SM--SM	4	1%	M<-->SM	7	1%
M<-->M	3	1%	SM<-->M	6	1%
S--S	2	0%	M--SM	5	1%
S--SM	1	0%	SM--M	5	1%
SM--S	1	0%	SM--S	5	1%
M--S	0	0%	SM--SM	2	0%
M--SM	0	0%	S--S	2	0%
S--M	0	0%	M--S	0	0%
SM--M	0	0%	S--M	0	0%

The share of relationships in which material nodes shape material, are shaped by material, or shape social material nodes decrease in prevalence after the workshop. After the workshop, the top five propositions were social nodes shaping and shaped by social nodes (S<-->S, increasing from 5% to 6%), social-material nodes shaped by social nodes (SM<--S, increasing from 4% to 6%), social-material nodes shaped by social-material nodes (SM<--SM, no change from 5%), social shaping social-material (S-->SM, increasing from 4% to 5%), and social-material shaping social-material (SM-->SM, increasing from 4% to 5%).

Discussion

We presented the Community Engagement Workshop as a means of bridging the persistence of the ‘engagement gap’ in engineering education. Further, we presented results from two summative assessment instruments in a pre–post efficacy study of the Community Engagement Workshop contributing to research on overcoming the engagement gap in engineering education. The Community Engagement Workshop equips participants to look beyond technology and listen to people; ask more questions to uncover social dimensions of engineering projects; and consider ways in which complex systems are shaped by social and social-material factors. The efficacy of the Community Engagement Workshop program offers one promising way to strengthen training on societal dimensions and social responsibility in engineering education, which Herkert (2005) terms macroethical concerns.

Limitations and Further Research

Several limitations with our assessment approaches offer room for further research. First, the small sample sizes make generalizing from the results impractical. Second and related, without a control or a comparison group, it is difficult to assess the effectiveness of the program relative to any other macroethically-oriented program with similar learning outcomes. This lack of ready comparison is the reason our design was a non-experimental pre-post study of efficacy (Shadish, Cook, & Campbell 2002), rather than of effectiveness. One possible way to account for these limitations and more rigorously analyze the effects of the workshop would be to secure funding to run multiple iterations of the workshop with much larger groups. Further, random assignment of recruited participants could lend further validity to a future study of program effectiveness. Given the success of our initial efficacy study, such research may be beneficial to the community, and also could be used to compare among alternative workshop designs.

A third limitation of our workshop relates to the lack of longitudinal follow up. While we have plans to conduct a one-year follow up of the project approach questionnaire, as of this publication, we have not conducted a follow-up survey. Finally, a fourth and more general limitation of assessment is that this workshop format differs from engineering in practice. This fourth limitation is endemic to training for responsible conduct and engineering ethics, more generally, because of the importance of context and situational interactions (Benya et al., 2013). One way to address this limitation would be to pair the Community Engagement Workshop with an engineering course that involved actual field work. Observation, interviews, and other qualitative assessments of participants during applied components of such a course, as well as follow-up assessment using project approach surveys and concept maps, could help ascertain how well participants are able to use lessons on looking beyond technology, listening to people, and empowering community in practice.

Given these findings that the Community Engagement Workshop generally does achieve its main goal—helping create more socially aware engineering students who are better equipped to listen to and empower communities—we are currently working to create more lasting impacts for participants after the workshop, as well as laying the groundwork to expand and scale up the workshop. We are developing more professionally designed take-away materials for the participants. We are also developing an alumni network via the internet and social media where former workshop participants can keep in touch, ask further questions of each other and share experiences (with former participants from their own workshop and from other workshops). For short-term expansion, we are adopting a facilitator mentorship model where a faculty member who plans to run a Community Engagement Workshop at his or her institution first participates in at least one other Community Engagement Workshop run by facilitators who have already run the workshop. Expressions of interest for this mentorship approach have already come in from colleagues in our network who work in many different countries. In the longer term, we hope to host annual or semi-annual ‘train the trainer’ events where a small group of faculty members wishing to run a Community Engagement Workshop at their institutions could come together and be trained by experienced facilitators. To accompany these efforts, we are developing professionally designed curriculum materials and learning guidance that will be placed online. The materials and training would cover different formats of the workshop (embedding it in another course, using it as part of responsible conduct of research training, or as a planned Broader Impact activity that could be written into technical research funding proposals). In curricular and extracurricular contexts where it is not possible to work with students over 16 contact hours, a few select activities from the workshop can be run with students on an ‘a la carte’ basis during orientation programs, at the beginning of capstone experiences for engineering students. For example, two of the authors were invited run two of the workshop activities in the early weeks of a senior undergraduate engineering, business, and design laboratory at the public university in the southwestern US to help students consider ways to look beyond technology when starting projects.

Although our original vision was to create a short workshop-style program (because engineering curriculums have little room for additional semester-long courses), we are also discussing ways to expand the workshop where curricula allow. We have identified at least two potential opportunities to do this: a planned university-wide course on Foundations of Community Engagement Course at one of the author’s home institution, and an elective course on community engagement for engineering masters students at another author’s home institution. One advantage of a longer course would be to expand the ground covered by the workshop. An expanded workshop might include not only the basics of understanding and framing problems with communities, but also methods and tools for collaboratively building visions for how the community might look when problems are solved, and designing strategies that motivated by a desire not only to solve a problem, but also to achieve a desirable future state. Another advantage of a longer course would be the possibility for students to establish a real relationship with a local community partner, through the long-term relationship of faculty, and work on an actual community engagement project during the course. This could be expanded into a practicum where students would work with a local partner over the course of multiple semesters, which in turn, could be a key component of a graduate certificate in Engineering and Community Engagement.

Conclusion

For a variety of reasons, technical students, be they engineers or scientists, often leave academic training programs underprepared to engage with communities and fully grapple with the challenges of 'global problem solving' to which they are often—and nobly—called. Recognizing this gap in the training of scientists and engineers, we set out to develop the Community Engagement Workshop. The Community Engagement Workshop provides technical students with an introduction to and experience with key knowledge and skills to engage with communities on engineering projects for development. We discussed a variety of challenges and opportunities for developing such a short-course, including the iterative process of program design, community and faculty partnership, and group work. Our findings indicate the Community Engagement Workshop is an efficacious means of advancing key lessons from the literature around listening to people, looking beyond technology, and empowering communities. As engineering and science fields continue to evolve to tackle 'grand challenges' facing humanity, it is increasingly important to prepare students to engage with the people intimately involved with these challenges; the

Community Engagement Workshop represents a step toward filling this engagement education gap.

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CHAPTER 5

CONCLUSION

'There will be no single policy intervention that can productively address all of these issues together, yet it is important to recognize that neither can they be considered or addressed separately ... there are many possible intervention points where relatively modest changes in policy or priorities might move things in the direction of stronger accountability and greater public value"

- Dan Sarewitz 2013 testimony to the U.S. House of Representatives committee on Science, Space, and Technology *(p. 11).*

Building from advances in sustainability science and social studies of science and technology, I have sought to contribute a means of designing, implementing, evaluating, and learning from intentional efforts to align scientific research and technological development with responsible innovation. As a first step, I asked how upstream interventions in the capacity, motivation, or opportunities available to people involved in science and engineering advance responsible innovation. In addition to offering a framework to develop and evaluate these upstream interventions, I presented the results of two interventions in the education and training of science and engineering graduate students. Drawing inspiration from the intervention research framework, I selected the Science Outside the Lab and Community Engagement Workshop program based off high scores for external and internal (to the researcher/research team) feasibility criteria (Chapter 2, Tables 1 and 2).

External barriers to the Science Outside the Lab and Community Engagement Workshop programs were low; each program fit plausibly within educational paradigms of science and engineering education. External assets were also supportive of the two programs I selected: each program already had approval to run; established participant networks or recruitment protocol; mode of content delivery; and were far enough out on the horizon so as to allow for development of evaluation materials. Finally, each program addresses root aspects of systemic challenges in science and engineering education: Science Outside the Lab the macroethical questions about the relationships among science and society; the Community Engagement Workshop about vital skills and practices to avoid presupposing community problems and solutions when undertaking development work. Having each program target early-career graduate students was also critical to addressing a root aspect of the system, as these students go on better aware of and prepared to engage the dilemmas of orientation, legitimacy, and control they are sure to encounter in future endeavors.

Pertaining to internal criteria, for each program I had strong relationships with the implementation teams (relationship scores: 2). Each program had a track record of being successfully run (asset scores: 2). Finally, each program had firm support from either a center (Community Engagement Workshop) or from self-sufficiency (Science Outside the Lab) (barriers score: 2). My work leveraged the normative and analytical approaches to solution development in inter- and trans-disciplinary contexts from sustainability (Kates et al., 2001; Clark 2007; Miller et al., 2013) and critical lenses and from social studies of science and technology (Marx 1987; Pinch and Bijker 1987; Latour 1992; Jasanoff 2004; Woodhouse and Sarewitz 2007; Sarewitz and Nelson 2008).

The intervention research framework for responsible innovation presents a means to intentionally redirect 'our technological systems and projects in ways inspired by democratic and ecological principals' (Winner 1993, p. 311). Educating scientists and engineers outside the lab can help mend rifts between science and society perpetuated by received, narrow ideologies about these relationships—ideologies perpetuating dilemmas of orientation, legitimacy, and control. As engineering and science fields continue to evolve to tackle "grand challenges," it grows increasingly important to prepare students to engage with the people intimately involved with these challenges; the Community Engagement Workshop represents a step toward filling this engagement education gap. Related, the work of Science Outside the Lab demonstrated that macroethics education programs can help scientists and engineers better understand the complexities and nuance of science policy, and that these efforts—and their rewards—are within grasp of researchers and educators. Combined, these efforts demonstrate the kinds of actions available to addressing dilemmas of orientation, legitimacy, and control through interventions for responsible innovation. In addition, and as discussed in the conclusions of Chapters 3 and 4, establishing the proof-of-concept for each of these programs is an important first step for scaling. The Science Outside the Lab model of engaging diverse practitioner communities to reveal the marriage of facts and values and the diverse roles of expertise can be extended outside of Washington, DC to cities, states, rural development operations, businesses, and other enterprises. The Community Engagement Workshop could be expanded through a "train the trainer" effort, eventually embedding as a pre-requisite training module for engineering curricula fieldwork requirements. Creative consideration of the above and future interventions to scale these programs offers a promising avenue for future research and development.

Reflections on Intervention Research and Portfolio Approach

An intervention research approach to addressing dilemmas in governing scientific research and technology development offers versatility, flexibility, and responsiveness to different understandings of efficacious management for societal aspirations. The framework advances an empirical approach that can test, as hypotheses for research management, the many recommendations placed in the conclusion sections of research articles. By delineating different mechanisms operating across innovation activities—human capacity and motivation, and social and physical environmental factors—applying and studying recommendations can begin to fill out the knowledge landscape of what might work and why in the governance of science and technology for sustainability. For example, figure 1 presents a small sample of other interventions that already exist at upstream, midstream, and downstream points in innovation processes. The efforts come from different paradigms but share the potential for offering insights through comparison using the intervention research framework for responsible innovation. The framework can facilitate review of different interventions at different phases of innovation processes, coupled with comparative analysis of the responsible innovation treatments, targets, outcomes, augmentations from sustainability science, and dilemmas tackled. Through comparison of the tradeoffs associated with different interventions, researchers and practitioners can come together to more systematically design and coordinate responsible innovation interventions for sustainability.

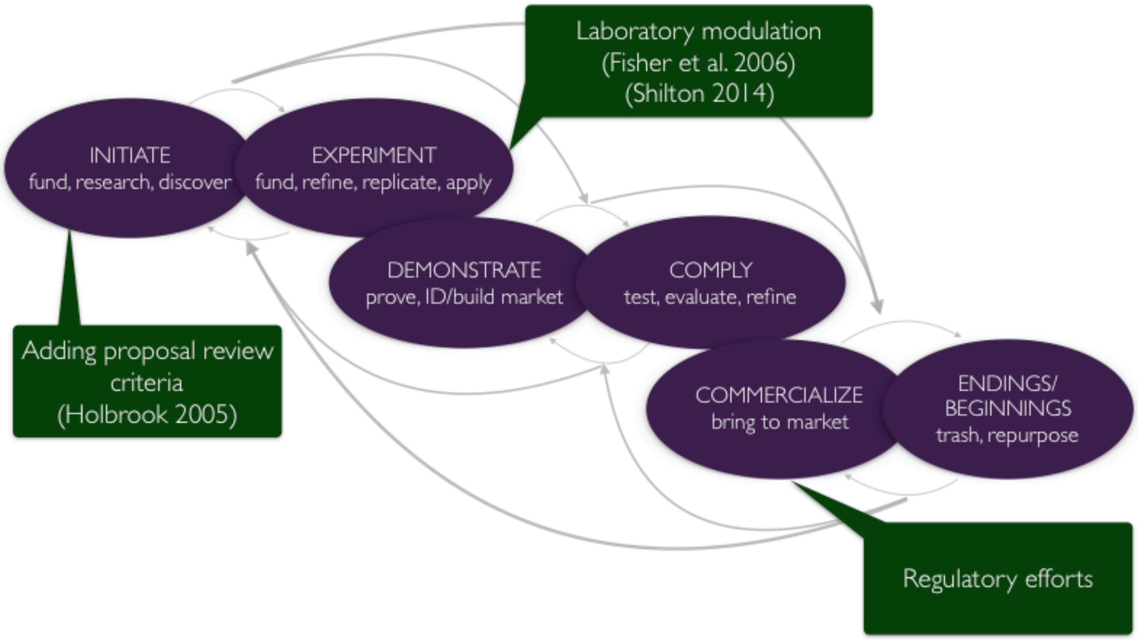
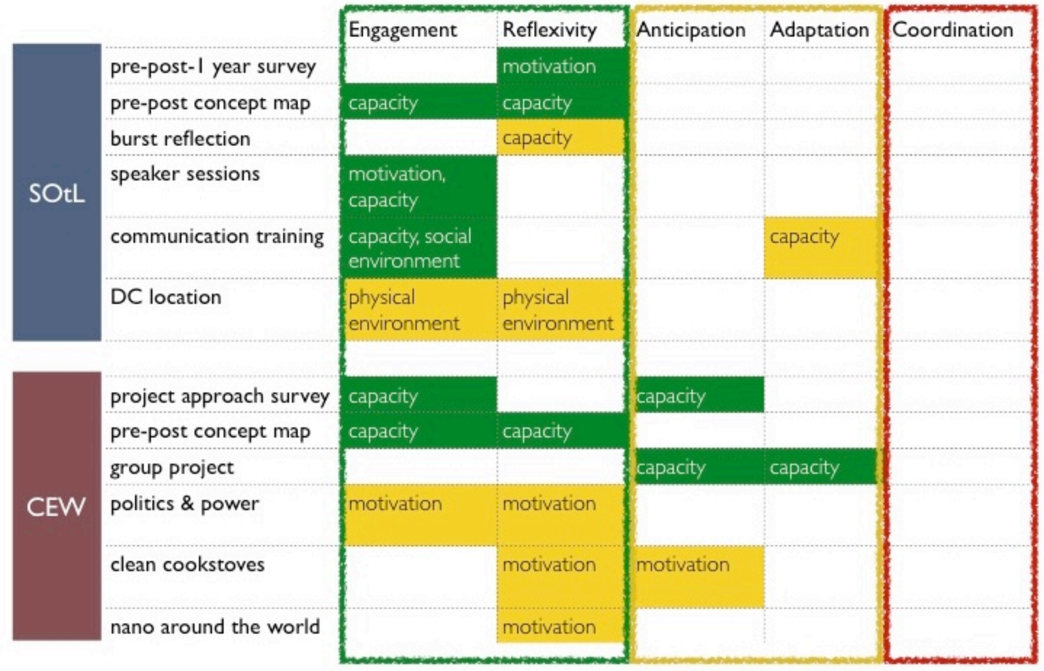


Figure 1: Presentation of example additional interventions already in place that could be compared using the intervention research framework.

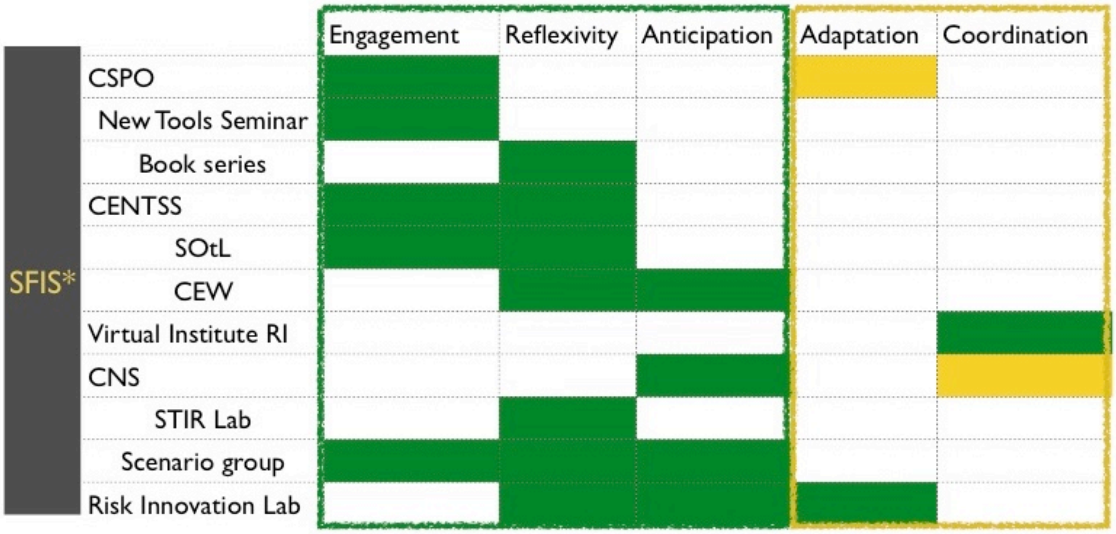
Using the framework to compare Science Outside the Lab and the Community Engagement Workshop begins to reveal differing returns on different interventions (Figure 1). Science Outside the Lab offered a two-week immersive experience of constant discussions that challenged Ph.D. science and engineering students received ideas about science and society relationships. Community Engagement Workshop offered a two-day workshop packed with rapid, facilitated experiences, a group project, and a small number of guest speakers to help science and engineering graduate students look beyond technological aspects of problems to consider human elements of individuals and their communities. Each program sparked student inquiry into otherwise unexamined beliefs about science and society relationships—that experts have firm grasps of problems facing and solutions needed by communities, that experts are best positioned to direct policy processes, and that benefits of science and engineering advances will inevitably flow to society. Combined, the programs most strongly offer opportunities for enhancing student capacity in reflexivity through appreciation and experience of engagement. As educational exercises, the ability to build adaptive capacity is limited, although iterations around group projects in the Community Engagement Workshop offer students a chance to revise their products based on lessons learned earlier in the workshop. Neither program places especial emphasis on anticipation or coordination, suggesting needs for responsible innovation program development around these areas.



		Engagement	Reflexivity	Anticipation	Adaptation	Coordination
SOtL	pre-post-1 year survey		motivation			
	pre-post concept map	capacity	capacity			
	burst reflection		capacity			
	speaker sessions	motivation, capacity				
	communication training	capacity, social environment			capacity	
	DC location	physical environment	physical environment			
CEW	project approach survey	capacity		capacity		
	pre-post concept map	capacity	capacity			
	group project			capacity	capacity	
	politics & power	motivation	motivation			
	clean cookstoves		motivation	motivation		
	nano around the world		motivation			

Figure 2: Comparison of Science Outside the Lab (SOtL) and Community Engagement Workshop (CEW) program strengths and gaps.

Taking an institute-level view, the above insights prove useful for strategy development. For example, within the Institute for the Future of Innovation in Society (Figure 2), an organization like the Center for Engagement and Training of Scientists and Engineers demonstrates strengths in building student capacities for reflexivity and engagement (tackling dilemmas of orientation and legitimacy). These strengths could be leveraged to build student capacity in adaptation by combining Science Outside the Lab- and Community Engagement Workshop -like-programs with course projects, or dissertation or thesis requirements, not unlike how University of Virginia requires all undergraduate engineers to write a chapter incorporating reflections on their work from science and technology studies. So integrated, early lessons sparked by Science Outside the Lab and Community Engagement Workshop might offer a chance for science and engineering students to act responsively to advance responsible innovation through their research. Gaps in anticipation and coordination capacity building, however, might suggest to the Institute that a risk innovation group focus on capacities in anticipation and coordination—facilitating scenario development across networks of entrepreneurs, technology developers, regulators, inserts groups, and civil entities (tackling dilemma of control). Efforts by the Center for Nanotechnology in Society, in its final year, to re-convene a series of scenario exercises offers the opportunity to study how anticipatory capacity translates to responses and adaption in research over time.



		Engagement	Reflexivity	Anticipation	Adaptation	Coordination
SFIS*	CSPO	🟩			🟨	
	New Tools Seminar	🟩				
	Book series		🟩			
	CENTSS	🟩	🟩			
	SOtL	🟩	🟩			
	CEW		🟩	🟩		
	Virtual Institute RI					🟩
	CNS			🟩		🟨
	STIR Lab		🟩			
	Scenario group	🟩	🟩	🟩		
	Risk Innovation Lab		🟩	🟩	🟩	

* indicates anecdotal summary, not based on in-depth research

Figure 3: Hypothetical snapshot of the portfolio of the School for the Future of Innovation in Society

Going further, strategic insights from the intervention research framework also accrue by considering the position of activities across the spectrum of innovation processes. The Institute might recognize that a portfolio could be biased toward upstream and midstream interventions. With this insight, strategic partnerships could be then built with research groups focused on regulatory science, public policy, law, and marketing to ensure that downstream interventions are also pursued and researched. Implicit here is the acknowledgement that the university unit may not be the appropriate home for unilateral interventions in adaptation or coordination capacities, for example.

Of course, none of the above information is free. Strategic operationalization of an intervention research approach to responsible innovation requires forethought and investment of human resources to develop, implement, monitor, and adapt interventions over time. Developing a portfolio approach to intervention research in social studies in science and technology could use indicators of the five responsible innovation capacities and three normative aspirations to recognize that while no project need account for *all* aspects for responsible innovation; *all* aspects should nonetheless be considered across a portfolio *for each phase* of innovation. Systematically building such a body of knowledge would allow for greater specification of theories about how efficacious and effective science and technology governance efforts for sustainability.

The goal of such a systematic approach would be to capture the diversity of efficacious and effective practices available for conducting responsible innovation for sustainability. The result is not about homogenization or standardization, but rather learning and building knowledge around the appropriateness of different approaches for different contexts. As public choice theory suggests (Ostrom and Ostrom 1971), heterogeneous approaches of heterogeneous entities serves a key function in democracy: better serving heterogeneous constituents. However, variability need not mean ignorance. Better coordination and information sharing advanced through a systematic approach to interventions could provide large payoffs in a resource-constrained environment. Indeed, as public science and technology funding bodies come under increasing pressure to demonstrate value to Congressional appropriators and publics, one has a hard time imagining pressure for more strategic and measured approaches to research governance being far off.

Foundations in inter- and trans-disciplinary work, collaboration, engagement, and solution orientation for sustainability, developed in the course of this dissertation, will be instrumental to conducting future research at the intersections of sustainability science and studies of science and technology. Any single intervention to advance responsible innovation for sustainability will be insufficient. Intentional change for responsible innovation will be a complicated, if not complex act of balancing multiple strategic, tactical, and operational concerns (Loorbach 2010). Future work must ask how upstream, midstream, and downstream interventions effect change over time and, ultimately, keep at bay the Cerberus of dilemmas, orientation, expertise, and control, in science and technology governance.

Insights from behavioral sciences and social studies of science and technology studies can be leveraged to point out potentially promising intervention points (i.e., have high-scores on the external and internal feasibility criteria proposed in Chapter 2). Attention might best be paid to systemically linked interventions. Working with public research program managers from different Federal agencies to integrate responsible innovation activities for sustainability into solicitation documents or review criteria offers one example. Such an act, inherently political, would benefit from a broad movement of support, entailing mobilization of interest groups marginalized by the current science and innovation status quo, as well as outreach to interest groups who benefit from the status quo (intervention research of political action for responsible innovation). Building the case for this type of highly-linked systemic change could be done by regularly soliciting expert and informed citizen input on the values, needs, and potential directions for research and innovation (intervention research on extended-peer (Funtowicz and Ravetz 1993) science advisory groups for responsible innovation). Such top-down interventions could be partnered with education and training of scientists and engineers (from early K-12 to graduate to professional education) in the spirit of Science Outside the Lab and the Community Engagement Workshop programs (intervention research on education and training of STEM workforce for responsible innovation). If the above proposals for intervention research sound over-reaching, I would encourage the reader to reflect on the fact that *all of these leverage points currently exist to advance the dominant paradigms of science-society relationships that have contributed to sustainability crises the world over.*

If one is serious about advancing responsible innovation, one must seriously reflect on the system of the status quo—its content and architecture, its form and function, its inputs and outputs, its byproducts, and all its complexity. For a system as large and complex as that of the techno-scientific enterprise, the need for commensurate complexity of interventions to enact change should come as no surprise (Ostrom 2007). The difficulty of selecting among seemingly incomparable research programs—the so-called "chalk and cheese" problem of scientific choice (Toulmin 1964)—remains. A problem-solving approach that spans disciplines and sectors of society—as done in sustainability and as championed through Arizona State University's vision for the New American University—attempts a plausible re-orientation for public research and larger knowledge endeavors (Crow and Dabars 2015). Such a re-orientation necessarily situates science, among other societal efforts, in dialogue among societal actions and societal aspirations. The dialogue entails inclusion, reflection, anticipation, coordination, intention, action, monitoring, and adaptation. Intervention research offers a promising platform for thoughtfully advancing responsible innovation for sustainability.

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APPENDIX A

CHAPTER 3 SURVEY SCALES AND RELIABILITY ANALYSIS

QUESTION	**POLARITY**	**SCALE**	**CRONBACH ALPHA**
The primary role of my research is to inform policy debates.	REG	policy debates	0.719
The primary role of science and engineering research is to inform policy debates.	REG	policy debates	
Informing policy debates is not the primary role of my research.	REV	policy debates	
Informing policy debates is not the primary role of science and engineering research.	REV	policy debates	
The knowledge I provide should be used to help solve societal challenges.	REG	social impact	0.670
The knowledge created by scientists and engineers should be used to help solve societal challenges.	REG	social impact	
The knowledge I provide should not be used to help solve societal challenges.	REV	social impact	
The knowledge created by scientists and engineers should not be used to help solve societal challenges.	REV	social impact	
As a scientist or engineer, I am not best positioned to provide insight for setting science and engineering policy priorities.	REG	policy priorities	0.823
Scientists and engineers should not define the priorities for science and engineering policy.	REG	policy priorities	
As a scientist or engineer, I am best positioned to provide insight for setting science and engineering policy priorities.	REV	policy priorities	
Scientists and engineers should define the priorities for science and engineering policy.	REV	policy priorities	
I should engage with policymakers to ensure that political debate is informed by the best available knowledge.	REG	personal involv	0.690
Scientists and engineers should engage with policymakers to ensure that political debate is informed by the best available knowledge.	REG	personal involv	
I should not get involved in science and engineering policy making or political processes.	REV	personal involv	
Scientists and engineers should not get involved or participate in science and engineering policy debates.	REV	personal involv	
My research clearly demonstrates the need for certain policy decisions.	REG	specific policies	0.707
Science and engineering research clearly demonstrates the need for certain policy decisions.	REG	specific policies	

My research does not demonstrate the need for any particular policy decisions.	REV	specific policies	
Science and engineering research does not demonstrate the need for any particular policy decisions.	REV	specific policies	
My research findings could be used as justification for a variety of political interests and I should be concerned about those outcomes.	REG	research use	0.752
Science and engineering research findings can be used as justification for a variety of political interests and the research community should be concerned about these outcomes.	REG	research use	
My research findings might be used as justification for a variety of political interests but that is not my concern.	REV	research use	
Science and engineering research findings might be used as justification for a variety of political interests but that is not the concern of the researchers.	REV	research use	
Providing a policy maker with more technical information will not equip him or her to make a better decision.	REG	technical info	0.750
Providing a policy maker with more technical information will equip him or her to make a better decision.	REV	technical info	
Policy questions should not be tackled in a scientific manner.	REG	scientific method*	0.816
Policy questions should be tackled in a scientific manner.	REV	scientific method*	
Science and engineering research is not the most important factor for shaping science and engineering policy.	REG	primacy of science	0.711
Science and engineering research is the most important factor for shaping science and engineering policy.	REV	primacy of science	
The generation of knowledge or engineered systems alone is not enough to justify the value of science and engineering research.	REG	value of science	0.758
The generation of knowledge or engineered systems alone justifies the value of science and engineering research.	REV	value of science	
Scientific and technological advances are necessary but not sufficient for resolving science and engineering policy debates.	REG	necessary vs sufficient	0.607

Scientific and technological advances are necessary and sufficient for resolving science and engineering policy debates.	REV	necessary vs sufficient	
The most important factor in resolving science and engineering policy debates is considering what different people believe and want.	REG	beliefs and wants	0.224
Considering what different people believe and want is irrelevant to resolving science and engineering policy debates.	REV	beliefs and wants	
Science and engineering research cannot alone be used to justify one policy over another.	REG	policy justification	0.603
Science and engineering research alone can be used to justify one policy over another.	REV	policy justification	
The basic research I conduct improves society merely by existing as a potential resource.	REG	linear model	0.694
Basic scientific research informs technical design and engineering applications, which yield societal benefits.	REG	linear model	
My work should be funded because it both creates new knowledge and advances public well-being.	REG	linear model	
When science makes discoveries, it paves the way for technology to be developed and society benefits as a result.	REG	linear model	
Opinions and cultures of organizations are the dominant factors shaping the way information is used in science and technology policy debates.	REG	meta1	n/a
Scientists and engineers represent one of many special interests competing to shape science and technology policy.	REG	meta2	n/a

*scientific method scale subsequently discounted because the items were deemed overly ambiguous

APPENDIX B

IRB APPROVALS FOR RESEARCH

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Ira Bennett
CSPO: Science, Policy, and Outcomes, Consortium for
480/727-8830
Ira.Bennett@asu.edu

Dear Ira Bennett:

On 4/9/2014 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	A Quantitative and Qualitative Study on the Impacts of the 'Science Outside the Lab' Science Policy Workshops
Investigator:	Ira Bennett
IRB ID:	STUDY00000947
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Separate 2014 group consent form with program details.pdf, Category: Consent Form; • SOtL Study HRP-503 Protocol.docx, Category: IRB Protocol; • Protocol 2_Reflection essays.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3_Perspectives Test.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4_Concept mapping.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 6_Burst Reflection.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 8_Solicitation to speakers.pdf, Category: Measures (Survey questions/Interview questions

	/interview guides/focus group questions); • Protocol 1_Demographic survey.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 2_Reflections essays protocol.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3_Perspectives Test Survey.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4_Concept map framework printout.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 5_Participant observation.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 7_Group debrief.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 1_Recruiting strategies for 2014 experimental group.pdf, Category: Recruitment Materials; • Protocol 1_Demographic survey recruiting.pdf, Category: Recruitment Materials; • SOtL Study Design Table (2014).pdf, Category: Resource list; • SOtL Study Design Table (longitudinal).pdf, Category: Resource list; • Protocol 1_Example control construction.pdf, Category: Technical materials/diagrams;

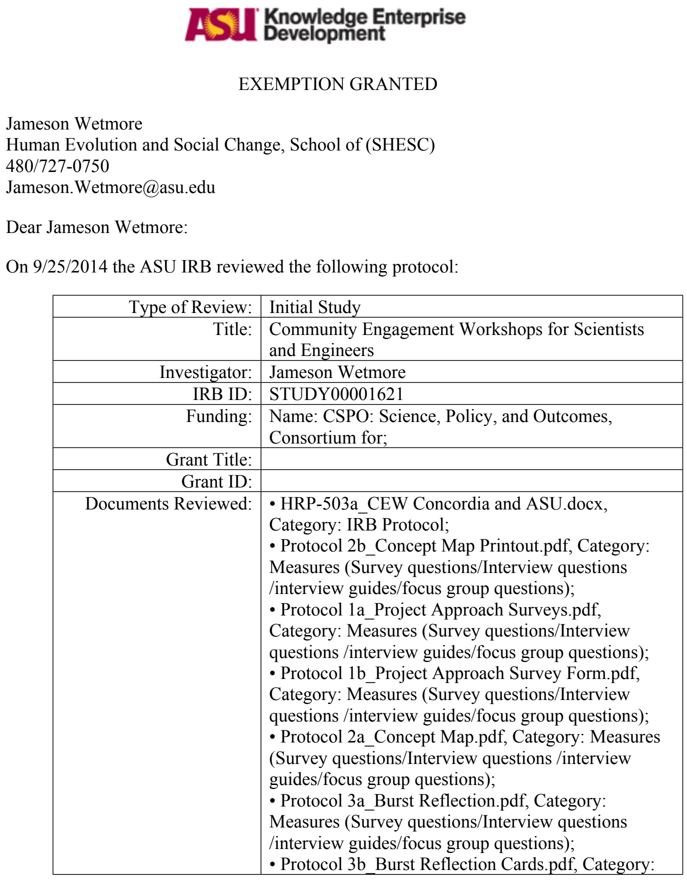
The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 4/9/2014.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Kiera Reifschneider
Kiera Reifschneider
Michael Bernstein



ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Jameson Wetmore
Human Evolution and Social Change, School of (SHESC)
480/727-0750
Jameson.Wetmore@asu.edu

Dear Jameson Wetmore:

On 9/25/2014 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Community Engagement Workshops for Scientists and Engineers
Investigator:	Jameson Wetmore
IRB ID:	STUDY00001621
Funding:	Name: CSPO: Science, Policy, and Outcomes, Consortium for;
Grant Title:	
Grant ID:	
Documents Reviewed:	• HRP-503a_CEW Concordia and ASU.docx, Category: IRB Protocol; • Protocol 2b_Concept Map Printout.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 1a_Project Approach Surveys.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 1b_Project Approach Survey Form.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 2a_Concept Map.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3a_Burst Reflection.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3b_Burst Reflection Cards.pdf, Category:

	Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4a_Group Project.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4b_Group Project handout.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4c_Group Project Assessment Form.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 5_Group Debrief.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Activities 3_CEW Light Switch.pdf, Category: Other (to reflect anything not captured above); • Activities 4_CEW Nano and Ghanaian Village Slides.pdf, Category: Other (to reflect anything not captured above); • Activities 5_CEW AgreeDisagree.pdf, Category: Other (to reflect anything not captured above); • Activities 6_CEW El Cajon Dam case.pdf, Category: Other (to reflect anything not captured above); • Activities 7_CEW Listening Skills slides.pdf, Category: Other (to reflect anything not captured above); • Activities 8a_CEW Politics advocacy exercise.pdf, Category: Other (to reflect anything not captured above); • Activities 8b_CEW Politics advocacy exercise.pdf, Category: Other (to reflect anything not captured above); • Activities 0_CEW Agenda for Students.pdf, Category: Other (to reflect anything not captured above); • Activities 1_CEW Detailed Agenda for Researchers.pdf, Category: Other (to reflect anything not captured above); • Activities 2_CEW Introductions and Overview.pdf, Category: Other (to reflect anything not captured above); • CEW Concordia and ASU Study Design Table.pdf, Category: Other (to reflect anything not captured above); • Recruiting 1_to Students.pdf, Category: Recruitment Materials;

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Ira Bennett
CSPO: Science, Policy, and Outcomes, Consortium for
480/727-8830
Ira.Bennett@asu.edu

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Title:	A Quantitative and Qualitative Study on the Impacts of the 'Science Outside the Lab' Science Policy Workshops
Investigator:	Ira Bennett
IRB ID:	STUDY00000947
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Separate 2014 group consent form with program details.pdf, Category: Consent Form; • SOtL Study HRP-503 Protocol.docx, Category: IRB Protocol; • Protocol 2_Reflection essays.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3_Perspectives Test.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4_Concept mapping.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 6_Burst Reflection.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 8_Solicitation to speakers.pdf, Category: Measures (Survey questions/Interview questions

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	• Recruiting 2_to Facutly.pdf, Category: Recruitment Materials; • Grant Renewal Proposal 2011-2015 without financial information.pdf, Category: Sponsor Attachment;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 9/25/2014.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Michael Bernstein
Michael Bernstein

	/interview guides/focus group questions); • Protocol 1_Demographic survey.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 2_Reflections essays protocol.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 3_Perspectives Test Survey.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4_Concept map framework printout.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 5_Participant observation.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 7_Group debrief.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 1_Recruiting strategies for 2014 experimental group.pdf, Category: Recruitment Materials; • Protocol 1_Demographic survey recruiting.pdf, Category: Recruitment Materials; • SOtL Study Design Table (2014).pdf, Category: Resource list; • SOtL Study Design Table (longitudinal).pdf, Category: Resource list; • Protocol 1_Example control construction.pdf, Category: Technical materials/diagrams;

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Michael Bernstein

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Human Evolution and Social Change, School of (SHESC)
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Funding:	Name: CSPO: Science, Policy, and Outcomes, Consortium for;
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	Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4a_Group Project.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4b_Group Project handout.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 4c_Group Project Assessment Form.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Protocol 5_Group Debrief.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Activities 3_CEW Light Switch.pdf, Category: Other (to reflect anything not captured above); • Activities 4_CEW Nano and Ghanaian Village Slides.pdf, Category: Other (to reflect anything not captured above); • Activities 5_CEW AgreeDisagree.pdf, Category: Other (to reflect anything not captured above); • Activities 6_CEW El Cajon Dam case.pdf, Category: Other (to reflect anything not captured above); • Activities 7_CEW Listening Skills slides.pdf, Category: Other (to reflect anything not captured above); • Activities 8a_CEW Politics advocacy exercise.pdf, Category: Other (to reflect anything not captured above); • Activities 8b_CEW Politics advocacy exercise.pdf, Category: Other (to reflect anything not captured above); • Activities 0_CEW Agenda for Students.pdf, Category: Other (to reflect anything not captured above); • Activities 1_CEW Detailed Agenda for Researchers.pdf, Category: Other (to reflect anything not captured above); • Activities 2_CEW Introductions and Overview.pdf, Category: Other (to reflect anything not captured above); • CEW Concordia and ASU Study Design Table.pdf, Category: Other (to reflect anything not captured above); • Recruiting 1_to Students.pdf, Category: Recruitment Materials;

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