

The Impact of a Design Workshop on the Quality of Educational Outreach Products and
Clean Energy Fellows' Knowledgeability of the Broader Impacts of their Research

by

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ABSTRACT

While deep disciplinary knowledge will be required to develop next-generation clean energy technologies, the skills to work across disciplines and with diverse stakeholders will also be required. Providing authentic and explicit opportunities for graduate students in science, technology, engineering, and math (STEM) to engage in the broader impacts (BI) of their research could support the development of these skills. A concurrent mixed methods action research study was conducted to evaluate the effects of a three-part, semi-structured design workshop on clean energy fellows' knowledgeability of the broader impacts of their research, their identification with the clean energy field, and their ability to develop high-quality educational outreach products. This study was grounded in a sociocultural theory of learning and informed by several conceptual frameworks: situated learning (Lave & Wenger, 1991), communities of practice (Wenger, 1998), and knowledgeability (Wenger-Trayner & Wenger-Trayner, 2015). Quantitative data was collected through a rubric and survey informed by guiding principles from the *Broader Impacts Review Document for National Science Foundation Proposals* (Center for Advancing Research Impact in Society, 2020). Qualitative data was collected through this survey and a focus group interview. Results demonstrated a significant, strong, and positive correlation between attendance at the design workshop attendance and Product of Lasting Value (PLV) quality. Unfortunately, the lack of respondents in the post-survey prevented the ability to quantify any changes that took place in fellows' knowledgeability of the BI of their research and their identification with the clean energy field due to the innovation. Yet, results from the focus group interview do show that some fellows experienced increased knowledgeability of the BI of their research and identification with the clean energy field, but these gains were not necessarily due to the PLV Design Workshop.

DEDICATION

This dissertation is dedicated to the friends and family who provided encouragement, love, and support throughout my doctoral journey during a pandemic. Thank you especially to Karen for all the sacrifices you made to help me make it through, including, but not limited to, getting a puppy during one of the busiest times of my life. I also dedicate this work in gratitude to the life and mentorship of Dr. Gary L. Chamberlain.

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CHAPTER 1

INTRODUCTION

Climate change is one of the most urgent, complex issues facing humanity today. Human influence on climate change is unequivocal and inextricably linked to energy production and consumption. Climate change, and humans' response to it, are also matters of equity. The most vulnerable communities are disproportionately affected by climate change despite contributing the least to its causes. Indeed, climate change is best classified as a wicked problem (Rittel & Webber, 1973). Because of this, there is no one clear path to a solution, and a rigid problem-solving approach will be futile (Jordan et al., 2014; Rittel & Webber, 1973).

As an educator supporting science, engineering, technology, and math (STEM) doctoral students who conduct clean energy research, I have a responsibility to ensure these future energy leaders can communicate across disciplines and with diverse stakeholders so that all have equitable and timely access to emerging science and technologies. In the chapter that follows, I discuss the larger context of climate change and the need for technologies related to the decarbonization of our energy infrastructure. I then highlight the role of the university in a constructive response to climate change and discuss the local context in which I can support the development of future energy leaders and innovators. I end by introducing an action research study I conducted to explore the effects of an intervention designed and implemented to support clean energy graduate fellows in their development of the skills necessary to positively contribute to clean energy solutions and the broader impacts of their research.

Larger Context

The Wicked Problem of Climate Change

Human influence on Earth's climate is unequivocal (Intergovernmental Panel on Climate Change [IPCC], 2018, 2021) and inextricably linked to humanity's use and production of energy (IPCC, 2014; Karl et al, 2009). One of the primary ways that humans have affected our climate is through the burning of fossil fuels and industrial processes (IPCC, 2014). These actions produce unnatural levels of carbon dioxide, a greenhouse gas that traps heat within Earth's atmosphere and causes land and water temperatures to rise (Earth Science Communication Team, n.d.). Despite the negative impact of fossil fuels, the world's main sources of energy are still oil, coal, and gas. In 2019, for instance, fossil fuels provided over 81 percent of the world's primary energy supply (International Energy Administration, 2021).

The effects of climate change have already been experienced by human and natural systems and will continue to worsen with increased warming (IPCC, 2018). Projected risks include negative impact on human health, livestock, and food security, as well as increases in the amount and intensity of heat waves, precipitation, and drought. Decarbonization of U.S. energy systems is critical, and the actions we collectively take in the next few years are crucial for reaching net-zero emissions in the US by mid-century (IPCC, 2018; Karl et al., 2009; Mackres, 2020; National Academies of Sciences, Engineering, and Medicine [NASEM], 2021). Achieving net-zero emissions in the US economy by 2050 would help limit our warming to the 1.5 degrees Celsius target and could “nearly eliminate adverse health impacts of fossil fuel use, which may be responsible for half a million premature deaths or more over the next decade—*public health impacts that fall disproportionately on low-income communities and communities of color* [emphasis added]” (NASEM, 2021, p. 4).

The Role of the University

In the report *Accelerating Decarbonization of the U.S. Energy System*, a cross-disciplinary consensus committee discussed the most critical actions for the 2020s to achieve the deep decarbonization we need (NASEM, 2021). They proposed

a social contract for deep decarbonization as a broadly shared understanding among the energy industry; local, state, and federal Governments; and U.S. families, businesses, workers, and communities to support efforts to advance a transition to a carbon-neutral U.S. economy so long as that transition meets societally determined criteria. (National Academies of Sciences, Engineering, and Medicine, 2021, p. 121).

This social contract will need to be created through engagement with diverse communities and deliberate attention to those who have borne the brunt of the burden of climate change (NASEM, 2021, p. 121). Thus, both technological and societal advances are necessary for the energy transformation required to prevent further climate change requires.

The suggestion of a social contract is appropriate for a wicked problem like climate change that requires more than just a technical fix. Wicked problems defy definition, singular solutions, and clear tests of completion (Rittel & Webber, 1973). As Rittel and Webber (1973) describe, they are unique, interconnected with other issues, and interpreted differently depending on one's worldview. It is also not possible to identify an exhaustive list of solutions to wicked problems, and solutions that are proposed are evaluated as either better or worse, not right or wrong (Rittel & Webber, 1973). Thus, authentic engagement with the diverse stakeholders who bring multiple perspectives to the issue of climate change is critical to sustainable solutions.

Education and universities, in particular, have a unique role to play in the response to these complex energy challenges (Colombo & Mattarolo, 2017; NASEM, 2021). Decarbonization will require a substantial increase in solar and wind production, the electrification of sectors that typically run on fossil fuels, the development of infrastructure to support renewable technologies, and further innovation in the clean energy arena (NASEM, 2021, p. 47). University research can continue to foster necessary advances and innovation in clean energy technology. Universities are also well-positioned, based on their regional context and mission, to serve the public good to help foster the paradigm shift required to promote sustainable and equitable energy development (Colombo & Mattarolo, 2017).

To be a part of the solution, however, universities will need to create spaces where interdisciplinary innovation can take place with authentic engagement from communities typically left out of energy-related decision making. While deep disciplinary knowledge will be required to develop next-generation clean energy technologies, the skills to work across disciplines and with diverse stakeholders will also be required. The authors of *Accelerating Decarbonization of the U.S. Energy System* propose an equitable distribution of scholarships that

should include appropriate training in skills in interdisciplinary research and communication, as well as collaboration with industry, government, and civil society stakeholders, in order to ensure that researchers are prepared to work effectively in teams on use-inspired research that contributes meaningfully to the needs of society and the economy. (NASEM, 2021, p. 220)

These suggestions will require higher education institutions to adopt a less siloed approach to students' education and to embed authentic curricular opportunities to develop these skills. The good news is that many institutions are prepared for this

holistic approach to education and regionally informed research and development of clean energy technologies.

Local Context

In 2013, the University of Washington (UW) founded the Clean Energy Institute (CEI) with state funds to “accelerate the adoption of a scalable and equitable clean energy future that will improve the health and economy of our state, nation, and world” (CEI, 2020, About section). CEI actualizes this mission through financial and technical support for interdisciplinary, cutting-edge research in next-generation solar energy, batteries, and advanced materials, and integration of these materials with the grid. To foster the adoption and scalability of clean energy technologies, the institute brings together industry, faculty, and students with access to world-class research facilities and events that foster cross-disciplinary conversations about clean energy technology. Additionally, CEI offers myriad educational programs intended to support “the next generation of clean energy leaders and innovators” (CEI, 2020, Education section) through research experiences for graduate students, undergraduate students, and community college teachers, and outreach to K-12 students.

Problem of Practice

The CEI Graduate Fellowship provides financial and professional development support to doctoral students to encourage innovative clean energy research, develop fellows’ science communication skills, and increase public awareness and understanding of clean energy issues (CEI, 2020, CEI Graduate Fellowship section). The purpose of this fellowship is to support the advancement of clean energy research and “to prepare and empower the next generation of clean energy leaders and innovators to have broader impacts on society for example, through technology transfer and commercialization, education and public outreach, science communication and mentorship” (CEI, 2020,

CEI Graduate Fellowship section). University doctoral students are eligible to apply for one to four quarters of financial support to conduct original clean energy research. Fellows awarded support are also required to participate in the interdisciplinary seminar series, at least two outreach events, and the development of a Product of Lasting Value (PLV).

The purpose of this PLV requirement is to provide fellows with experience attending to the broader impacts of their research and to produce educational products that can advance understanding of clean energy sciences. In theory, this design project has the potential to positively contribute to the growth of future energy leaders, or CEI Graduate Fellows, and to disseminate information about clean energy research to our broader community. As mentioned above, the goal of the PLVs is to provide “fellows with experience in broader impact programs and products” as well as to add “to our library of materials that CEI can share with the scientific community and the public” (CEI, 2020, CEI Graduate Fellowship section). In the past, graduate fellows have been expected to spend about 10 hours developing a product that CEI would then add to its list of resources, most of which are housed on CEI’s website. Final products have ranged from video tutorials on scientific techniques to K-12 lesson plans to wiki articles that explain aspects of clean energy research. Designing an educational project like a PLV can also provide fellows with an authentic opportunity to engage in dialogue across the boundaries of their discipline with scaffolded support from CEI. It is critical to an equitable energy transformation that future energy leaders and innovators can engage with diverse stakeholders. Further, annual dissemination of PLVs addresses the urgent need for clean energy research to be communicated quickly and broadly.

In 2020, I joined the CEI at UW as the Associate Director of Education & Workforce Engagement and one of my main responsibilities was to support the CEI

Graduate Fellowship program. I was intrigued by the PLV requirement and the potential for this to support the growth of CEI Graduate Fellows and disseminate clean energy research. After supporting one cohort of fellows with their design of PLVs, however, I observed several challenges with this requirement that inspired me to inquire more deeply into this problem of practice. First, there was a wide range in the quality of PLVs produced. Second, the open-ended nature of the project seemed to make the identification of a project idea overwhelming for many fellows. Third, a lack of infrastructure made it difficult for me to support fellows throughout the design process. Fellows typically design the PLV on their own time because this project is not associated with a class. Finally, it was unclear what growth CEI Graduate Fellows experienced from this project.

Research Cycle 1: A Systematic Review of PLVs

To explore this problem of practice more systematically, I conducted an initial cycle of research (Cycle 1) to gain a more comprehensive understanding of the PLV graduate fellowship requirement. Specifically, I was interested to know what types of products had already been designed and whether I would be able to gather any information about the intended audiences for these PLVs. I also hoped that a more in-depth review of PLVs would allow new questions and insights about PLVs to arise that might inform future research questions. This initial cycle of research was guided by the following research questions:

RQ 1: What products of lasting value (PLV) already exist?

RQ 2: How can these existing PLVs be categorized by product type (medium), intended audience, topic, and authorship?

RQ 3: What opportunities for growth or further research do these findings elicit?

To answer these research questions, I conducted a document analysis with existing PLVs that have been published on the CEI website. This research method “is a systematic procedure for reviewing or evaluating documents” (Bowen, 2009, p. 27) and has many advantages in my study. First, the data were readily and publicly accessible on our website, which allowed me to begin this cycle of research right away. Further, because I was new to this context and project, these documents provided historical context for me about the PLV requirement and ideas that could inform future questions. As Bowen (2009) summarizes, “documents provide background and context, additional questions to be asked, supplementary data, a means of tracking change and development, and verification of findings from other data sources” (pp. 30-31). Thus, document analysis was an appropriate method for this initial cycle of research.

The purpose of this document analysis was to conduct reconnaissance on the PLV graduate fellowship requirement. Specifically, I was interested in gaining a better understanding of the products that had been previously designed to elicit opportunities for growth and further research into this curriculum requirement. I gathered both quantitative and qualitative data to provide a more comprehensive perspective of this project. The documents analyzed were PLVs published on a specific webpage designed to host CEI’s library of PLVs. The PLVs are categorized by five different formats: videos, demonstrations, lessons, articles, and displays and events (CEI, 2020, Products of Lasting Value section). The most popular format for PLVs has been videos. In response to my first and second research questions, I found that 57 PLVs had been published on CEI’s website. The vast majority of these PLVs were created by an individual author (n=49), and videos were the most popular medium produced. Of the 57 PLVs reviewed, there were 30 videos, 12 articles, seven displays and events, five lessons, and three demonstrations. At the date of my initial review, there had been a total of 345,452 views

of the videos and the number of views per video ranged from 45 to 129,378. The oldest videos had been uploaded in August 2015 and the newest had been uploaded in May 2020. The dates of two videos were unknown.

I also gathered qualitative data about the intended audience and general purpose for each PLV. After an initial review of the PLVs, my coding of the intended audiences for each PLV showed that the number of products for the scientific community (n=22), public (n=21), and K-12 community (n=21) were balanced and that at least two PLVs did not fit into these three subcategories. After a second review of four PLVs, I identified some opportunities for growth or further research (RQ3). In particular, I wondered if the majority of PLVs really were designed for the scientific community. Second, I realized that inviting students to clarify their purpose for the PLV could be helpful. Asking fellows to identify the purpose of their PLV early in the design process, could support their ability to identify strategies help them address this purpose. Finally, the videos designed to demonstrate a process assumed that one would be replicating the study. From my recent experience with this project, I know that some students are interested in developing products that will be used to onboard new members to their lab. These are likely students early in their scientific career, and it is interesting to think about the creation of a PLV for novice scientists versus experienced scientists.

I found this document analysis to be an incredibly fruitful research method, especially for an initial cycle of research. Even though existing documents can be informative, their use in research tends “to be very *underutilized*” (Mertler, 2020, p. 139). One of the benefits of this collection of data was that I could continue to further analyze and review PLVs to inform the redesign of this project. Some of the main takeaways from this cycle of research included my intent to incorporate more attention to the purpose of PLVs and the assessment of achieving this purpose. In addition, I

became interested in reflecting upon whether more PLVs are produced for the scientific community because doing so is easier for those already in this community, or because there is a significant need to disseminate information about processes and equipment to members new to a particular lab or discipline through bridge artifacts.

Research Cycle 2: Clean Energy Fellow Interviews

This initial cycle of research was important for me to document and observe the products that had been developed over the years. Yet, I was still missing a deeper understanding of how fellows experience and perceive this project. Therefore, I conducted a second cycle of inquiry (Cycle 2) in fall 2021 to explore graduate fellows' experiences with the PLV fellowship requirement more formally (see Table 1 for a summary of these research cycles). The purpose of this research cycle was to gather reconnaissance on their experience and to identify ways to better prepare and support them during this project. PLVs should be related to both students' research and the clean energy field, so I also was curious to learn how students describe the connection between their research and clean energy. Cycle 2 was guided by the following research questions:

RQ 1: How do CEI Graduate Fellows connect their research to clean energy?

RQ 2: How do CEI Graduate Fellows perceive and experience the products of lasting value project?

RQ 3: What types of preparation and support would CEI Graduate Fellows find helpful for the development of a PLV?

To answer these questions, I conducted semi-structured interviews. In preparation for these interviews, I gained Institutional Review Board permissions from both Arizona State University and my work institution. (See Appendix A for IRB documents.) I then recruited participants using convenience sampling (Creswell & Guetterman, 2019) from the two cohorts with whom I have worked directly — the 2020-to-2021 cohort of fellows

who have already completed PLVs and the 2021-to-2022 cohort of fellows who had recently been informed of the project. I chose to work with these cohorts because I personally knew the educational context in which they developed or were introduced to the project. This also allowed me to gather reconnaissance on the graduate fellows' experiences with the PLV project from its start through its completion.

Table 1

Summary of All Cycles of Inquiry for this Study

Cycle	Research Questions	Research Action(s)
1	RQ 1: What products of lasting value (PLV) already exist? RQ 2: How can these existing PLVs be categorized by product type (medium), intended audience, topic, and authorship? RQ 3: What opportunities for growth or further research do these findings elicit?	Inventory of existing PLVs; Document Analysis of 4 PLVs
2	RQ 1: How do CEI Graduate Fellows connect their research to clean energy? RQ 2: How do CEI Graduate Fellows perceive and experience the products of lasting value project? RQ 3: What types of preparation and support would CEI Graduate Fellows find helpful for the development of a PLV?	Semi-structured, one-on-one interviews with 4 CEI Graduate Fellows
3	RQ1: How does the PLV Design Workshop increase the quality of products of lasting value? RQ2: How and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research? RQ3: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field?	Implementation and evaluation of a 3-part, semi-structured PLV Design Workshop

Four fellows participated in these interviews — two students who had already completed the project and two fellows who had yet to design their PLVs. To help facilitate the four interviews, I developed a semi-structured interview protocol with four questions and one subquestion (see Appendix B). The first two questions invited students to describe their academic and research backgrounds and how their current research uniquely contributed to the field of clean energy. The next two questions invited

students to share their current or past experiences with the PLV requirement and the types of support they believed would be helpful for this project. Each interview was conducted and recorded via Zoom (<https://zoom.us/>). I then transcribed the audio using Otter.ai software (<https://otter.ai/>). I conducted line-by-line initial coding with this transcript and wrote memos as needed. I then compiled these initial codes into a spreadsheet to perform a cycle of Focused Coding and wrote memos as needed.

While several strong concepts emerged from this data analysis, two concepts specifically related to my research questions for this cycle of research were identified: a *generous contribution of knowledge* and *PLVs as a dialectical project*. The first concept emerged from fellows' discussion of their current research. While all four interviewees were able to articulate how their research was connected to the clean energy field, they each also made it clear that the fundamental research they do is somewhat removed from clean energy applications. As one fellow mentioned, the "bridge" between their research and application is much longer than other scientists. What I found particularly impressive, and humbling, was the contribution that students are making to humanity's collective knowledge of matter and materials and the optimism that seemed to motivate their research. Another remarked that the projects they just completed were "improving our existing understanding ... of some properties of materials." Inherent in this hard work of creating new knowledge of materials was the potential for future applications of this knowledge to clean energy. This generous contribution of knowledge seems to embody hope, rigor, and futures thinking. For this action research study, it seems important to consider the length of the "bridge" between one's research and application to identify audiences that might most benefit from their products of lasting value.

The second theme to emerge that clearly related to this action research study was the perception of *PLVs as a dialectical project*. Overall, the design of PLVs involved

conflicting feelings, tensions, and contradictions. There was a palpable sense of this tension as students talked about their experiences with this project. These tensions ranged from wondering how to communicate highly specialized science and science that is still emerging in a product that may be disconnected from the audience. One student started by stating that PLVs were great but not necessary and ended by stating that they were necessary. This student also noted the inherent contradiction between a product of *lasting* value with *changing* science. In all four interviews, there was a recognition of both the value and limitations of this project.

The two interviewees who had already designed PLVs noted the tension of balancing research, graduate school, and this project. Important to my redesign of the PLV curriculum, they both ended up changing their initial ideas and “trimmed down” their ideas. One person’s idea shifted from creating a full lesson plan to a crafty, hands-on activity. The other ended up volunteering to help our outreach team create a video tour of their lab. This fellow noted that convenience of a “premade idea” and a structured project resulted in a less stressful project, though it also resulted in disappointment that they did not get to create a product they really cared about due to these time constraints. This made me realize that more support is needed during the ideation phase of designing PLVs and that semi-structured support throughout the project may be helpful to overextended doctoral students.

Overall, students recognized the value of the PLV requirement. Interestingly, each student associated the PLV with science communication. Students believed it is important to be able to communicate their science with others, and this importance seemed to transfer to the PLV requirement. There were many other takeaways that will inform the design of my innovation. For instance, one participant noted the helpfulness of last year’s peer feedback session, and others requested feedback from and interaction

with the target audience. I also learned that current fellows feel disconnected from their peers, encouraging me to create more opportunities and spaces for students to interact. Finally, fellows seemed to have little information about previous PLVs and how their own PLVs were used. This disconnect suggests more communication from me is critical for this project to be successful and rewarding for students.

Research Cycle 3: Redesigning the PLV Curriculum

These two initial cycles of research confirmed the potential for the PLV requirement to be a valuable learning experience for CEI Graduate Fellows and to generate content for a wider audience. This research also confirmed that fellows need more support throughout the design process and that the quality of PLVs is inconsistent. Yet, one question that remained was what fellows were gaining and learning from this program requirement. Considering the urgency around decarbonization and the promise of this design project, I conducted a third cycle of research to evaluate whether an innovation in the form of a workshop for CEI Graduate Fellows could better support the development of higher-quality products to bridge the divide between clean energy research and the public and support fellows' professional development. The PLV Design Workshop was developed as a three-part, semi-structured design workshop for CEI Graduate Fellows. It explicitly addressed the broader impacts of research and included engagement with potential users of these PLVs. The research questions that guided Cycle 3 were:

RQ1: How does the PLV Design Workshop increase the quality of products of lasting value?

RQ2: How and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research?

RQ3: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field?

These questions and the innovation were informed by several conceptual frameworks: communities of practice (Lave & Wenger, 1991; Wenger, 1998), knowledgeability (Wenger-Trayner & Wenger-Trayner, 2015), and boundary objects (Akkerman & Bakker, 2011; Star and Griesemer, 1989; Wenger, 1998). To answer these research questions, a concurrent quantitative and qualitative mixed methods action research design was employed to leverage the strengths of both qualitative and quantitative research methods.

In the chapters that follow, I discuss the theoretical and conceptual frameworks that are foundational to this study and outline the methodology for this research. Chapter two presents the theoretical perspectives guiding this study and chapter three outlines the methods employed to conduct this cycle of research. Chapter four then presents the data analysis and results by research question. Finally, chapter five discusses the research findings in greater detail, the limitations of this study, and implications of this research.

CHAPTER 2

THEORETICAL PERSPECTIVES GUIDING THIS STUDY

Graduate students in science, technology, math, and engineering (STEM) will be working on some of the most vexing challenges of our time. Most of these challenges require more than just a technical fix. For instance, the decarbonization of our energy infrastructure that is critical to address climate change (IPCC, 2018; Karl et al., 2009; Mackres, 2020; NASEM, 2021) will require both the research and development of new technologies as well as a “social contract for deep decarbonization” (NASEM, 2021, p. 121) to ensure equitable and acceptable decision making. Educators, like myself, who support the professional development of graduate STEM students have a responsibility to prepare these students to effectively engage in the broader impacts (BI) of their research.

This action research study was designed to explore how an extracurricular project, the design of a Product of Lasting Value (PLV), has the potential to help disseminate contemporary clean energy science quickly *and* support the development of skills graduate students will need to engage in the broader impacts of their research. In this chapter, I discuss the theoretical and conceptual frameworks that guided the development of this action research study and the PLV Design Workshop, an innovation designed to support CEI Graduate Fellows’ professional development and design of PLVs. First, I review recommendations from the Committee on Revitalizing Graduate STEM Education for the 21st Century (NASEM, 2018) and introduce the concepts of broader impacts (BI) and impact identity. Next, I introduce a sociocultural theory of learning and discuss three conceptual frameworks that have emerged from this field: situated learning, communities of practice (COP), and landscapes of practice. I then

discuss boundary objects as a tool for learning and as a way of conceptualizing the PLV requirement.

Graduate STEM Education and the Broader Impacts of Research

In response to concerns about students' lack of career preparation, the Committee on Revitalizing Graduate STEM Education for the 21st Century convened in early 2017 to review the status of graduate STEM education in the United States (NASEM, 2018). In a consensus study report, this committee noted that while students are graduating with a strong ability to perform disciplinary research, other professional skills are lacking. Both industry experts and students have expressed a desire for more “transferable professional skills” such as “science communication, entrepreneurship, leadership, management, outreach, and the ability to work as part of an interdisciplinary team” (NASEM, 2018, p. 112). To better prepare students, experts from this committee recommended a shift in graduate STEM education programs to become more student-centered rather than institution-centered (NASEM, 2018). The authors also recommended that doctoral programs find ways to reflect the dynamism of the STEM field in their programs, become more inclusive, and periodically review their requirements and curriculum. Ideally,

students would have opportunities to communicate the results of their work and to understand the broader impacts of their research. This includes the ability to present their work and have exposure to audiences outside of their department, ranging from peers in other departments to the broader scientific community and nontechnical audiences. Students would also understand and learn to consider ethical and cultural issues surrounding their work, as well as the broader needs of society. (NASEM, 2018, p. 4)

This focus on broader impacts (BI) is aligned with the review criteria of one of the nation’s major funding institutions — the National Science Foundation (NSF). The NSF was created in 1950 by Congress as an “independent federal agency” to progress science and advance the health, security, and prosperity of the nation (NSF, n.d., About: At a Glance section). Each year, the agency receives more than 42,000 grant proposals (NSF, n.d., How We Work section) and awards about 12,000 new proposals (NSF, n.d., About: At a Glance section). To vet these proposals, NSF (NSF, n.d., About: How We Work section) uses a highly competitive and rigorous merit review process based on two criteria — intellectual merit and BI, or the potential for science to “benefit society” (NSF Proposal & Award Policies & Procedures Guide [NSF PAPPG], 2020, p. II-10).

Despite a growing value for the BI of research by NSF and other agencies (Risien & Storksdieck, 2018), more support for the successful implementation of BI activities is needed. In the National Alliance for Broader Impacts’ (NABI) 2018 report, *Current State of Broader Impacts: Advancing Science and Benefiting Society*, several recommendations were posited by stakeholders involved in BI activities. Some of these recommendations were related to a need for increased clarity from the NSF about the broader impact criterion of grant proposals while others were related to a need for increased support at the “individual, institutional, and national levels” (p. 4). In addition, it was suggested that educating those involved in BI activities about NSF’s BI criteria and building principal investigators’ (PI) “BI capacity” were “crucial to advancing BI” (NABI, 2018, p. 4).

One approach for building this capacity is to support the development of scientists’ “impact identity,” which Risien and Storksdieck (2018) describe as “a concept that integrates scholarship in a scientific discipline with societal needs, personal preferences, capacities and skills, and one’s institutional context” (p. 58). They suggest

that both scientists and their audience will benefit if a researcher approaches BI activities from an integrated, whole self. According to Risien and Storksdieck (2018), scientists who are successful in science and contribute positively to society have three commonalities:

First, they blend disciplinary strength and passion with a deep conviction and commitment to broader societal impacts. Second, they draw on a rich set of partnerships that enable them to engage in practices likely to have meaningful impacts. Finally, their professional identity expands well beyond their discipline or the confines of their research topic. (p. 64)

These characteristics are not too far removed from the transferable, interdisciplinary skills that both graduate STEM students and their future employers desire.

Other approaches for supporting graduate students' ability to engage with the BI of their research are to provide students with "authentic outreach experiences" (Heath et al., 2014, p. 518). Heath et al. (2014) assessed a formal training program for graduate biology students to learn about the broader impacts (BI) and communication of scientific research. The goals of this course include providing graduate students with "authentic outreach experiences" (Heath et al., 2014, p. 518) that create community connections, practice writing about the broader impacts criteria for major science funders, and the opportunity to develop science communication skills and the design of educational outreach activities. Throughout this 14-week course, students practice writing a grant proposal, communicate about their research through a local magazine and radio show, and design an outreach activity for an informal science event at a museum (Heath et al., 2014). Through the collection of post-course surveys, feedback on the broader impact of a grant proposal, and graduate mentor surveys, Heath et al. (2014) found positive student outcomes related to their course goals. Notably, the 18 students who participated

reported that the course significantly changed their feelings of preparedness to write a BI proposal and design and conduct outreach. One of the main insights I gained from this study was the intentionality around providing authentic and relevant outreach opportunities for students. I, too, connected CEI's PLV requirement with the National Science Foundation's (NSF's) Broader Impacts criterion in order to help students prepare for future grant proposals and outreach engagement. This study demonstrates the value of these activities for students and provided an example of how to incorporate these criteria into curricula and assessments.

Other studies have effectively used rubrics to prepare graduate STEM students for outreach. Latimore et al.'s (2014)

rubric examined whether the plan (1) identified a need, (2) defined the desired outcomes/goals, (3) identified priority audience, (4) described strategy/approach, (5) discussed resources needed, and (6) evaluated the effectiveness of the outreach activity. These criteria were identified by the authors as essential for high-quality plans. (p. 137)

Rubrics can also make use of criterion-related evidence to establish the validity of the rubric used (Moskal & Leydens, 2000). For instance, a rubric designed to evaluate the impact of the NSF's Integrative Graduate Education and Research Training (IGERT) program on graduate students was informed by the IGERT program's mission and vision, NSF's criteria for grant proposals, and literature on interdisciplinarity (Hackett & Rhoten, 2009). Explicitly connecting outreach activities and assessment strategies to NSF's BI criteria can be a way to support graduate students' understanding of and ability to engage with the BI of their research. These studies informed the development of my own data collection and analysis methods.

In sum, it seems incumbent upon those of us working with STEM graduate students, or future Principal Investigators (PI), to continue to support the development of core disciplinary skills and provide support for students to develop a more holistic set of skills. Not only will this prepare students to be successful in their careers, but it will also help them contribute to the BI of their research such as clean energy solutions to climate change. As the Committee on Revitalizing Graduate STEM Education for the 21st Century (NASEM, 2018) suggested, this requires a shift from an institution-centered focus to a student-centered one. I believe it also requires a more holistic and social perspective of learning than we might normally observe in a university setting. In the section that follows, I discuss a sociocultural theory of learning and several conceptual frameworks that have implications for this action research study.

A Sociocultural Theory of Learning

While many theories of learning focus on the cognitive processes that occur at an individual level or even an interpersonal level (Lave & Wenger, 1991), social theories of learning expand the unit of analysis for learning to include the social, cultural, and historical context of the learner. Sociocultural approaches to learning and development “are based on the concept that human activities take place in cultural contexts, are mediated by language and other symbol systems, and can be best understood when investigated in their historical development” (John-Steiner & Mahn, 1996, p. 191). One of the foundational scholars in this field is Lev Vygotsky, a Russian psychologist who first posited these ideas in the 1920s and 1930s. Vygotsky became frustrated with the inability of the leading theories of the time and his contemporaries to fully explain complex processes of human psychology (Cole & Scribner, 1978). Neither the reductionist approach of scientists nor the speculative, descriptive approach of Gestalt theorists of the time provided the holistic and scientific explanations for complex psychological

processes that he was after (Cole & Scribner, 1978). Vygotsky sought a “sociocultural theory of higher mental processes” (Cole & Scribner, 1978, p. 6) that integrated both science and complex human thought processes. Vygotsky’s main contributions include a focus on learning as a dynamic and dialectical process, the Zone of Proximal Development, and semiotic mediation, which are discussed in greater detail here.

Learning as a Process

By nature, the process of learning is complex and challenging to observe. While learning outcomes or products are often easy to observe, the process of learning is much more difficult if not impossible to observe directly (Vygotsky, 1978). To study these invisible processes, Vygotsky proposed a dialectical method of study which is characterized by the analysis of process over objects, explanation over description, and dynamic analysis of behaviors that have already been automatized (1978). He believed that higher mental functions should be studied as a process from beginning to end because studying only the aspects of those functions that you can observe externally may ignore critical underlying or internal differences that could explain these functions. Learning conceptualized as a dynamic and dialectical process is a theme that can be found in later versions of sociocultural theory and has important implications for the work of educators like me.

Support for Learning

Two other major Vygotskian contributions to the sociocultural theory of learning are the Zone of Proximal Development (ZPD) and semiotic mediation. The ZPD represents a dynamic developmental state between what one already knows and what one could know with support. “It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more

capable peers” (Vygotsky, 1978, p. 86). Because one’s actual developmental level represents what they have already learned, educators should create the conditions that foster development toward their full potential (Vygotsky, 1978). Semiotic mediation describes the use of tools — physical or psychological — to co-construct knowledge. These tools, signs, and symbols are rooted in social and cultural contexts and serve as a way for an individual to transform “interpersonal processes into intrapersonal ones” (John-Steiner & Mahn, 1996, p. 194). As John-Steiner and Mahn (1996) highlighted, “Vygotsky conceptualized development as the transformation of socially shared activities into internalized processes. In this way he rejected the Cartesian dichotomy between the internal and the external” (p. 192). Both the ZPD and semiotic mediation are foundational to theories of sociocultural learning and continue to be expanded upon today. Because many diverging theories have been influenced by Vygotsky’s ideas, the interpretation that has been used in this action research study — situated learning — is discussed next.

Situated Learning

Building upon this sociocultural theory of learning, Lave and Wenger (1991) propose that learning is “situated activity” (p. 29) that occurs as learners acquire new skills and knowledge through “legitimate peripheral participation” (p. 29) in communities of practice (COP). Through this framework, learning is viewed as an integral component of evolving membership and participation as a whole person in a community. Its distinguishing process — legitimate peripheral participation — concerns the process by which newcomers become part of a community of practice. A person’s intentions to learn are engaged and the meaning of learning is configured through the process of becoming a full participant in a sociocultural

practice. This social process includes, indeed it subsumes, the learning of knowledgeable skills. (Lave & Wenger, 1991, p. 29)

Learning, then, is inextricably connected to social practice, and it changes not only the learner — through evolution of identity — but the COP as well (Lave & Wenger, 1991).

From the perspective of situated learning, the unit of analysis for learning becomes much broader than the individual, the development of a specific skill, or even a pedagogical context. As evidence of this, Lave and Wenger (1991) differentiate their interpretation of the Vygotskian concept of internalization from other social theorists. Other interpretations of internalization focus on the individual learner in interaction with another who scaffolds the distance between what the individual knows and does not know in a much smaller social context (Lave & Wenger, 1991). Situated learning, on the other hand, broadens the context of learning to include “the structure of the social world in the analysis, and taking into account in a central way the conflictual nature of social practice” (Lave & Wenger, 1991, p. 49). Of particular importance is the transformation of the sociocultural context due to members of a community engaging in a “shared practice” (Lave & Wenger, 1991, p. 49). Thus, situated learning involves the dynamic negotiation of relationships, identity, and activity in the social world by whole persons (Lave & Wenger, 1991).

Implications for this Study

With respect to this action research study, three main insights are important to take away from the theory of situated learning. First, learning and teaching must be uncoupled (Lave & Wenger, 1991). While learning can occur in the pedagogical contexts of classrooms, situated learning invites us to focus our attention on the larger sociocultural context of learners and the motivations for learning. Lave and Wenger (1991) invite us to think bigger than a curriculum or an interpersonal context. They argue

“that learning must be understood with respect to a practice as a whole, with its multiplicity of relations - both within the community and the world at large” (Lave & Wenger, 1991, p. 114). Second, an essential characteristic of legitimate peripheral participation is that the motivation for learning is “about increasing participation” (Lave & Wenger, 1991, p. 112) rather than performance for grades. As learners become more masterful practitioners, their contributions become more valuable to the community and they may gain an increased sense of belonging. This motivation arises from “co-participating in practice” (Lave & Wenger, 1991, p. 112), which is in stark contrast to the motivation for learning to earn good grades or pass a test.

When the motivation for learning is not about increasing participation, then “the focus of attention shifts from co-participating in practice to acting upon the person-to-be-changed. Such a shift is typical of situations, such as schooling, in which pedagogically structured content organizes learning activities. (Lave & Wenger, 1991, p. 112)

This shift occurs often when an activity is devoid of “cultural identity” (Lave & Wenger, 1991, p. 112) and can result in an objectification of the learner. Lave and Wenger (1991) write that “a deeper sense of the value of participation to the community and the learner lies in *becoming* part of the community” (p. 111).

The third insight is that access is at the heart of learning. Since learning occurs through participation in community, access to learning opportunities and resources is both essential and problematic (Lave & Wenger, 1991). Becoming a full member of a community of practice requires access to a wide range of ongoing activity, old-timers, and other members of the community; and to information, resources, and opportunities for participation. The issue is so central to membership in

communities of practice that, in a sense, all that we have said so far is about access. (Lave & Wenger, 1991, p. 101)

For example, learning to use the tools of a trade is important to one's ability to constructively contribute; these tools also provide insight into the sociocultural history of one's context (Lave & Wenger, 1991). Because COP encompass dynamics of power, control, and manipulation, newcomers can be prevented from gaining full access to the tools and artifacts that are necessary for full membership (Lave & Wenger, 1991).

These three insights suggested the need for the PLV Design Workshop to attend to a broader unit of analysis for learning and to embrace and support the dynamic process of learning. Ensuring that the development of the PLV is an authentic opportunity to increase fellows' legitimate participation in BI activities is also important. In other words, PLVs and the process of designing them should not be "devoid of cultural identity" (Lave & Wenger, 1991, p. 112). They should be impactful to the designer and our larger community and increase fellows' ability to communicate about their research with respect to its BI. My decision to incorporate dialogue with peers and community representatives into the PLV Design Workshop was inspired by this theory of situated learning. Connecting fellows with potential audiences for their PLV also increases the authenticity of this project. Finally, explicitly sharing information about the NSF's BI guidelines was a way to increase access to an important professional practice in the field of STEM research. As the recommendations in the NABI (2018) report on the Current State of Broader Impacts suggest, educating researchers about these criteria and building research capacity to engage in BI are critical components to advancing the societal benefits of research. My hope is that this innovation increases fellows' access to information about BI and the opportunity to participate in BI activities.

Communities of Practice

Wenger (1998) later expanded upon the theory of situated learning and legitimate peripheral participation with the book *Communities of Practice: Learning, Meaning, and Identity*. In this text, Wenger (1998) details the special nature of COP and argues that neither community nor practice alone constitute a COP. Rather, COP refer to a group of people mutually engaged with one another in a “joint enterprise” who possess a “shared repertoire” (Wenger, 1998, 73). Membership in a COP is about mutual engagement. Mutual engagement requires relationships with the diverse members of a community and inclusion in the authentic matters of a community. COP also cohere as a result of the “negotiation of a joint enterprise” (Wenger, 1998, p. 77), which refers to the collective, dynamic, and negotiated response of a community of practice to its situation. Through this joint enterprise emerges a sense of mutual accountability (Wenger, 1998). Finally, COP can also be characterized by a collective repertoire that arises from “shared histories of learning” (Wenger, 1998, 103) and practicing with each other. This repertoire may or may not be reified and can include:

routines, words, tools, ways of doing things, stories, gestures, symbols, genres, actions, or concepts that the community has produced or adopted in the course of its existence, and which have become part of its practice. The repertoire combines both reificative and participative aspects. It includes the discourse by which members create meaningful statements about the world, as well as the styles by which they express their forms of membership and their identities as members.

(Wenger, 1998, p. 83)

Even with this repertoire and shared history, COP may or may not be formally recognized and their boundaries may be ambiguously or clearly defined through titles, jargon, or even a glass ceiling (Wenger, 1998). In addition, Wenger (1998) warns that it

is critical to keep in mind that COP are diverse spaces where negotiation of meaning and identity continuously occur with all the conflict and tensions that entails; this framework does not describe or prescribe the ideal community. Yet, it is through mutual engagement, joint enterprise, and shared repertoire that *practice* serves as “the source of coherence” and meaning for a community (Wenger, 1998, 73). The COP framework has provided me with new perspectives on STEM doctoral students and the BI of research. It has helped me to situate CEI Graduate Fellows in their learning journey as doctoral students gaining expertise in a specific lab. And, I now view engagement in the BI of one’s research as working across boundaries of one’s COP.

Of particular relevance to this action research study, boundary objects and brokering have a unique capacity to foster connections across communities. Returning to the broader social context as a unit of analysis, it is important to remember that COP do not exist in isolation and are in constant interaction with the external world (Wenger, 1998). By nature of their membership and nonmembership, COP create boundaries as well as opportunities to connect beyond these boundaries (Wenger, 1998). Boundary objects such as artifacts, terminology, and even physical spaces can coordinate interconnections between COP (Wenger, 1998). In addition to boundary objects, brokers can serve as connectors between communities of practice and the external world. Brokers connect communities and foster learning through the sharing of ideas, practices, or creating space for new ideas. They also serve as translators, coordinators, conflict managers, and aligners of perspective (Wenger, 1998).

Learning at the Boundary

To better understand *how* learning occurs at the boundaries of COP, Akkerman and Bakker (2011) reviewed the literature on boundary crossing and boundary objects. Boundary crossing was first used to describe professionals who are required to work

outside their area of expertise and must navigate and make sense of these differences. The concept of boundary objects (which was first introduced by Susan Leigh Star) has been used to describe artifacts that “bridge intersecting practices” (Akkerman & Bakker, 2011, p. 134). Through their literature review, Akkerman and Bakker (2011) hoped to gain knowledge of “the nature of boundaries” and “the dialogical learning mechanisms that take place at boundaries” (p. 137).

The concept of boundaries is complex and often seems paradoxical. For instance, Akkerman and Bakker (2011) define boundaries “as sociocultural differences that give rise to discontinuities in interaction and action” (p. 139) but point out that communities who experience this discontinuity must also experience some sort of continuity if they have come to interact. Boundaries can both divide and connect. This is evidenced by the way that boundary objects can be used to collaborate across COPs, despite the “interpretive flexibility” (Star, 2010) they have in different COPs. This is also demonstrated by the way brokers and boundary crossers can feel that they both belong and do not belong to a community. “Both this multivoicedness and the unspecificity at boundaries trigger dialogue and negotiation of meaning, explaining why encounters of boundaries are often described not only as challenging but also as worthwhile to investigate in relation to learning” (Akkerman & Bakker, 2011, p. 150). Thus, boundaries are ambiguous by nature (Akkerman & Bakker, 2011).

In addition to this finding, Akkerman and Bakker (2011) suggest that boundaries should be understood as “dialogical phenomena” (p. 132) and identified four “dialogical learning mechanisms” (p. 150) that can occur at boundaries: identification, coordination, reflection, and transformation. Identification clarifies boundaries through the differentiation of one practice from another. Here, “the learning potential resides in a renewed sense making of different practices and related identities” (Akkerman & Bakker,

2011, p. 143). Learning can also occur through coordination between communities to make boundaries easier to cross (sometimes even without awareness of the crossing). The purpose is not to construct a boundary but to overcome it (Akkerman & Bakker, 2011). Reflection is a third learning mechanism wherein interaction with other practices expands one's perspectives of their own practices. This new perspective has the potential to change one's identity and inform their future practice. While reflection and identification seem similar, their outcomes are much different. Identification results in greater certainty around one's identities and practices while "reflection results in an expanded set of perspectives and thus a new construction of identity that informs future practice" (Akkerman & Bakker, 2011, p. 143).

Finally, the fourth learning mechanism that was identified through this literature review was transformation, wherein practices are either significantly altered or newly created through collaboration and co-creation. While the use of boundary objects is often for the purpose of coordination, they do not necessarily "pass cleanly and unproblematically between COP and satisfying the needs of all" (Lee, 2007, p. 313). But they "can come with socially negotiated and disruptive processes that give them meaning" (Akkerman & Bakker, 2011, p. 151). In fact, boundary objects also can reduce the need for different communities to interact or collaborate (Akkerman & Bakker, 2011).

Implications for this Study

Star and Griesemer (1989) claim that "scientific work is heterogeneous" yet requires cooperation in order to maintain the reliability and integrity of findings "across time, space, and local contingencies" (p. 387). They argue that boundary objects are one tool that can help scientists maintain some coherence across diverse practices while still allowing for flexibility around local use and interpretation (Star and Griesemer, 1989).

This view of scientific work and boundaries directly applies to my context. While the graduate fellows I work with are working toward full participation in a particular lab group as well as their larger disciplinary field, the clean energy fellowship is meant to be an interdisciplinary space to advance clean energy research. One way of conceptualizing the PLVs is as a boundary object meant to communicate across communities of practice in order to support interdisciplinary advances. This is especially the case for PLVs that are designed for the STEM community. Additionally, these boundary objects can be seen as a tool to communicate across more distinct COPs such as the boundary between a chemistry lab group and a middle school science classroom.

Viewing PLVs as boundary objects also allows me to apply the findings from Akkerman and Bakker's (2011) literature review. First, the idea that boundaries should be understood as "dialogical phenomena" (Akkerman and Bakker, 2011, p. 132) suggests that paying attention to discourse and language will be important as students design PLVs and communicate with potential users of these products. Second, several studies they read showed that "artifacts can fail as boundary objects" if they do not accurately "capture multiple meanings and perspectives" (Akkerman and Bakker, 2011, p. 141). Wenger (1998) also argues that because boundary objects are self-contained entities, a true bridge between COP is not guaranteed and how different users interpret them cannot be controlled. Thus, Wenger (1998) recommends that "artifacts and people travel together" as "accompanied artifacts stand a better chance of bridging practices" (pp. 111 – 112). Wenger (1998) also suggests that designing artifacts is really "designing for participation" (p. 108) rather than simply for use.

The crucial issue is the relationship between the practices of design and the practices of use. Connecting the communities involved, understanding practices, and managing boundaries become fundamental design tasks. It is then

imperative to consider a broader range of connections beyond the artifact itself, both to reconcile various perspectives in the nexus and to take advantage of their diversity. (Wenger, 1998, p. 108)

These ideas affirmed my design decision to connect fellows with representatives of the target audience for their PLVs. With an accurate view of boundary objects, the design of such artifacts could encourage a more bidirectional and collaborative relationship between our graduate fellows and those who use the PLVs that are designed. In addition to providing the right balance of structure and freedom, I believe that my task is to also provide an opportunity for graduate students to authentically engage at the boundaries of their disciplinary COP. Specifically, I hope to encourage reflection rather than identification as a learning mechanism to help students expand their own knowledge and to design a more authentic, effective PLV.

Toward Knowledgeability

Building on the idea of COP and interaction across boundaries, Wenger-Trayner and Wenger-Trayner (2015) argue that professionals interact with a multitude of practices. They further discuss the idea of a social “body of knowledge as a landscape of practice” (2015, p. 15) and suggest that a profession has complex relationships with multiple COP and boundaries. To distinguish between the types of knowing that are required within a COP versus across several communities, Wenger-Trayner and Wenger-Trayner (2015) use the terms competence and knowledgeability, respectively. Competence refers to “the dimension of knowing negotiated and defined within a single community of practice,” while “knowledgeability manifests in a person’s relations to a multiplicity of practices across the landscape” (Wenger-Trayner & Wenger-Trayner, 2015, p. 13).

To better understand this metaphor, Wenger-Trayner and Wenger-Trayner (2015) describe the characteristics of a landscape of practice as political, flat, and diverse. Landscapes of practice are political in that there are often hierarchies that prioritize the competence recognized in one COP over another. In addition, some COP may also have more power or influence over others. Despite unequal recognition across the landscape, “all practices are practices” (Wenger-Trayner & Wenger-Trayner, 2015, p. 16); they are locally produced and meaningful. Even when external mandates might be imposed on a COP, the community itself responds to the regulation or does not. Landscapes of practice are also diverse. Gaining deep expertise and experience in one community of practice naturally creates a boundary with others. The differences in a COP’s culture, norms, or even the different interpretations of the same words can create confusion, tension, and misunderstandings at these boundaries (Wenger-Trayner & Wenger-Trayner, 2015).

Yet, boundaries hold incredible potential for positive change, and learning to navigate work at the boundaries is important for professionals like our graduate fellows. According to Wenger-Trayner and Wenger-Trayner (2015), “crossing boundaries, boundary encounters, and boundary partnerships are necessary for the integration of a landscape of practice” (p. 18). They suggest explicitly focusing on boundaries and addressing their inherent learning potential and challenges with pedagogy and pose a particularly relevant question for this action research study: “What kind of boundary objects and activities can support this boundary-oriented pedagogy and create points for engaging multiple perspectives” (Wenger-Trayner & Wenger-Trayner, 2015, p. 18)?

Becoming knowledgeable about a landscape of practices is a learning process that is shaped by a person’s experience of and identification with different practices (Wenger-

Trayner & Wenger-Trayner, 2015). Wenger-Trayner and Wenger-Trayner (2015) describe three “modes of identification” (p. 20) as engagement, alignment, and imagination, which all have an effect on one's identification with a particular practice. Engagement refers to one’s “direct experience” (Wenger-Trayner and Wenger-Trayner, 2015, p. 20) of the practices within a community while alignment can be described as coordination among different aspects and perspectives of a context or contexts. Imagination is also an important mode of identification, as it helps one to envision possibilities as well as themselves within a given context. Professionals can also experience identification and disidentification within a landscape at various scales of practice. These experiences of identification as well as a practitioner’s own competence within a particular community of practice, their experience of multi-disciplinary work, and their engagement at the boundaries all contribute to one’s knowledgeability within a landscape of practice.

Implications for this Study

According to Wenger-Trayner and Wenger-Trayner (2015), “knowledgeability is a complex achievement” (p. 23).

Knowledgeability entails translating this complex experience of the landscape, both its practices and their boundaries, into a meaningful moment of service. The ability to do this depends on the depth of one’s competence in one or more core practice(s), which ground the experience of the landscape in specific locations; and it also depends on one’s knowledgeability about other practices and significant boundaries in the landscape. (Wenger-Trayner and Wenger-Trayner, 2015, p. 23)

From my perspective, this description of the complexity of knowledgeability and its application in the real world is directly transferable to a researcher’s ability to

successfully engage with the BI of their research and aligned with the need to support the development of scientists' impact identity. Recall that graduate STEM students and their potential employers believe that these new scientists are graduating with strong disciplinary skills but need improvement in skills related to interdisciplinary teams and outreach (NASEM, 2018). Thus, the opportunity that exists with the innovation for this action research study is to use the development of a “boundary object” as an authentic opportunity to engage beyond its COP to a larger landscape of practices. Through fellows’ participation in an interdisciplinary fellowship and the required development of a PLV, they have an opportunity to practice “participative connections” (Wenger, 1998, p. 111) that seem aligned with the larger STEM field’s values around the broader impacts of scientific research.

Near the end of the book, *Communities of practice: Learning, meaning, and Identity*, Wenger (1998) asserts that “*learning cannot be designed*: it can “be designed for – that is, facilitated or frustrated” (p. 229). The COP framework, then, suggests that the task of those who design for learning need to strike a balance between the dualities and tensions that are necessary for learning: participation and reification, designed and emergent, local and global, and identification and negotiability (Wenger, 1998, p. 240). I believe my task, then, is to provide a semi-structured space and opportunity for our graduate fellows to experience these tensions in order to create an authentic PLV.

Summary

Today’s graduate STEM students are working on some of humanity’s most wicked problems. While deep expertise in their fields of practice is critical to potential solutions, so too is their ability to work across a landscape of practice. I believe that to do this effectively and sensitively, graduate students need to be knowledgeable about the broader impacts of their research and be given authentic opportunities to develop the

skills to work across boundaries during graduate school. These opportunities should also encourage students to develop their impact identity and come to this work with their whole selves. As the Committee on Revitalizing Graduate STEM Education for the 21st Century (NASEM, 2018) recommended, those of us in higher educational institutions should periodically review our requirements. This action research study was developed to systematically inquire into the CEI Graduate Fellowship requirement to develop a PLV. As discussed in this chapter, the design of this study was inspired and informed by a sociocultural theory of learning, specifically situated learning, communities of practice, and knowledgeability. In Chapter 3, I discuss the method for my research as well as its innovation, the PLV Design Workshop.

CHAPTER 3

METHOD

The Clean Energy Institute (CEI) at the University of Washington (UW) is well-positioned to contribute both technical expertise and social support for effective responses to climate change. Each year, we support approximately 30 doctoral students through the CEI Graduate Fellowship to conduct interdisciplinary research and participate in extracurricular activities related to clean energy solutions. As part of their fellowship, doctoral students are required to develop a Product of Lasting Value (PLV), an educational product designed to share some aspect of their research with a broader audience. Specifically, the learning objectives for this project are that fellows will build community with other CEI Graduate Fellows, gain a deeper understanding of the broader impacts of their research and impact identity, increase their ability to communicate their research across disciplinary boundaries, and develop the ability to design and evaluate broader impact activity proposals. Ideally, these products would disseminate contemporary knowledge about clean energy research and help fellows develop the skills necessary to contribute to equitable, interdisciplinary clean energy solutions.

Many great PLVs have been produced throughout the years, yet little is known about the effect the design of these products has on our graduate fellows' perceptions of the broader impacts of their research or the skills they gain through this project. I believe the urgency and complexity of climate change compels us to engage students in learning opportunities that more explicitly and authentically reflect the opportunities they will have to contribute effectively to climate change mitigation. Thus, the purpose of this action research study was to create and implement a more supportive PLV curriculum to better foster the professional development of CEI graduate fellows and to ensure the

quality of PLVs. The goals for this specific cycle of research, Cycle 3, were to evaluate the effect of a three-part, semi-structured design workshop, the PLV Design Workshop, on the quality of graduate fellows' PLVs, fellows' knowledgeability of the broader impact of their research, and fellows' identification with the clean energy field.

In this chapter, I define action research and discuss how this study incorporated this methodology. I then review the research questions that guided this cycle of research and describe the setting, the participants, and my own role in this particular study. Finally, the innovation and its rationale will be discussed as well as the timeline used for the collection, analysis, and interpretation of data.

Action Research

Action research is the systematic inquiry into a specific, local problem related to a practitioner's work (Mertler, 2020; Creswell & Guetterman, 2019; Ivankova, 2015). Considered applied research, it is generally conducted by practitioners interested in finding immediate solutions to issues related to their practices and improving their practices (Mertler, 2020; Creswell & Guetterman, 2019; Ivankova, 2015). Throughout multiple cycles of inquiry, the practitioner can learn more deeply about an issue, identify a focus for research, develop a plan for collecting and analyzing data, and create solution-oriented action plans based on these findings (Creswell & Guetterman, 2019).

Because action research has been informed by a variety of traditions and used in a diversity of contexts (Herr & Anderson, 2012), it is important to be transparent about how action research has informed this study. I agree with Ivankova's (2015) description of action research as being characterized by a community orientation, focus on one's practice, participation, collaboration, reflection, and empowerment (Ivankova, 2015). According to Argyris et al. (2008),

action research is a participatory process concerned with developing practical knowing in the pursuit of worthwhile human purposes. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities. (p. 5)

Unlike traditional research, the practitioner and community's insider knowledge of the problem of practice is viewed as an asset and can result in the empowerment of the community that participates in the resolution of an issue. The purpose of action research is to find solutions to real-world problems faced by educators in the field and to increase these educators' ability to critically reflect and improve upon their practices, ultimately helping to close the gap between theory and practice (Mertler, 2020).

Action research has been informed by a variety of traditions and is used in a diversity of contexts (Herr & Anderson, 2012). Because the phrase is an umbrella term, Herr & Anderson (2012) believe those who employ action research "should be able to defend the particular tradition from which they have chosen to work" (p. 2) and be sure not to apply an approach ill-suited to one's context. For this study, I draw from the action research traditions such as Lewin's use in organizational contexts that privileged problem-solving determined from within the context (p. 4), traditions such as participatory action research and action research in education that honor the practitioner's knowledge and expertise of their own context. Not only has this influenced the design of this study, but it has also informed the design of my innovation.

Previous Cycles of Research

The cycle of research that I discuss below was informed by two previous cycles of research — Research Cycle 1: A Systematic Review of PLVs and Research Cycle 2: Clean Energy Fellow Interviews. The purpose of Research Cycle 1 was to conduct

reconnaissance for this action research study. Specifically, I was interested in learning what PLVs already exist (research question 1), how these PLVs can be categorized (e.g., product type, intended audience, topic, and authorship) (research question 2), and what opportunities for growth these products elicit (research question 3). Through this cycle of research, I learned the 57 PLVs that are currently listed on our website represented a wide range of quality and that the primary medium employed was video. Most of these products had individual authors, suggesting that students did not engage in much interdisciplinary collaboration. Finally, a document analysis suggested that helping fellows to more clearly identify the purpose and audience for their PLVs might increase the quality and effectiveness of their products. While this cycle of research provided helpful insights about existing PLVs and potential topics for PLV curricula, it did not provide information about the effect of PLVs on the graduate fellows who design them.

To better understand how fellows experience this project, I conducted a second cycle of research guided by the following questions:

RQ 1: How do graduate researchers connect their research to clean energy?

RQ 2: How do graduate fellows perceive and experience the products of lasting value project?

RQ 3: What types of preparation and support would graduate fellows find helpful for the development of a PLV?

To answer these questions, I conducted one-on-one semi-structured interviews with four clean energy fellows. Two of these students participated in fellowships during the previous academic year and had already designed a PLV. The other two students were current fellows who have recently been informed of the project and are in the initial stages of brainstorming ideas. There were many important insights that emerged from these interviews; what I highlight here are those that specifically informed the proposal

that follows. One theme that emerged is that each fellow is conducting foundational research that has potential for *future* applications in clean energy research. This work on foundational research has applications for the identification of appropriate PLV audiences and topics. A second theme that emerged is that PLVs are perceived and felt to be a dialectical project; there are many tensions that are inherent to this design project. For instance, doctoral students are incredibly busy and have little time to spend on these projects — even if they are interested in designing PLVs. Also, one student pointed out that creating products that have *lasting* value about science that is still *emerging* is an inherent contradiction. Supporting students to identify projects that are narrow in scope and providing opportunities for students to update previous projects are two design outcomes from these interviews.

Other important takeaways from these interviews were the interest in and helpfulness of feedback from peers and the target audience. During the previous academic year, I facilitated a peer feedback session for students to share their current drafts of PLVs with others to get constructive feedback from peers. It was interesting to learn that this was helpful to at least one alumnus and also that new fellows were suggesting this even before participation in a peer feedback session. Additional support for peer feedback is that one student mentioned feeling disconnected from other peers and noted that more collaboration on these projects could help them better connect. This insight from fellows supports the goal of designing an intervention that fosters increased collaboration among this community of clean energy fellows.

Finally, and importantly, all students associated PLVs with science communication and recognize the value of and need for this skill. From the lens of communities of practice, I believe that as students learn to participate more fully in their disciplinary fields it will become increasingly important for them to have opportunities

to practice communicating across boundaries. This will aid in the rapid dissemination of science and technologies that are critical to climate change solutions as well as the ability to communicate with stakeholders most affected by climate change. I believe this PLV project has transformative potential for both students and the larger community; therefore, I designed and facilitated an intervention to explore the effect of a more structured PLV curriculum on both CEI graduate fellows and PLVs. Specifically, this action research study was guided by the following questions:

RQ1: How does the PLV Design Workshop increase the quality of products of lasting value?

RQ2: How and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research?

RQ3: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field?

In the discussion that follows, I will introduce the specific setting in which the study took place and the participants involved in this research. Next, I will discuss the intervention and research strategies that were employed to collect and investigate the data that emerged from the implementation of the intervention. Finally, I will share the timeline and procedures that were used to conduct this research.

Setting

This study took place at the UW CEI. The UW is a public university whose primary mission is “the preservation, advancement, and dissemination of knowledge” (UW, 2022, Vision & values section). The UW has become a global leader in research; it is recognized as a Carnegie Research I University and was recently ranked as the sixth-best global university by the U.S. News & World Report. (U.S. News & World Report,

2022). The CEI was created in 2013 with funds from Washington state to “accelerate the adoption of scalable clean energy future that will improve the health and economy of our state, nation, and world” (UW CEI, 2020, About section). The institute brings together faculty and graduate researchers from many different scientific disciplines, as well as partners from industry and policy, to advance clean energy solutions.

The UW Seattle campus served as the physical location for this study, and the PLV Design Workshop used both physical and digital spaces provided by the university. All three sessions of the workshop occurred in a large classroom on campus that is also the gathering space for the CEI Interdisciplinary Seminars that CEI Graduate Fellows are required to attend. I used university email and Google Drive to communicate with fellows about the PLV Design Workshop and to share resources with them.

Participants

The PLV Design Workshop was developed for the 2021-2022 cohort of CEI Graduate Fellows. CEI Graduate Fellows are university doctoral students who have completed at least one year of their doctorate and are conducting research that is aligned with one of CEI’s main research thrusts. While most fellows are from the STEM fields such as chemistry, engineering, and materials science fields, we have also awarded fellowships to students conducting clean energy research through non-STEM disciplines such as political science. CEI research is inherently interdisciplinary, and cross-departmental collaborations are welcomed (UW CEI, 2020, CEI Graduate Fellowship section). Fellowships are typically one to two quarters in length and occur during fall, winter, and spring quarters. All 26 CEI Graduate Fellows from this cohort were invited to attend the workshop and were invited to voluntarily participate in this study. Those who did participate were self-selecting. Over the course of the three-day PLV Design Workshop, attendance from CEI Graduate Fellows ranged from 10 to 15 participants.

Attendance for workshop sessions one, two, and three was 14 fellows, 10 fellows, and 15 fellows, respectively. Eighteen fellows agreed to allow their PLV Check Ins to be used in this study and, thus, these 18 fellows' PLVs were evaluated for this study. After the workshop, I recruited volunteers from the 2021-2022 cohort of CEI Graduate Fellows to participate in a focus group interview and 4 fellows volunteered.

Role of the Researcher

For this action research study, I developed and facilitated each session of the workshop, administered each survey, and conducted the focus group interview (Mertler, 2020). As associate director for education and workforce engagement at UW CEI, I manage the CEI graduate fellowship program, facilitate training events in which CEI Graduate Fellows participate, and maintain frequent communication with each cohort throughout the academic year. While this ultimately makes me an insider for this project, my role as a researcher is not without nuances. I have been hired as a staff member to help support the UW CEI Graduate Fellowship, which affords me the authority to request fellows to take part in activities such as this series of design workshops. While the expectation to participate is communicated, fellows' participation is ultimately voluntary for these extracurricular projects. This project is not assigned a grade and it is unlikely that funding would be withheld for an incomplete project.

Additionally, I see my role as facilitator of the PLV project as a broker, or one who helps to connect and coordinate communities of practice that offer a rich opportunity for learning (Wenger, 1998). Wenger (1998) notes that brokering is difficult work and requires one to have enough legitimacy to be heard but enough distance not to be pulled into full membership of a community of practice. In fact, "uprootedness is an occupational hazard of brokering" (Wenger, 1998, p. 110). Through the lens of the

community of practice framework, the concept of boundaries and boundary objects afford a valuable analysis for this action research study.

Innovation

Design

For this mixed methods action research study, I designed and facilitated a three-part semi-structured design workshop, the PLV Design Workshop, to support CEI Graduate Fellows' design of a PLV, a requirement of the CEI's Graduate Fellowship. The purpose of this intervention was to provide a more structured PLV curriculum to better support the professional development of CEI graduate fellows and to ensure the creation of high quality PLVs. Through a more interactive and supported design experience, my goal was to provide a more explicit and authentic opportunity for fellows to reflect upon the broader impacts of their research and to interact across disciplinary boundaries. Before implementing this innovation, I worked with Arizona State University's and the UW's Institutional Review Boards (IRB) to determine exempt status for this study. See Appendix C to review the IRB documents for this cycle of research. Three PLV Design Workshop sessions were spaced throughout the spring quarter to provide support throughout the design process and allow time for students to work on drafts between sessions. The PLV Design Workshop is described below and a more detailed description of each workshop session can be found in Appendix D.

Session 1: Building Teams, Generating Ideas

Each session of the workshop was held on a different Thursday afternoon during spring quarter, about two weeks apart to allow time for students to develop their PLVs. Session 1: Building Teams, Generating Ideas took place March 31, Session 2: Peer Feedback took place April 14, and Session 3: Community Engagement was held April 28. The content and focus of the PLV Workshop were sequenced to provide support for

different aspects of the design process. For instance, the objectives for Session 1: Building Teams, Generating Ideas were to provide the opportunity for fellows to brainstorm ideas for PLVs. This semi-structured opportunity to brainstorm PLV ideas was incorporated after the results from my Research Cycle 1 suggested that project parameters that are too open-ended can be overwhelming for students when trying to identify a PLV idea. Participants were also provided the chance to collaborate with other fellows and reflect upon their own impact identity. In this first session, participants were asked to contribute to a collective clean energy map, reflect on their own impact identity, and generate PLV ideas through small group interactions. I included multiple and diverse opportunities for graduate fellows to interact, as previous cycles of research suggested students felt fairly disconnected from their cohort. At the end of this session, fellows were asked to complete a PLV Check In to provide me with feedback on their current ideas for this project.

Session 2: Peer Feedback

The purpose of Session 2: Peer Feedback was to provide fellows with an opportunity to give and receive peer feedback on their current PLV proposals or drafts. Using a semi-structured feedback format, students gave a short presentation of their current PLV draft in small groups. Their peers were then allowed to ask clarifying questions about the PLV. Once the presenter answered these questions, the small group then freely discussed the merits of and potential improvements for the PLV. This session built upon a virtual peer feedback session that I facilitated with the previous year's cohort. In addition to peer feedback, other objectives for this session were to help fellows identify strategies for engaging audiences from different communities of practice, communicating constructively with their peers, and continuing to build community with other fellows. At the end of this session, fellows were asked to complete another PLV

Check In to provide me with feedback on their current ideas for this project and to track changes in their ideas over time.

Session 3: Community Engagement

Finally, Session 3: Community Engagement provided fellows with an opportunity to engage in dialogue with representatives of their target audiences, or more external audiences than their CEI Graduate Fellowship cohort, and to gather more feedback on their current PLV drafts. The objectives for this workshop were to improve fellows' ability to communicate their research across disciplinary boundaries, develop fellows' ability to design and evaluate broader impact activity proposals, and increase fellows' awareness of their own disciplinary norms, values, and blind spots. The session began with participant introductions in small groups and an icebreaker that invited small groups to identify both commonalities and differences among their disciplines.

Participants were then asked to get into small groups that I had planned before the session. I grouped fellows according to the target audience for or content of the PLVs and placed community members in these groups based on their expertise. In these new small groups, fellows and community members then participated in a feedback activity similar in structure to the peer feedback activity in Session 2 of the PLV Design Workshop. We ended with a whole group report out about insights gained during this session. Then, graduate fellows were asked to complete another PLV Check In, and representatives of target audiences were invited to complete a post-session evaluation. After this last session, fellows had about one month to incorporate feedback they received into their PLV and turn in a final draft by June 3. In addition to the final PLV draft, students were asked to complete a slide for a slideshow that was used during the PLV Showcase at CEI's End of Year Seminar. Finally, all 2021-2022 CEI Graduate Fellows were invited to

complete an anonymous post-survey and a small group of fellows was recruited to participate in a focus group interview.

In addition to CEI Graduate Fellows and one DIRECT Trainee Fellow, other participants in these workshops include a representative from the CEI communications team and eight community members who attended the final day of the PLV Design Workshop. The CEI communications team has always supported the PLV requirement through the uploading of PLVs each year to the CEI website. For the past two years, the communications team also suggested PLV topics for fellows, such as research explainers or updates for specific webpages on our website. One member of the communications team coached those fellows who chose to contribute a research explainer to the website. This colleague joined the PLV Design Workshops this year, shared new PLV ideas with fellows, and provided feedback to fellows from ideation to final draft. I also recruited eight community members to participate in the final day of the PLV Design Workshop to provide a more external perspective and feedback on PLV drafts. These participants were recruited from my network of university partners, current and former CEI Education & Training Fellows who have extensive experience with K-12 outreach, and former cohorts of CEI Graduate Fellows with previous background designing PLVs and conducting outreach. Table 2 summarizes the timeline and procedure for this implementation of this innovation.

Table 2*PLV Design Workshop – Timeline and Procedures*

Timeframe	Actions	Data Type & Procedures
November - December 2021	Completed Research Cycle 0: A Systematic Review of PLVs.	QUAL: Conducted document analysis of existing PLVs.
November - December 2021	Completed Research Cycle 1: Clean Energy Fellow Interviews.	QUAL: Acquired IRB approval. Recruited four graduate students for semi-structured interviews. Conducted and coded interviews.
February 2022	Defended Dissertation Proposal (DP).	Incorporate reconnaissance into final DP. Submitted to committee. Defended Dissertation Proposal.
March 2022	Acquired IRB approval.	Submitted IRB documents to both ASU and home institution and received exempt status.
March 2022	Designed theory of change model.	Created an innovation configuration map for each workshop.
March - April 2022	Recruited participants.	Communicated purpose and timeline of workshop with graduate fellows and potential stakeholders for Session 3.
March 31, 2022	Facilitated Session 1: Building Teams & Generating Ideas.	QUAL & QUAN: Administered Pre-questionnaire. Facilitated workshop. Administered PLV Check In 1.
April 14, 2022	Facilitated Session 2: Peer Feedback.	QUAL: Facilitated workshop. Administered PLV Check In 2.

April 28, 2022	Facilitated Session 3: Community Engagement.	QUAL & QUAN: Facilitated workshop. Administered PLV Check In 1. Administered Post-questionnaire and feedback form with community members.
May 2022	Showcased PLVs.	CEI staff incorporated a short, PLV showcase into the End of Year Seminar.
July 2022	Conducted 1 Focus Groups.	QUAL: Facilitated focus group interview with CEI Graduate Fellows.
Spring - summer 2022	Drafted rubric with stakeholders.	Drafted rubric and invited colleagues to review. Tested with PLVs to assess clarity and intra-rater reliability.
August - September 2022	Assessed final PLV drafts.	QUAN: Researcher assessed final PLVs using rubric and PLV Check Ins.
August - September 2022	Analyzed and interpreted data.	Quantitative and qualitative data analyzed and integrated to answer RQs.
October 2022	Wrote final paper.	Completed study and wrote up results.

Quantitative and Qualitative Methods

This action research study employed a concurrent quantitative and qualitative mixed methods action research design. This allowed me to leverage the strengths of both qualitative and quantitative research methods to answer the research questions for this

study. Below I discuss the instruments developed in detail and the process used to collect data by research question in order to establish transferability of this study (Mertler, 2020). I then discuss how data were analyzed for each research question. Finally, I discuss the trustworthiness (Ivankova, 2015) of the data and threats to reliability and validity.

Research Question 1

One of the main goals of this study was to determine if the PLV Design Workshop increased the quality of products of lasting value (RQ 1). Based on CEI's goals for this project, I chose to define quality based on guiding principles from the *Broader Impacts Review Document for National Science Foundation Proposals* (The Center for Advancing Research Impact in Society [ARIS], 2020), which has been designed to help grant proposers, reviewers, and others evaluate the broader impacts (BI) portion of NSF grants. It is likely that many of our fellows will become PIs and submit proposals to the NSF at some point in their future, and this way a tangible way to align my metrics with requirements of NSF proposals. Two instruments were critical to answering this research question—the PLV Rubric and the PLV Check Ins.

Quantitative Instrument: PLV Rubric

An analytic rubric was created to quantitatively evaluate each PLV and better understand the impact of the PLV Design Workshop on the quality of PLVs. Like all rubrics, this instrument included criteria that should be addressed by each PLV, such as purpose or target audience, as well as performance levels with descriptions for each criterion (Brookhart, 2018). The four criteria assessed via this rubric were: purpose of PLV, target audience, design strategy, and communication. Each criterion had four performance levels, with 4 representing the highest level of performance and 1

representing the lowest. Descriptions for the highest level of performance for each criterion are shown in Table 3 and the full rubric can be viewed in Appendix E.

Table 3

PLV Rubric Criteria with Level 4 Performance Descriptions

PLV Rubric Criteria	Level 4 Performance Descriptions
Purpose of PLV	Purpose and desired outcomes of PLV is explicitly communicated and specific; PLV medium strategic for purpose; purpose advances CEI’s mission or outreach goals.
Target Audience	PLV’s target audience is explicitly communicated and specific; PLV classified as universal (benefits all) or inclusive (benefits marginalized communities) based on Inclusive-Immediacy Criterion; PLV medium is appropriate and engaging for target audience.
Design Strategy	Multiple, effective means of engagement, representation, and action/expression* to encourage audience learning and/or measure outcomes; value-add is creative with potential to be transformative; scale of PLV and resources used resulted in high-quality, complete, thorough product; PLV leverages existing infrastructure in an enhanced way or suggests new, sustainable mechanisms for reaching target audience.
Communication	PLV bridges the gap between disciplinary and target audience language (strategic use of jargon); disciplinary assumptions/ blind spots were well-mitigated; background information was strategically provided; communication was inclusive and engaging.

An analytic rather than holistic rubric was used to gather more descriptive data about each criterion for the PLVs and — in future years — provide students with more feedback on their products (Mertler, 2000). Many researchers have suggested that rubrics are beneficial to student learning as they can clarify expectations and help orient

students toward a learning goal (Brookhart, 2018). Thus, the incorporation of broader impacts guiding principles into this rubric was to foster students' growth with respect to their understanding of the broader impacts of research. Throughout the PLV Design Workshop students were introduced to the NSF's broader impact criteria, impact identity (Risien & Storksdieck, 2018), and the Inclusion-Immediacy Criterion (IIC) (Woodson et al., 2021) throughout the PLV Design Workshop. In future years, I intend to introduce this rubric at the beginning of the year to better guide the project.

PLV Rubric Validity. Criterion-related evidence was used to establish the validity of this rubric (Moskal & Leydens, 2000). Rubric criteria were drawn from the *Broader Impacts Review Document for National Science Foundation Proposals* (ARIS, 2020) which can help “proposers to think critically about how their BI activities will incorporate into their research portfolio over time and begin to develop their ‘impact identity’ ” (p. 1). In addition to the inclusion of NSF's Broader Impact criteria, the rubric was also informed by the IIC, which is a relatively new framework that “assesses BIs by tracking who will benefit from the project and how the impact relates to the central goal of the grant (Woodson et al., 2021, p. 3). The inclusion of this model was to encourage consideration of equity and inclusion with respect to the PLVs and their dissemination.

PLV Rubric Reliability. Because I was the only person using the rubric to assess PLVs, it was important to establish intra-rater reliability. One of the most important first steps a researcher can take to establish reliability of a rubric is to be sure that the instrument has been well-designed. As Moskal and Leydens (2000) note, rubrics with “well-defined score categories” (p. 4) will help with both inter-rater and intra-rater reliability, the latter most appropriate for this action research study. To evaluate the rubric for well-defined criteria and performance descriptions, I first reviewed this draft of the rubric descriptions and levels of performance for clarity (Moskal & Leydens,

2000), checking clarity through the evaluation of a few existing PLVs with the rubric. After this exploratory use of the rubric, it was clear that to fully assess the quality of PLVs, I would need information from the PLV Check Ins as well as the product itself. This is because several products such as videos or webpages did not include information about the purpose and audience for the PLV, but fellows did provide this information in their PLV Check Ins. I also invited colleagues to review the rubric and updated the rubric with feedback from a colleague, most notably adding content to the Design Strategy Criterion related to Universal Design for Learning (CAST, 2022, About CAST section).

I then conducted an initial review of a sample of PLVs with the updated rubric. To do this, I gathered all PLVs and created a spreadsheet with each fellow's final PLV Check In. I quickly skimmed the PLVs and conducted an initial review of four PLVs (authored by six fellows) from the 2021-2022 CEI Graduate Fellow Cohort. This review helped to identify some issues with a few rubric criteria. Specifically, I removed descriptions for the Purpose of PLV and Target Audience criteria to be "well-justified," as this was not addressed in the workshops. I then added a descriptor about specificity to both the Purpose of PLV and Target Audience criteria. After a few more reviews of PLVs, I moved the following description from the Target Audience criterion to the Design Strategy criterion, which represents a more valid categorization: PLV leverages existing infrastructure in an enhanced way or suggests new, sustainable mechanisms for reaching target audience.

After my first full review of all PLVs with the new rubric, I checked in with a colleague to get some external perspective on the rubric. I invited the colleague who works most closely with me during the PLV Workshops to review three PLVs that earned a high, medium, and low score from me. I first introduced the rubric, then invited them to evaluate these three PLVs. Through this activity, we learned that their scores were

much more conservative than mine. While they identified the same PLV as I did for lowest quality, they did not differentiate between the PLVs that I scored as high versus medium. This inspired me to conduct a second round of scoring to be sure that I was scoring consistently and did this after a few days to ensure that my scoring was not affected by fatigue (Moskal & Leydens, 2000). I printed rubrics and reviewed each PLV. Yet, even after this second review, I checked three PLV scores and recognized that some of the inconsistencies that I was getting might be due the fact that the “differences between score categories” (Moskal & Leydens, 2000 p. 5) were not clear. I then moved three performance-level descriptors to the more appropriate criterion and conducted a final review.

For the final review, I again printed rubrics for each PLV to encourage myself to “revisit the established criteria” (Moskal & Leydens, 2000, p. 4) and remain consistent with my assessment. I also recorded clear rules about how I would score criteria with evidence in more than one performance level in my research journal. Finally, I scored PLVs based on one criterion at a time to ensure consistent assessment across all PLVs. Once complete, I double-checked scores I gave to partners to assess my intra-rater reliability, as well as a few PLVs with the same score. This final round of scoring was much more consistent.

Qualitative Instrument: PLV Check Ins

I administered three non-anonymous PLV Check Ins digitally via Google Forms after each session of the workshop to help answer research question 1. The purpose of these PLV Check Ins were threefold: they served as a formative assessment to help me monitor fellows’ progress and to request specific types of support, they invited timely feedback from fellows on each session of the workshop, and they documented information about and changes made to fellows’ projects. These surveys included eight

open-ended questions that solicited information about fellows' current drafts of PLVs. See Appendix F for a sample of the PLV Check In. Fellows were asked to identify group members and the title, purpose, audience, desired outcomes or goals, and strategies for their PLV. In addition, they were asked to provide feedback on the workshop session and to identify any other resources or support they needed from me to develop their PLVs. For the final PLV Check In, fellows were also asked to share how they intended to present their project at our end-of-the-year PLV Showcase. On each PLV Check In, respondents were asked if they would allow data to be used in this action research study.

Data from the PLV Check Ins proved invaluable for assessing final products with the PLV Rubric. The open-ended responses from fellows' last (or only) PLV Check In allowed a more accurate assessment of PLV quality, especially with respect to target audience and purpose for each product. PLV Check Ins were also used to collect feedback from fellows about the PLV Workshop. Respondents were asked to share what was most and least valuable about each session of the workshop. This data was collected to improve future iterations of the workshop and not answer a specific research question. Therefore, data analysis and results can be found in Appendix G.

Research Questions 2 and 3

There were two primary instruments were used to collect data for research questions two and three. Recall that RQ2 was focused on whether participation in the PLV Design Workshop increased CEI Graduate Fellows' knowledgeability of the broader impacts of their research and RQ3 was focused on how participation in the workshop strengthened fellows' identification with the clean energy field. The two main instruments designed to gather evidence for these questions were a PLV Workshop Survey and a Focus Group Interview Protocol. Since the PLV Check In has already been

introduced, this section will only discuss the PLV Workshop Survey and the Focus Group Interview protocol.

Quantitative and Qualitative Instrument: PLV Workshop Survey

A PLV Workshop Pre-Survey and Post-Survey were developed to collect data on fellows' perspectives on their knowledgeability of the broader impacts (BI) of research (RQ2) and their identification with the clean energy field (RQ3) before and after the intervention. The 11-question pre-survey and the 12-question post-survey included both Likert-style answers and open-ended answers. The Likert-style questions invited fellows to share how interested they were in exploring different types of BI activities, how related their research was to each BI activity, and how knowledgeable they felt about each BI activity on a five-point scale. There were also three Likert-style questions that focused on fellows' engagement, alignment, and future engagement with the clean energy field. Open-ended questions invited students to list any other broader impact activities in which they were interested, the strengths and skills they were bringing to these activities, and any benefits they might gain from their engagement with BI activities. On the post-survey, students were also asked to mark which sessions of the PLV Design Workshop they attended, if any. See Appendix H for the PLV Workshop Pre-Survey.

Questions developed for the survey were informed by examples of broader impacts from the NSF Proposal & Award Policies & Procedure Guide (NSF PAPPG, 2020), Wenger-Trayner and Wenger-Trayner's (2015) concept of knowledgeability, and Risien and Storksdieck's (2018) concept of impact identity. There were two sections of the survey. Section 1: Perspectives on Broader Impacts invited fellows to review the 10 examples of BI (NSF PAPPG, 2020) and evaluate their interest in each BI, how related their research is to each BI, and how knowledgeable they felt about each BI on a five-

point Likert-type scale. The BI examples as written in the NSF PAPPG (2020) and the PLV Surveys are:

- full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM);
- improved STEM education and educator development at any level;
- increased public scientific literacy and public engagement with science and technology;
- improved well-being of individuals in society;
- development of a diverse, globally competitive STEM workforce;
- increased partnerships between academia, industry, and others;
- improved national security;
- increased economic competitiveness of the U.S.;
- use of science and technology to inform public policy; and
- enhanced infrastructure for research and education. (pp. II-11 to II-12)

These questions applied Wenger-Trayner and Wenger-Trayner's (2015) concept of knowledgeability to CEI Graduate Fellows' perspectives and experiences of the BI of research.

Three open-ended questions invited fellows to share any other BI they were interested in exploring, personal skills and strengths that could support BI activities, and ways they might benefit from engaging in BI activities. These three questions were included to help students begin to reflect upon their impact identity (Risien & Storksdieck, 2018). Section 2: The Clean Energy Field was a very short section with only 3 Likert-style questions that asked students to rate how engaged they felt in the clean energy field, how likely it is that they would continue to be involved in this field, and how aligned their research is with the clean energy field. The purpose of these questions was

to better understand fellows' identification (Wenger-Trayner & Wenger-Trayner, 2015) with the clean energy field (RQ4).

PLV Workshop Survey Validity and Reliability. As Mertler (2020) suggests, “evidence of validity based on test (or instrument) content” (p. 155) is likely most appropriate for practitioner-researchers. This type of validity is concerned with whether the instrument content is aligned with what one wants to measure and was used to establish the validity of this survey. For this instrument, my main goal was to learn how interested and knowledgeable CEI Graduate Fellows feel they are with respect to the BI of research. I was also curious to see if there was any relationship between how aligned their research was to broader impacts and their feelings of knowledgeability. Since most fellows are STEM doctoral students and likely familiar with the NSF, I chose to include in this instrument 10 common examples of BIs directly from NSF's PAPPG. The instrument then explicitly asks them to rate themselves according to their interest, knowledgeability, and the relatedness of their research. To evaluate the reliability of the quantitative questions in this survey, I used IBM SPSS Statistic (Version 28) to compute Cronbach's alpha for each of the subscales in this survey: interest, knowledgeability, and relatedness of research. This is a way to statistically measure the internal consistency of a tool and is appropriate for an instrument like this that was only administered once to participants (Mertler, 2020).

I also wanted to assess fellows' identification with the clean energy field. Wenger-Trayner and Wenger-Trayner (2015) describe three “modes of identification” (p. 20) as engagement, alignment, and imagination, which all influence one's identification with a particular practice. Therefore, the three Likert-style questions included in Section 2 of this survey explicitly addressed these three different modes of identification and

Cronbach's alpha was also computed to determine the internal consistency of this clean energy subscale.

Qualitative Instrument: Semi-Structured Interview Protocol

A semi-structured interview protocol was developed for a focus group interview with CEI Graduate Fellows. The purpose of this focus group was to provide participants with an opportunity to reflect upon and synthesize their experiences within a group setting as well as to provide me with the opportunity to elaborate on findings from the PLV Workshop Survey with respect to research questions 2 and 3. An interview protocol was developed to use as a guide for my facilitation of the focus group. It included six questions ranging from introductory questions about student names, research, and PLVs to more reflective questions about participants' experience and evaluation of the PLV Design Workshop. The protocol also invited participants to share whether the workshop influenced their ideas about the broader impacts of their research and their identification with the field of clean energy. To review the interview protocol, please refer to Appendix I.

Data Collection and Analysis

Research Question 1

Products of Lasting Value Rubric

To assess the quality of PLVs, I reviewed each fellow's final (or only) PLV Check In along with their product and scored them on all four criteria. Then, IBM SPSS Statistic (Version 28) was used to compute descriptive statistics for the PLV quality, specifically the mean, standard deviation, and range for each criterion and total rubric score. To explore the relationship between PLV Rubric Scores and fellows' attendance at the PLV Design Workshop, Spearman's rho correlation coefficient was calculated. The results of this analysis are presented in Chapter 4.

PLV Rubric data was also analyzed by participant type. Thirteen Products of Lasting Value were turned in by 18 fellows who volunteered to have the data from their PLV Check Ins used in this study. Two types of participants took part in this study — fellows who either worked on their own to create PLVs or were the only team member to participate in this study or fellows who had 1 other team member participate in the study. I refer to these first participants as individuals and the latter as partners. Because the check ins were needed to assess products, I gave rubric scores for each fellow not for each PLV. Therefore, data was also analyzed by participant type and compared to the aggregate results.

Research Questions 2 and 3

PLV Workshop Survey

A voluntary and anonymous PLV Workshop Pre-Survey and Post-Survey were administered digitally using the survey software QuestionPro at the start of the PLV Design Workshop and at the end. During the first session of the workshop, I introduced the survey via QR code on one of my introductory slides and gave students time to complete it. Fifteen surveys were completed. Unfortunately, no post-surveys were completed. I believe there were two main reasons for this discrepancy. First, I gave fellows time in Session 1 to complete the pre-survey but did not ask students to stay after Session 3 to complete the post-survey. Second, fellows may have confused my request for them to complete the final PLV Check In with the request to complete the PLV Workshop Post-Survey. While I attempted some follow-up to gather post-survey responses, I also needed to be sure that fellows would complete CEI's Annual Graduate Fellow Survey, which is administered at the end of spring quarter.

It was my hope that any changes between the pre- and post-survey would help determine if the PLV Design Workshop increased fellows' knowledgeability of the BI of

their research (RQ2) and strengthened their identification with the clean energy field (RQ3). Despite the inability to observe explicit changes between a pre- and post-survey, the data collected from the pre-survey were analyzed to provide a baseline about fellows' perspectives on the BI of their research and the clean energy field.

Quantitative Data Analysis. There were four total subscales in this survey: Interest in BI, Relatedness of Research to BI, Knowledgeability of BI, and Identification with Clean Energy. For each subscale in section one of this survey, descriptive statistics were used to summarize the data. Specifically, I used IBM SPSS Statistic (Version 28) to compute the mean average, standard deviation, and range for the Interest in BI, Relatedness of Research to BI, and Knowledgeability of BI subscales. I also computed the mean rating and standard deviation for each question in each category. This allowed me to compare, on average, fellows' interest, research, and knowledgeability for each BI.

Qualitative Data Analysis. The three open-ended questions from section one of the survey were analyzed using several rounds of coding. First, I read through survey responses to get a sense of the data and jotted down notes as I read. One day later, I added all responses into a spreadsheet. I used descriptive coding to identify the main topic or topics of each comment, which allowed me to create an index of fellows' ideas related to each question (Saldaña, 2021). These codes were added to the column next to each response. I reviewed these codes a day later and used pattern coding to categorize descriptive codes into larger themes or concepts. As I did this, I reviewed and revised descriptive codes as needed. Finally, I reviewed these Pattern Codes one day after I created them and summarized them with descriptions and frequency counts. I constantly compared these patterns to each other as well as the Descriptive Codes and updated both descriptive and Pattern Codes to summarize the concepts more accurately behind

fellows' answers. Below I share the Pattern Codes that resulted from analysis of the three open-ended questions in this survey.

Integration of Mixed Methods. The point of interface for the integration of the quantitative and qualitative data from the PLV Workshop Survey occurred during the interpretation of results. Point of interface describes the place where quantitative and qualitative data are integrated (Ivankova, 2015). After data for each strand of the survey were collected and summarized — either through descriptive statistics or qualitative coding — I interpreted these results together to make conclusions about research questions 2 and 3.

Focus Group Interview

Four CEI Graduate Fellows from the 2021-2022 cohort volunteered to participate in one focus group designed to learn more about their experience with the PLV Design Workshop and their perspectives on the broader impacts of their research. Participants were recruited during the PLV Workshop as well as by email. I shared a consent form via email during recruitment and in follow-up emails with interested participants. Once enough fellows had volunteered, I scheduled a time and reserved a room on campus for us to meet. The interview took place on July 1, just over a month after the PLV Showcase and two months after the last session of the PLV Design Workshop. Each participant was informed that their participation was voluntary and that data from the interview would be confidential. Each participant signed a consent form before the focus group. The 60-minute interview was conducted in person on campus and recorded via a Zoom video (<https://zoom.us/>) and Recorder Plus: Voice Recorder App (<https://recorderplus.com/>).

I used the six steps of analyzing and interpreting data that are common for qualitative data (Creswell & Guetterman, 2019). These can be summarized as preparing data for analysis, exploring data through coding, creating descriptions and themes from

codes, using visuals and narratives to represent findings, interpreting results based on personal analysis and literature, and validating the findings (Creswell & Guetterman, 2019, p. 237). To prepare for data analysis, the recordings were uploaded to the Otter.ai (<https://otter.ai/>) software and transcribed. The Recorder Plus software produced a higher-quality audio recording, so I reviewed the transcript produced from this audio recording twice, editing as needed. Despite better quality, some audio was undecipherable due to face masks, multiple people talking at once, or other factors. Duplicate words and words such as 'like' were still included, but "uh" and "um" were not transcribed.

For an initial exploration of the data, I printed the transcript and hand-coded using a combination of In Vivo and Descriptive Coding techniques. In Vivo coding uses interviewees' own words as codes and is an opportunity to incorporate participant voice in one's study and analysis and descriptive coding summarizes text with words or phrases (Saldaña, 2021). I then conducted a second round of coding using the same techniques as a sort of internal check on these codes. This second round was conducted in a spreadsheet, which allowed me to capture all cycles of coding and compare the analytical progress of codes across time. Columns included the following headings: Order, Speaker, Transcript, and 1st Coding Cycle – Initial Coding. As I continued to iterate with coding, I took breaks between each cycle of coding to prevent fatigue. With each new cycle of coding, I added columns and codes to the spreadsheet. I often struggle to move from a very descriptive code to a more macro or meso level of coding, so this served as a sort of metacognitive tool to help me progress to a third and fourth cycle of coding with Concept Codes. Saldaña (2021) notes that this type of coding is often referred to as "analytic coding" (p. 152) since it assigns a broader idea to data than mere description or topic. To transition to a thematic analysis of these codes, I reviewed an

alphabetized list of codes and created a word cloud to visual the codes. I updated codes closely related but worded differently and tried to reduce the number of codes. I ended up with 42 different Concept Codes. When accounting for Concept Codes with unique subcodes, there were a total of 72 Concept Codes.

Pattern Coding was then employed to group these 72 codes into eight unique categories, concepts and themes (Saldaña, 2021). Pattern Codes attempt to generate explanations of broader themes represented by these codes (Saldaña, 2021). However, a few of the Pattern Codes were descriptions of categories rather than explanatory themes. To create the Pattern Codes, I reviewed the codes after a period of time away and made a few changes. For example, I moved one code — “timing of new insights” — to a more appropriate category, which left me with two of the same codes that had been placed in my catch-all category, Miscellaneous, Not Major Themes. This code was eventually subsumed by another theme (Fellows least identified with clean energy stand to gain the most). I also realized that some of the data and codes in Fellow Background & Context were being used to support another theme — Fellows least identified with clean energy stand to gain the most — so I moved these codes. I then changed Fellow Background & Context to PLV Background & Context. Finally, I reviewed the final Concept Codes and the largest category — Workshop Pros and Cons — to develop two separate categories: Workshop Outcomes and Evaluation of Workshop. After more time away, I reviewed these last two categories and assigned more explanatory codes. Some of the resulting Pattern Codes were less relevant to the research questions posed in this study, but all are listed in Table 4 for transparency.

Table 4*Initial and Final Pattern Codes from Focus Group Interviews*

Initial Pattern Codes	Final Pattern Codes
CEI Fellowship offers multiple opportunities for growth	CEI Fellowship offers multiple opportunities for growth
Fellows' background & context	PLV background & context
Fellows least identified with clean energy stand to gain the most	Fellows least identified with clean energy stand to gain the most
Gains in Broader Impacts, but questions remain	Gains in Broader Impacts, but Questions Remain
Miscellaneous, Not Major Themes	
More transparent, accountable, and sustainable infrastructure for PLVs	Are PLVs worth the effort?
Target Audience	Target Audience
Workshop Pros and Cons	Workshop Outcomes
More structured support needed	

Note. Bolded text represents a code that was updated.

Throughout the coding process, I recorded memos about different codes and themes, wrote reflections on my process and challenges, and kept notes of procedure. In Chapter 4, each Pattern Code is described and included with its corresponding list of Concept Codes. The final Pattern Codes were used to develop eight assertions with respect to the research questions for this study.

Trustworthiness, Reliability, and Validity

In this chapter, I introduced the method for this action research study as well as the instruments used to collect data for this study. For each quantitative instrument

introduced, I provided specific information about measures taken to address validity and reliability of these items. In this section, I report more broadly on strategies used to ensure trustworthiness of the qualitative data and identify potential threats to validity and reliability. Trustworthiness refers to the “accuracy and believability” (Mertler, 2020, p. 141) of qualitative data. To establish trustworthiness of data, a researcher can ensure their data are credible, transferable, dependable, and confirmable (Mertler, 2020). To establish the credibility, or believability, of data collected and presented in this action research study, I have made an effort to transparently communicate issues and complexities among the data and analysis. For instance, I have incorporated contradictory opinions from interview participants and analyzed PLV Rubric Scores in more than one way to make a fair assessment of PLV quality despite the number of teammates who participated in the study. I attempted to describe in detail the context for this study, the steps taken to develop instruments, and how I collected and analyzed data to establish transferability of this study (Mertler, 2020). In order to support confirmability of the data, I presented results separately from my analysis and interpretation and used In Vivo codes when possible to let the data “speak for itself.” Finally, to establish dependability, I have taken responsibility for communicating changes that took place over the course of this study such as the need to drop unreliable questions from the pre-survey and the lack of post-survey results.

Some of the other strategies I have used to support the trustworthiness of this study’s data include triangulation, peer checks, external audits, negative cases analysis, and reflexivity (Mertler, 2020). I used four different instruments to collect both quantitative and qualitative data to support final claims about the study. Quantitative data was collected with the PLV Rubric for RQ1 (PLV Quality). Quantitative and qualitative data were collected with the PLV Workshop Pre-Survey and qualitative data

was collected with a focus group as evidence for RQ2 (BI Knowledgeability). Quantitative data from the PLV Workshop Pre-Survey and qualitative data from the focus group were collected to support RQ3 (Identification with Clean Energy). Finally, I checked in with a peer when developing the rubric and asked faculty to help review my process for analyzing quantitative data. I made sure to describe contradictory results, especially with the focus group, to make sure all data was presented accurately. Finally, I used several tools to encourage my own reflection about my interpretations and to document my process. I had a researcher journal to track overall procedures and questions. For each instrument, I kept a separate document to record my process for coding qualitative data and computing descriptive statistics.

Additionally, I employed Innovation Configurations (IC) maps to envision ideal forms of student participation and engagement for each workshop session (Hall & Hord, 2006). As Hall and Hord (2006) note, innovations created for educational systems are often adapted by the users during implementation. While this is not necessarily negative, this often occurs due to a lack of clarity or consideration of what the implementation of an innovation should look like during the design stage (Hall & Hord, 2006). Developing each map required me to think in advance about the ideal participation and to consider potential issues with the session. I also used these as reflection tools. After the first two sessions, I used the map to reflect on how the session went and to identify any changes that I wanted to make to the upcoming session. I recorded my evaluation of how each session went with notes that I will use to inform future workshops. These IC Maps can be found in Appendix J.

Despite these efforts, there are still some threats to the reliability and validity of the data I collected that are important to point out. One of these is related to the reliability of the PLV Workshop Survey. Because I was unable to find a survey that

measured knowledgeability of BI of research, I created my own survey based on NSF content and my interpretation of Wenger-Trayner and Wenger-Trayner's (2015) concept of knowledgeability. While I did establish internal reliability among each subscale in this survey, I did not compare results with external measures (e.g., test-retest or parallel forms). Another threat to reliability and validity involves the PLV Rubric used to assess the PLVs. I originally intended to have other members from our community help score PLVs, which would have involved a more robust review of the rubric and establishing inter-rater reliability. Due to time constraints, this was not possible. Finally, one threat to the validity of data collected from the Focus Group Interview could occur from my interview style. Reviewing the transcript revealed how often I added more context and background information to a question rather than asking a question directly and simply. While this style was more conversational, it also could have made the questions more ambiguous or influenced the types of answers I received. Further, each cycle of research informed the next. This even happened while coding, making connections to prior interviews or making connections with other analysis of qualitative data in this particular research cycle. While I tried to stay focused on each body of evidence while coding, it is possible that other data influenced my focus and insights. With these threats in mind, the data collected for this cycle of research are presented and analyzed separately in Chapter 4. I also discuss further the complementarity of data and address limitations of this study in Chapter 5.

CHAPTER 4

DATA ANALYSIS AND RESULTS

The purpose of this concurrent mixed methods action research study was to evaluate how and to what extent a semi-structured design workshop, the Product of Lasting Value (PLV) Design Workshop, supports the professional development of CEI Graduate Fellows and increases the quality of educational outreach products. More specifically, this action research study was designed to answer the following research questions (RQs):

RQ1: How does the PLV Design Workshop increase the quality of products of lasting value?

RQ2: How and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research?

RQ3: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field?

In Chapter 3, the qualitative and quantitative instruments as well as the methods used to collect and analyze data were discussed. In this chapter, data collected from each instrument is presented and then analyzed according to relevant research questions (see Table 5 for a summary of this process).

Table 5*Summary of Data Collection and Integration by Research Question*

Research Question	Method of Data Collection	Method of Integration
RQ1: PLV Quality	QUAN: PLV Rubric QUAL: PLV Check Ins	PLV Check Ins were used to collect data for assessment via PLV Rubric
RQ2: BI Knowledgeability	QUAN & QUAL: PLV Pre-Survey QUAL: Focus Group Interview	Focus groups served to elaborate on pre-survey results
RQ3: Identification with Clean Energy	QUAN & QUAL: PLV Pre-Survey QUAL: Focus Group Interview	Focus groups served to elaborate on pre-survey results

Research Question 1 (PLV Quality)

To assess the quality of the PLVs that were created by the 2021-2022 cohort of CEI Graduate Fellows — RQ2 (PLV Quality)— I used an analytic rubric to review each PLV created by fellows who agreed to allow their data to be used in this study. Because the PLV Check Ins provided important data about the target audience and intended purpose of each product, they were necessary for a thorough and accurate review of the PLVs. The rubric assessed each PLV based on four criteria: Purpose of PLV, Target Audience, Design Strategy, and Communication. Each criterion had four performance levels described with scores ranging from 4 (high) to 1 (low). Thus, the highest total score possible was 16 while the lowest total score possible was 4. Again, each Product of Lasting Value and the author’s most recent PLV Check In were used to generate rubric scores.

The quantitative results from the PLV Rubrics will be presented for all participants and for each participant type. First, aggregate data representing rubric scores for the 18 fellows who agreed to allow their data to be used in this study will be presented. Next, data will be disaggregated by participant type and summarized. Ten of

the 18 fellows who participated had one other teammate participate in this study and will be referred to as “partners.” Eight of the 18 fellows either worked by themselves to create a PLV or were the only teammate to participate in the study. These participants will be referred to as “individuals.” See Table 6 for a summary of these participants. Because this study had ten partner participants, the data presented in this section represent 18 PLV Check Ins but only 13 PLVs.

Table 6

Number of Fellows, PLV Check Ins, and PLVs by Participant Type

Participant Type	No. Fellows	No. PLV Check Ins	No. PLVs
Individual	8	8	8
Partner	10	10	5
Total	18	18	13

PLV Rubric Results

In general, the quality of PLVs reviewed was fairly high. The mean total rubric score was 12.61 (SD = 3.01) out of sixteen points possible, and the mean score for all four rubric criteria was 3.15 (SD = .75). See Table 7 for descriptive statistics of these scores. The criterion with the highest mean score was the Purpose of PLVs (M = 3.50, SD = .51), and it also had the smallest range (range = 1.00). The mean scores for the Target Audience, Design Strategy, and Communication were 3.06 (SD = .87), 3.00 (SD = .91), and 3.06 (SD = 1.11), respectively, and they all had a range of three. While the average total rubric scores represented a fairly high quality of PLVs, it is important to note that the range of individual scores was quite large. For example, the highest total rubric score was 16.00, while the lowest total rubric score was 7.00. Thus, many PLVs have some room for slight improvement, and a few could be categorized as poor quality.

Table 7*Descriptive Statistics for Total and Criterion Rubric Scores*

Criteria ^a	<i>M</i>	<i>SD</i>	Range	Min	Max
Purpose of PLV	3.50	.51	1.00	3.00	4.00
Target Audience	3.06	.87	3.00	1.00	4.00
Design Strategy	3.00	.91	3.00	1.00	4.00
Communication	3.06	1.11	3.00	1.00	4.00
Total Rubric	12.61	3.01	9.00	7.00	16.00

^a *n* = 18 for each score

To explore the relationship between PLV quality and participation in the PLV Workshop, I disaggregated the scores (total and sub constructs) by the number of sessions attended. As Table 6 shows, mean rubric scores increase as workshop attendance increases. The mean rubric scores for fellows who attended zero, one, two, and three workshop sessions were 7.00 (*n* = 3, *SD* < .00), 12.60 (*n* = 5, *SD* = 1.67), 14.00 (*n* = 5, *SD* = 2.00), and 14.60 (*n* = 5, *SD* = .89), respectively. This trend was also demonstrated for the mean scores for each rubric criterion except for Communication where the mean score and standard deviation for PLVs created by fellows who attended 2 and 3 workshop sessions was the same (*M* = 3.60, *SD* = .55). To further explore this relationship between PLV Total Rubric Scores and workshop attendance, I used IBM SPSS Statistic (Version 28) to calculate the Spearman's rho correlation coefficient for these two variables. Results show a significant, strong, and positive correlation between these two variables, $r(16) = .723$, $p < .001$, which confirms that scores increased as the number of sessions attended increased.

In general, rubric scores increased substantially from zero sessions attended to one session attended. For example, the mean total rubric jumped 5.60 points from zero to one session attended. Yet, the increase in mean total rubric scores from one to two sessions attended was only 1.40 points and the increase in mean total rubric scores from two to three sessions attended was only .60 points. As the evidence in Table 6 shows, this

trend was true for all rubric criteria except for the Purpose of the PLV. The mean Purpose of PLV criterion score for fellows who did not attend the workshop at all was 3.00 ($SD = .00$). This is much different than criterion scores for Target Audience ($M = 1.67, SD = .58$), Design Strategy ($M = 1.33, SD = .58$), and Communication ($M = 1.00, SD = .00$) when no sessions were attended. Overall, results still show that higher attendance at workshop sessions is associated with higher rubric scores.

Table 8

Comparison of Mean PLV Rubric Scores and Workshop Attendance

No. Sessions Attended	Total Rubric Score <i>M (SD)</i>	Purpose of PLV Score <i>M (SD)</i>	Target Audience Score <i>M (SD)</i>	Design Strategy Score <i>M (SD)</i>	Communication Score <i>M (SD)</i>
0, $n = 3$	7.00 (.00)	3.00 (.00)	1.67 (.58)	1.33 (.58)	1.00 (.00)
Minimum	7.00	3.00	1.00	1.00	1.00
Maximum	7.00	3.00	2.00	2.00	1.00
1, $n = 5$	12.60 (1.67)	3.40 (.55)	3.00 (.71)	3.00 (.00)	3.20 (.84)
Minimum	10.00	3.00	2.00	3.00	2.00
Maximum	14.00	4.00	4.00	3.00	4.00
2, $n = 5$	14.00 (2.00)	3.60 (.55)	3.40 (.55)	3.40 (.55)	3.60 (.55)
Minimum	12.00	3.00	3.00	3.00	3.00
Maximum	16.00	4.00	4.00	4.00	4.00
3, $n = 5$	14.60 (.89)	3.80 (.45)	3.60 (.55)	3.60 (.55)	3.60 (.55)
Minimum	14.00	3.00	3.00	3.00	3.00
Maximum	16.00	4.00	4.00	4.00	4.00
Total, $n = 18$	12.61 (3.01)	3.50 (.51)	3.06 (.87)	3.00 (.91)	3.06 (1.11)
Minimum	7.00	3.00	1.00	1.00	1.00
Maximum	16.00	4.00	4.00	4.00	4.00

One important thing to keep in mind about the data presented so far is that it includes data from both individual and partner participants. Since it could be argued that including PLV Rubric Scores for each fellow in the latter category doubles their influence on the data, I also reviewed the rubric scores and workshop attendance separately for these two groups. Overall, the rubric scores for both participant types were

quite similar. As Table 9 shows, the mean total rubric score for individual participants was 12.50 ($SD = 2.83$) and the mean total rubric score for partner participants was 12.70 ($SD = 3.30$). Scores for separate rubric criterion were also similar for each group. For both participant types, the mean Purpose of PLV Score was 3.50 and the mean Design Strategy Score was 3.00. The mean Communication Score for individual participants was slightly higher ($M = 3.13$, $SD = 1.13$) than for partner participants ($M = 3.00$, $SD = 1.16$). The largest difference in rubric criterion scores for participant types occurred for Target Audience. On average, partner study participants scored higher on this criterion ($M = 3.20$, $SD = .79$) than individual study participants ($M = 2.88$, $SD = .99$). Despite these differences, the data generally depict similar quality of PLVs for both individual and participant types.

Table 9

Mean Rubric Scores and Session Attendance by Participant Type

	Individual Study Participants <i>n</i> = 8			Partner Study Participants <i>n</i> = 10		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Purpose of PLV Score	3.50	.54	1.00	3.50	.53	1.00
Target Audience Score	2.88	.99	3.00	3.20	.79	2.00
Design Strategy Score	3.00	.54	2.00	3.00	1.16	3.00
Communication Score	3.13	1.13	3.00	3.00	1.16	3.00
Total Rubric Score	12.50	2.83	9.00	12.70	3.30	9.00
No. Sessions Attended	1.25	.89	3.00	2.00	1.16	3.00

Overall, rubric scores for each participant type also increased as the number of workshop sessions attended increased (see Table 10 to review the data). To determine if there was still a significant correlation between these two variables when the data was disaggregated by participant type, Spearman's rho correlation coefficient was computed for each group. For individual study participants, results showed a significant, strong, positive relationship between workshop attendance and total rubric scores, $r(6) = .755$, p

< .030. The correlation coefficient for partner study participants also demonstrated a significant, strong, positive relationship between workshop attendance and total rubric scores, $r(8) = .716$, $p < .020$. For all participants, then, results show that as workshop attendance increased, rubric scores also increased.

Table 10

Comparing PLV Quality and Workshop Attendance by Participant Type

No. Sessions Attended	Total Rubric Score	
	<i>M (SD)</i>	
	Individual Participants	Partner Participants
0 Sessions	7.00 (-) <i>n</i> = 1	7.00 (.00) <i>n</i> = 2
1 Session	12.60 (1.67) <i>n</i> = 5	- <i>n</i> = 0
2 Sessions	16.00 (-) <i>n</i> = 1	13.50 (1.91) <i>n</i> = 4
3 Sessions	14.00 (-) <i>n</i> = 1	14.75 (.96) <i>n</i> = 4
Total	12.50 (2.83) <i>n</i> = 8	12.70 (3.30) <i>n</i> = 10

Analysis of PLV Rubric Results

One of the main goals of the PLV Design Workshop was to support the development of high-quality PLVs. Specifically, I wanted to know if attending the workshop could increase the quality of products (RQ1). PLV Rubric results show a significant, strong, and positive relationship between workshop attendance and PLV quality. As attendance at workshop sessions increased, the mean rubric scores also increased. Yet, correlation should not be interpreted as causation, and other factors that might have influenced this positive relationship. For instance, students who decided to attend the PLV Design Workshop are likely more interested or engaged in this project than those who do not attend. Further, students who attended workshop sessions might have had more time during spring quarter to both attend the workshops and to work on

designing their PLVs outside of the workshop. This could also have led to higher quality of products.

Additionally, overall results for PLV Rubric Scores demonstrate that many CEI Graduate Fellows are able to design high quality PLVs. The mean scores for each criterion also show that fellows generally can identify a somewhat specific purpose for their product, align their PLV to its target audience, use some effective design strategies for reaching their audience, and communicate their science in a manner appropriate for their audience. However, some PLV scores were very low, suggesting that some fellows need more support to create high quality PLVs. In future iterations of the PLV Design Workshop, it could benefit fellows to use the rubric to self-assess their PLVs and to provide specific feedback to their peers.

One other trend that is important to review is the dramatic increase in mean criteria scores from zero sessions to one session for all criteria except for the Purpose of PLV criterion. Overall, there was little variation in scores for the Purpose of PLV. While this criterion received the highest mean score (Purpose of PLVs), it also had the smallest range (range = 1.00). Even for fellows who attended no workshop sessions, the mean score for this criterion was 3.00 which was much higher than the other rubric criteria. This fact and the observation that there is no substantial increase in scores from no sessions to 1 session, make me question a few things about this particular criterion. First, it is possible that the performance level descriptions for this criterion were not differentiated enough for all four performance levels. Therefore, this criterion needs to be reviewed for validity. Another factor that could contribute to this exception lies in the nature of this performance task. To achieve a high score for the Purpose of PLV, fellows simply needed to identify a purpose, align it with the CEI's mission, and choose an appropriate medium for this purpose. The tasks for the other 3 criteria were much more

difficult. These required students to identify *and implement* communication and design strategies tailored to a specific audience. More research into the task of identifying a purpose for one's PLV and a review of the four performance level descriptions for the Purpose of PLV criterion are both needed before the next iteration of the workshop.

Research Question 2 (BI Knowledgeability)

The second research question for this action research study was: how and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research? To answer this question, I collected data with the PLV Workshop Survey and elaborated on these results with a Focus Group Interview. In this section, I first present the quantitative and qualitative results from the PLV Workshop Survey. I then present qualitative results from the Focus Group that specifically relate to RQ2 (BI Knowledgeability). Finally, I integrate this data to draw conclusions about this specific research question.

PLV Workshop Pre-Survey Results

At the beginning of the first session of the PLV Design Workshop, I invited CEI Graduate Fellows to participate in an anonymous PLV Workshop Pre-Survey. The first section of this survey, Section 1: Perspectives on Broader Impacts, was designed to collect data on fellows' perspectives about their knowledgeability of the broader impacts (BI) of their research (RQ2). This section invited fellows to reflect on the following 10 BI examples that were taken directly from the National Science Foundation's Proposal & Award Policies & Procedures Guide (NSF PAPPG, 2020) for this survey:

- full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM);
- improved STEM education and educator development at any level;

- increased public scientific literacy and public engagement with science and technology;
- improved well-being of individuals in society;
- development of a diverse, globally competitive STEM workforce;
- increased partnerships between academia, industry, and others;
- improved national security;
- increased economic competitiveness of the U.S.;
- use of science and technology to inform public policy;
- enhanced infrastructure for research and education. (p. II-11)

Respondents were asked to review these 10 examples and then answer Likert-style questions for three different subscales: their interest in exploring each BI, the relatedness of their research to each BI, and their knowledgeability about each BI. In addition, three open-ended questions invited participants to share other BI activities they were interested in, the personal skills and strengths they brought to BI activities, and the potential benefits of participating in BI. The original intent of this tool was to pair pre- and post-survey data to identify any changes that took place throughout the PLV Workshop with respect to RQ2.

While 15 participants completed the pre-survey, no post-surveys were completed. This was likely due to confusion between the final PLV Check In and the PLV Workshop Post-Survey and the fact that I did not administer the post-survey during the workshop as I did for the pre-survey. Therefore, it is important to note that the data collected from the pre-survey provides a snapshot of CEI Graduate Fellow perspectives on the BI of research at the beginning of the intervention and is unable to depict any changes that took place throughout the workshop.

Quantitative Results

In Section 1 of the PLV Workshop Pre-Survey, fellows were asked to review 10 different BI activities and then answer the following questions with respect to each BI activity:

- How interested are you in exploring each type of broader impact?
- How related to your research is each broader impact?
- How knowledgeable are you about each BI?

Fellows could choose from five responses for each question: very interested (5) to not interested at all (1), very related (5) to not related at all (1), and very knowledgeable (5) to not knowledgeable at all (1). No neutral response was provided as an option. To determine the internal consistency of this instrument, IBM SPSS Statistic (Version 28) was used to compute Cronbach's alphas for all three subscales. The Interest in BI subscale (10 items; $\alpha = .714$), Relatedness to BI subscale (10 items; $\alpha = .747$), and Knowledgeability in BI subscale (10 items; $\alpha = .873$) all showed good levels of reliability. To summarize fellows' responses, descriptive statistics were computed for each BI activity. Table 11 shows the mean rating and standard deviation for each question and BI activity.

On average, CEI Graduate Fellows who completed the pre-survey ($n = 15$) reported more interest than knowledgeability or relatedness of their research with respect to BI activities. The mean rating for interest in BI activities was 3.73 ($SD = .52$, range = 2.00), the mean rating for knowledgeability of the same BI activities was 2.51 ($SD = .65$, range = 2.40), and the mean rating for how related their research was to these BI activities was 2.17 ($SD = .67$, range = 2.30). In other words, these average ratings summarize that fellows were "somewhat interested" to "interested" in these BI activities, "slightly knowledgeable" to "somewhat knowledgeable" about these BI activities, and their research was only "slightly related" to these BI activities.

Table 11*Descriptive Statistics for Mean BI Scores by Question*

	Interest in BI		Relatedness to BI		Knowledge-ability in BI	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
N=15 (Valid N = 13)						
full participation of women, persons with disabilities, and under-represented minorities in...STEM	4.33	0.72	1.93	1.16	3.53	0.83
improved well-being of individuals in society	4.33	0.82	3.67	1.29	2.87	1.13
use of science and technology to inform public policy	4.20	0.86	1.93	1.28	2.67	0.90
enhanced infrastructure for research and education	4.20	0.94	1.93	1.10	2.07	0.88
increased public scientific literacy and public engagement with science and technology	4.13	0.83	2.13	0.83	2.93	0.92
improved STEM education and educator development at any level	4.00	0.93	1.40	0.83	2.67	0.72
development of a diverse, globally competitive STEM workforce	3.87	0.83	1.87	1.13	2.53	0.83
increased partnerships between academia, industry, and others	3.33	1.18	2.53	1.46	2.07	1.00
improved national security	2.40	1.18	1.60	0.99	1.53	0.74
increased economic competitiveness of the U.S.	2.47	1.36	2.73	1.71	2.13	1.06

Note. The broader impacts listed in this table are directly quoted from the NSF's Proposal & Award Policies & Procedure Guide (NSF PAPPG, 2020, p. II-11).

With respect to respondents' interests, results show that fellows were most interested in the "full participation of women, persons with disabilities, and

underrepresented minorities in science, technology, engineering, and mathematics (STEM)” and “improved well-being of individuals in society” (NSF, 2020, p. II-1) with mean scores of 4.33 ($SD = 0.72$) and 4.33 ($SD = 0.82$), respectively. However, four other BI activities also had fairly high ratings, with mean scores of 4.00 or higher. These included: “improved STEM education and educator development at any level,” “increased public scientific literacy and public engagement with science and technology,” “use of science and technology to inform public policy,” and “enhanced infrastructure for research and education” (NSF, 2020, p. II-1). On average, fellows were least interested in “improved national security” (NSF, 2020, p. II-1) with a mean score of 2.40 ($SD = 1.18$). Though, mean scores for “increased economic competitiveness of the U.S.” (NSF, 2020, p. II-1) was also of low interest ($M = 2.47$, $SD = 1.36$). Overall, results from this pre-survey show that CEI Graduate Fellows are interested in a variety of BI activities, especially activities that support the well-being of others, inclusion in STEM, education, policy, and partnerships.

While CEI Graduate Fellows reported high interest in most BI activities, they generally felt only slightly knowledgeable about these BI activities ($M = 2.51$, $SD = .647$, range = 2.40). On average, fellows felt most knowledgeable about “full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM)” (NSF, 2020, p. p. II-1) and least knowledgeable about “improved national security” (NSF, 2020, p. II-1) which had a mean rating of 3.53 ($SD = 0.83$) and 1.53 ($SD = 0.74$), respectively. Every other BI activity for this subscale had a mean rating between 2.00 and three, which corresponds to slightly or somewhat knowledgeable.

Finally, CEI Graduate Fellows generally see only a slight relationship between the 10 BI activities and their research. All BI activities except for one received mean ratings

under 2.73. “Improved STEM education and educator development at any level” (NSF, 2020, p. II-1) was considered least related to fellows’ research and had a mean rating of 1.40 ($SD = 0.83$), despite being of high interest to fellows. Fellows generally found “improved well-being of individuals in society” (NSF, 2020, p. II-1) to be the most related to their research with a mean rating of 3.67 ($SD = 1.29$). Yet, even this rating corresponds to “somewhat related” to research. In sum, despite high interest in a diversity of BI activities, CEI Graduate Fellows generally felt that their research is unrelated and their knowledgeability is somewhat low with respect to the same activities.

Qualitative Results

In addition to the Likert-style questions, respondents were asked three open-ended questions in Section 1: Perspectives on Broader Impacts in the PLV Workshop Pre-Survey. These questions were:

1. Please describe any other broader impacts that you are interested in exploring.
2. What personal skills and strengths do you have that could support broader impact activities?
3. How might you benefit from engaging in broader impact activities?

These questions provided an opportunity for me to hear from fellows about broader impact activities in their own words and served to elaborate on the quantitative results. For each question, I used Descriptive Coding to generate a list of topics from fellows’ answers. Pattern Coding was then employed to categorize and build themes from these codes. These qualitative results are summarized in this section. See Appendix K for a summary of PLV Workshop Coding.

When CEI Graduate Fellows had the opportunity to share other BI they were interested in exploring, many shared specific interests or audiences with which they were interested in engaging. After several rounds of coding, 12 Descriptive Codes and five

Pattern Codes emerged from fellows' responses. See Table 12 for a summary of the five themes that emerged from responses to Question 1. The theme with the highest frequency (n = 6) was *Justice*, and this incorporated several codes and data generally related to the goal of "improvement of people's lives" (PLV Workshop Pre-Survey, 2022). Descriptive Codes that were included in this category included: environmental justice, JEDI in STEM, just governmental and economic systems, and improving lives through sci policy and infrastructure. The theme with the next-highest frequency of codes was *Energy* and this incorporated several explicitly related In Vivo codes such as "our net carbon neutral future," "energy resiliency," "global materials supply," and "renewable energy" (PLV Workshop Pre-Survey, 2022). "*Personal Preferences*" (Risien and Storksdieck, 2018, p. 62) was assigned as a Pattern Code to synthesize several comments that I interpreted as related to impact identity. For this question in particular, three responses noted an interest or capacity to work with a specific audience such as low-income or coastal communities. *Education* and *Policy* were two explicit Pattern Codes that emerged from the data and had the fewest Descriptive Codes — 2 and 1, respectively. In sum, data suggests that many fellows are interested in BI activities that advance justice and support clean energy solutions.

Table 12*Pattern Codes and Descriptions for Open-Ended Question 1*

Please describe any other broader impacts that you are interested in exploring.	
Pattern Codes with Frequency Counts	Code Description and Examples
Justice, 6	This pattern code incorporates descriptive codes associated with justice and the goal of “improvement of people's lives” (PLV Workshop Pre-Survey, 2022). The arena and approach to working toward justice differed from science policy and infrastructure to more “equitable and accessible STEM education for public K-12 schools” (PLV Workshop Pre-Survey, 2022). This also incorporated 2 comments coded as environmental justice.
Energy, 4	Codes in this category are specifically related to energy in some way such as energy resiliency of communities, carbon neutrality, and the “global materials supply” (PLV Workshop Pre-Survey, 2022).
"Personal Preferences," 3	The pattern code, Personal Preferences, comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their “personal identities and intrinsic motivators” (p. 62). Codes included in this category for this question relate to fellows’ interest or experience working with specific audiences.
Education, 2	This code refers to interests in education. It included both “public literacy” and concern for improving “education throughout a student's life” (PLV Workshop Pre-Survey, 2022).
Policy, 1	The pattern code includes interest specifically related to policy.

When asked fellows to share personal skills and strengths that would support their engagement with BI activities, several CEI Graduate Fellows identified communication skills and personal experience or passion for working with specific causes or groups as strengths. Qualitative coding for this open-ended question resulted in 20 Descriptive Codes and seven Pattern Codes (see Table 13 for a summary of these codes). The Pattern Code with the highest frequency count was *Communication Skills* (n

= 9). Several fellows listed science communication as a strength and others mentioned writing or graphic skills. The pattern code with the next-highest frequency count was “*Personal Preferences*” (Risien & Storksdieck, 2018, p. 62). I interpreted several strengths as related to the “personal identities and intrinsic motivators” (Risien & Storksdieck, 2018, p. 62) of fellows. Codes included in this category relate to fellows’ interest or experience working with specific audiences, their passion for improving STEM culture, or topics that are of personal interest to them. Another theme that emerged was *Transferable Skills*, which included Descriptive Codes such as leadership, event planning, or interdisciplinary knowledge that could serve fellows well in their futures and careers. This code was applied to four Descriptive Codes. The last four Pattern Codes had frequency counts of 3 or 2. These included *Disciplinary Skills*, *Content Knowledge*, and *Teaching*, which were all fairly explicit categorizations. Finally, one other theme I observed was *Representation in STEM*, which referred to comments where fellows identified their social identification with groups historically underrepresented in STEM as strengths. These responses were important insights related to the power of representation in STEM and the ability to communicate and identify with underrepresented groups in STEM. Overall, fellows identified a diversity of specific strengths and skillsets they have that would support their engagement in BI activities.

Table 13*Pattern Codes and Descriptions for Open-Ended Question 2*

What personal skills and strengths do you have that could support broader impact activities?	
Pattern Codes with Frequency Counts	Code Description and Examples
Communication Skills, 9	Several fellows included communication skills as strengths. This pattern code incorporates many different communication skills such as writing, graphics, general communication, and science communication more specifically.
"Personal Preferences," 8	The pattern code Personal Preferences comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their "personal identities and intrinsic motivators" (p. 62). Codes included in this category relate to fellows' interest or experience working with specific audiences, their passion for improving STEM culture, or topics that are of personal interest to them.
Transferable Skills, 4	This pattern code incorporates what I interpret to be transferable skills such as leadership, event planning, or interdisciplinary knowledge that would serve fellows well in their futures and careers.
Disciplinary Skills, 3	This pattern code describes strengths related to disciplinary skills or expertise such as data science or research skills. One fellow called out the fact that they "do science" (PLV Workshop Pre-Survey, 2022) as a strength.
Representation in STEM, 3	While this pattern code might also fall under the concept of "Personal Preferences," I wanted to highlight it separately for its unique value. Several fellows noted their social identification with non-dominant groups in STEM as strengths. These responses were important insights related to the power of representation in STEM, the ability to communicate and identify with underrepresented groups in STEM.
Content Knowledge, 2	Two fellows listed a type of content knowledge as a strength such as "clean energy literacy" or a critical understanding of "green capitalism" (PLV Workshop Pre-Survey, 2022).
Teaching, 2	Two fellows felt that teaching and/or lesson planning were strengths or skills that they brought to BI.

The last open-ended question from section one of the PLV Workshop Pre-Survey invited fellows to share potential benefits of engaging in broader impact activities. Qualitative analysis of responses to Question 3 resulted in 12 Descriptive Codes and seven Pattern Codes (see Table 14 for a summary of all Pattern Codes for Question 3). Interestingly, *knowledgeability of BI* (n = 5) was the theme with the highest frequency count. Fellows suggested that engaging in BI could lead to increased ability to engage in different BI activities, better understanding of others' needs, and becoming a "more well-rounded ... researcher" (PLV Workshop Pre-Survey, 2022) – all aspects I interpreted as contributing to knowledgeability of the BI landscape. The Pattern Code with the next-highest frequency was "*Personal Preferences*" (n = 4) and was inspired by comments related to fellows' "personal identities and intrinsic motivators" (Risien & Storksdieck, 2018, p. 62). With respect to the benefits of engaging in the BI of research, fellows expressed a desire to "give back to those who have helped me" and that "doing good makes you feel good" (PLV Workshop Pre-Survey, 2022). The rest of the Pattern Codes had frequency counts of 3 or fewer Descriptive Codes. These themes included skills such as *Science Communication*, *Intercultural Awareness*, and *Transferable Skills* such as developing "interpersonal skills" and making them "more competitive" (PLV Workshop Pre-Survey, 2022) for future applications. While several transferable skills were identified as benefits, CEI Graduate Fellows seemed more interested in being better able to navigate BI activities and more intrinsically motivated to engage in BI for the personal satisfaction they would gain.

Table 14*Pattern Codes and Descriptions for Open-Ended Question 3*

How might you benefit from engaging in broader impact activities?	
Pattern Codes with Frequency Counts	Code Description and Examples
Knowledgeability of BI, 5	One pattern I observed were benefits that I interpreted as directly related to the Knowledgeability of BI. This included benefits such as better understanding of and ability to engage in different BI activities. It also included better understanding of others' needs and becoming a "more well-rounded ... researcher" (PLV Workshop Pre-Survey, 2022).
Personal Preferences, 4	The pattern code Personal Preferences comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their "personal identities and intrinsic motivators" (p. 62). With respect to the benefits of engaging in the BI of research, fellows expressed some intrinsic motivators such as "doing good makes you feel good" and a desire to "give back to those who have helped me" (PLV Workshop Pre-Survey, 2022).
Science Communication, 3	Three fellows felt that engaging in BI activities would make them "a better science communicator" (PLV Workshop Pre-Survey, 2022).
Connections, 2	The pattern code Connections refers to the ability of BI activities to facilitate connections with new people, whether this was in one's field or with students.
Intercultural Awareness, 2	Intercultural Awareness describes the ability of BI activities to help fellows learn about "people from different areas of life" (PLV Workshop Pre-Survey, 2022).
Disciplinary Expertise, 1	Disciplinary Expertise refers to the ability to engage in BI activities to deepen one's research or expertise.
Transferable Skills, 1	One other theme that arose from one fellow's comments was that of transferable skills. They identified some benefits as developing "interpersonal skills" and making them "more competitive" for future applications (PLV Workshop Pre-Survey, 2022). This comment seemed directly related to transferable skills that will help one secure a job.

Analysis and Integration of PLV Workshop Pre-Survey Results

Overall, both quantitative and qualitative PLV Workshop Survey results suggest that CEI Graduate Fellows are interested in broader impact activities and understand that engaging in such activities have personal benefits such as making them “more well-rounded” (PLV Workshop Survey, 2022) researchers. Yet, they feel substantially less knowledgeable about these same activities, and they do not see research as related to these activities. In general, the qualitative results elaborated on quantitative results providing increased specificity about personal interests, strengths, and motivators for engaging in BI activities. Yet, I view the low quantitative scores for the BI Knowledgeability subscale as contradictory to the impressive list of strengths and skills that fellows shared in their open-ended responses. While I interpreted fellows’ skills and strengths as related to their knowledgeability about BI activities, fellows did not. Another interesting trend was that only a few students included their disciplinary expertise as a strength that could support their BI activities. Overall, these results suggest that CEI Graduate Fellows likely need more support from me to make the connection between the strengths, skills, and experience they already possess as valuable and connected to knowledgeability about the BI of their research.

Focus Group Interview

In addition to the PLV Workshop Survey, one focus group interview was conducted to collect data collected for RQ2 (BI Knowledgeability) and RQ3 (Identification with Clean Energy). It also offered an opportunity for me to follow up on questions that emerged throughout this cycle of research. Four CEI Graduate Fellows agreed to participate in the focus group. Two of the interviewees attended all three sessions of the PLV Design Workshop while the other two interviewees attended only one session. The focus group was conducted in person, recorded with two different

sources as a backup, and then transcribed using the Otter.ai software. After a second round of editing, this transcript was approximately 9,300 words. In this section, a description of the methods used to analyze the transcript will be described first. Then only results and analysis related to RQ2 (BI Knowledgeability) will be discussed. Results related to RQ3 (Identification with Clean Energy) will be presented in the next section. For a summary of all codes generated from this interview, please see Appendix L.

Several rounds of coding were used to get familiar with the transcript and to generate themes systematically and inductively from this data. An initial cycle of coding was applied to this transcript using In Vivo and Descriptive Coding. I then conducted a second cycle of coding with the same approach, partly as an internal check. To gain a more “meso or macro” (Saldaña, 2021) understanding of this data, I employed Concept Coding for a third cycle of coding, checking and updating these codes after a period of time away from the transcript. Finally, Pattern Coding was employed to group and summarize the Concept Codes into categories and themes (Saldaña, 2021). Eight Pattern Codes were identified and these were used to make assertions related to the research questions and the PLV Design Workshop. Each Pattern Code is defined, along with its respective Concept Codes and Assertion in Appendix M.

Qualitative Results for Focus Group Interview

During the interview, I asked the CEI Graduate Fellows if they had any thoughts on whether the PLV Workshop encouraged any growth or learning about the BI of their research, reassuring them that it was fine to say no. One theme related to RQ 2 (BI Knowledgeability) that emerged from this discussion was: *gains in broader impacts, but questions remain*. This theme incorporated the somewhat contradictory ideas that I observed related to the BI of research. It included four concept codes: *growth in BI*, *imposter syndrome mitigated*, *PLV/research disconnect*, and *What's the relationship*

between BI, PLVs, and research? The Concept Codes *Growth in BI* and *Imposter syndrome mitigated* were applied to content where fellows described positive increases in understanding of or confidence in the BI of their research. The Concept Codes *PLV/Research Disconnect* and *What's the relationship between BI, PLVs, and Research?* were applied to ideas that demonstrated difficulty making connections between the PLV and one's research or between the PLV, one's research, and the concept of BI. See Table 15 for a summary of the Pattern Code, corresponding Concept Codes, and assertion related to RQ 2 (BI Knowledgeability).

Table 15

Focus Group Interview Codes and Assertion for RQ2

Pattern Code with Corresponding Concept Codes	Assertion
<p>Gains in Broader Impacts, but Questions Remain</p> <ul style="list-style-type: none"> • Growth in BI • Imposter syndrome mitigated • PLV/Research Disconnect • What's the relationship between BI, PLVs, and Research? 	<p>While some fellows have increased understanding of the BI of their research, it is unclear to what extent this increase was related to the PLV Design Workshop.</p>

Overall, this theme synthesizes findings from the focus group interview that show some increase in fellows' understanding of the BI of their research (RQ3), but also some confusion about BI and difficulty connecting PLV with BI. One quote from the focus group interview sums this theme up well. Fellow 2 recalled one workshop session where I listed different types of BI activities on a PowerPoint slide. They said "that helped me a lot to be able to be like: Oh, I guess this is a broader impact of my research. But I also feel like...our PLV wasn't really related to our research at all" (Focus Group Interview, 2022).

Fellow 1, who did not explicitly say they developed a greater understanding of the BI of their research, said “it’s easy for us to see ... this is a broader impact. But taking that final thing and turning it into a PLV was kind of tricky” (Focus Group Interview, 2022). The other fellows also seemed to struggle with connecting their PLV to the BI of their research. Fellows 3 and 4 ultimately chose something very fundamental to their research that could be turned into an educational product or workshop.

Analysis of Focus Group Interview Results

While data from the focus group affirms that some CEI Graduate Fellows reported gains in their understanding of the Broader Impacts of their research, it remains unclear to what extent the PLV Design Workshop influenced this growth. For instance, three of the four interviewees believed they learned more about BI this year, but only Fellow 2 attributed this to the PLV Design Workshop. The other two fellows mentioned other opportunities provided by the CEI Fellowship that contributed to new insights about the BI of their research such as a Lunch and Learn they participated in as part of this fellowship’s outreach requirement. Therefore, one other question that remains is how effective the workshop was in supporting CEI Graduate Fellows’ knowledgeability of the BI of their research.

Integration of Results for RQ2

One of the goals of this study was to determine how and to what extent participation in the PLV Design Workshop increased fellows’ knowledgeability of the BI of their research. Unfortunately, data collected from the PLV Pre-Workshop Survey and the focus group interview do not provide enough evidence to answer this question. While one fellow in the focus group interview did acknowledge increased understanding of the BI of their research due to one of the workshop sessions, no others explicitly made this

connection. Without any post-surveys completed, it is simply not possible to quantify any changes that may have taken place with respect to knowledgeability of BI.

There is one important meta-inference that can be made from the pre-survey and the focus group interview, however. CEI Graduate Fellows seem to struggle to relate several BI activities to their disciplinary research. This was demonstrated both with the low ratings for the Relatedness of BI subscale on the pre-survey and in the focus group interview. For instance, Fellow 4 explained that their PLV was “not exactly a direct ... broad impact” such as the development of technology, but the goal was “to try to inspire people to sort of find that curiosity. ... And that's kind of how you started to become a scientist” (Focus Group Interview, 2022). I found this such an inspirational motivation for a PLV and interpreted this as an important BI of research. Yet, I am not sure that the fellow recognized this as a BI of research. It seems that fellows may be looking for a direct connection between a BI and the specific research they conduct. Therefore, helping fellows to think more broadly about how their research or their experience in STEM could benefit society may help them better understand how they can engage with the BI of their research.

Research Question 3 (Identification with Clean Energy)

The last research question for this study focused on CEI Graduate Fellows’ identification with the clean energy field. Specifically, it asked how and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows’ identification with the clean energy field? The PLV Workshop Survey and one Focus Group Interview were both used to gather data for RQ3 (Identification with Clean Energy). In this section, quantitative results from the PLV Workshop Pre-Survey will be presented and analyzed first. Then, qualitative results from the interview will be

presented and analyzed. This section will close with a comparison of these results in order to integrate results with respect to RQ3 (Identification with Clean Energy).

PLV Workshop Pre-Survey Results

Recall that the PLV Workshop Survey was an anonymous survey administered digitally at the beginning and end of the PLV Design Workshop. While the pre-survey received 15 responses, the post-survey received no responses. Still, data from the pre-survey provides an important snapshot of CEI Graduate Fellows' identification with the clean energy field. The PLV Survey had two sections, the second of which was related to RQ3 (Identification with Clean Energy). Section 2: The Clean Energy Field had three Likert-style questions that asked fellows to evaluate their identification with the field of clean energy using a 5-point Likert-style scale. Fellows were asked the following three questions:

- How engaged do you feel with the field of clean energy?
- How likely is it that you will be involved in clean energy in the future?
- How aligned is your research with the field of clean energy?

Fellows could choose from five responses for each question: very engaged (5) to not engaged at all (1), very likely (5) to not likely at all (1), and very aligned (5) to not aligned at all (1). No neutral response was provided as an option. To determine the internal consistency of this instrument, SPSS was used to compute Cronbach's alphas for the clean energy subscale. The internal reliability of the Clean Energy Subscale was somewhat low (3 items; $\alpha = .680$), but still within acceptable levels (Ursachi et al., 2015).

Overall, results show that CEI Graduate fellows identify with the clean energy field. On average, fellows felt engaged with the field of clean energy ($M = 4.20$, $SD = .94$) and were likely to be involved in this field in the future ($M = 4.33$, $SD = .72$). Most fellows also felt that their research was aligned with the clean energy field ($M = 3.93$, SD

= .96). Yet, one fellow felt only slightly engaged and two fellows felt that their research only slightly aligned with clean energy. These responses represented the lowest ratings selected (2.00). Table 16 shows the frequency of ratings for all three questions. Despite a few exceptions, at least 80 percent of respondents selected ratings of four or five, confirming that most fellows identified or strongly identified with the clean energy field.

Table 16

Frequency Table for Clean Energy Subscale Ratings

Rating	Engagement N (%)	Future Involvement N (%)	Research Alignment N (%)
5	7 (46.7 %)	7 (46.7 %)	4 (26.7 %)
4	5 (33.3 %)	6 (40.0 %)	8 (53.3 %)
3	2 (13.3 %)	2 (13.3 %)	1 (6.7 %)
2	1 (6.7 %)	0	2 (13.3 %)
1	0	0	0

Analysis of PLV Workshop Pre-Survey Results

The three questions in the Clean Energy subscale of the PLV Workshop Survey were designed to focus on the three “modes of identification” (Wenger-Trayner & Wenger-Trayner, 2015, p. 20), or engagement, alignment, and imagination. Together, these questions were designed to gain an understanding of fellows’ overall identification with the field of clean energy. According to results from the PLV Workshop Pre-Survey, most CEI Graduate Fellows at the beginning of the workshop did strongly identify with the clean energy field. Unfortunately, without any results from the post-survey, no changes throughout this study can be observed or quantified.

Focus Group Interview

The focus group did provide an opportunity to elaborate on the results from the pre-survey with respect to RQ3 (Identification with Clean Energy). Toward the end of the focus group, I asked the four interviewees if the workshop or the CEI Fellowship had any

effect on their connection to the field of clean energy and invited them to reflect on what they know now versus at the beginning of the year. The group was evenly divided; Fellows 1 and 2 saw no change in their connection to clean energy while Fellows 3 and 4 felt more connected to the field of clean energy. Through several cycles of qualitative coding, one theme related to RQ3 (Identification with Clean Energy) emerged that sheds some light on this divide: *fellows least identified with clean energy stand to gain the most*. This theme and its corresponding Concept Codes are shared in Table 17.

Table 17

Focus Group Interview Codes and Assertion for RQ3

Pattern Code with Corresponding Concept Codes	Assertion
<p>Fellows least identified with clean energy stand to gain the most.</p> <ul style="list-style-type: none"> ● Fellow 1 Background: interdisciplinary, clean energy-focused research ● Fellow 2 Background: interdisciplinary, clean energy-focused research ● Fellow 3 Background: disciplinary, theoretical research ● Fellow 4 Background: disciplinary, experimental research ● New Perspectives about Career ● New Perspectives about Clean Energy ● New Perspectives about Peers ● No Change in CE Connection for those already engaged ● Theorist vs. Experimentalist 	<p>Fellows least connected to the clean energy field before the CEI Fellowship made the most gains with respect to identification with the clean energy field, but not necessarily because of the PLV Design Workshop.</p>

This theme consists of Concept Codes that describe the four interviewees' disciplinary and research backgrounds. It also includes Concept Codes related to changes in fellows' perspectives about their career, clean energy, or even their peers. According to this theme, fellows' backgrounds may be a factor in how much change we see with respect to identification of the clean energy field. For instance, Fellows 1 and 2 were

currently working in clean energy research. When asked if their identification with clean energy had changed, they both said no. As Fellow 2 said, “I don't think it really changed for me. If I'm honest. It was just kind of ... really confirmation” (Focus Group Interview, 2022). On the other hand, Fellow 3 had a dramatically different experience. They said:

Well, it changed everything for me. Like, we're used to being like, very core, like fundamentals [science] usually clueless about what's happening outside in the [world]. I also learned that ... there's a lot of money in clean energy. (Focus Group Interview, 2022)

Fellows 3 and 4, who do not conduct clean energy research, felt a much stronger connection to the field of clean energy after the CEI Fellowship. Fellow 4 told the group that their lab's research “could have clean energy like applications, but I didn't really think about those as much before I joined the program. And so, I've had to think about those a lot more” (Focus Group Interview, 2022). Fellow 3 admitted they had “never really cared about” the “clean energy aspect” but had realized the economic opportunities that exist in this field over the course of their fellowship. In fact, this influenced a change in perspective about their career path and they said “maybe I don't want to do academia after all” (Focus Group Interview, 2022). As I learned in this focus group, some students already come into our fellowship passionate about and working in this field, and others have much less experience or interest in the field. For this focus group, the fellows who least identified with clean energy prior to the CEI Graduate Fellowship saw the greatest increase in identification with the clean energy field.

Despite stronger identification with the field of clean energy, Fellows 3 and 4 did not attribute this increase to the PLV Design Workshop. They cited several other aspects of the CEI Fellowship that contributed to this gain such as conversations with CEI's Entrepreneur-In-Residence, Interdisciplinary Seminars, and even filling out the CEI

application. Thus, to what extent the workshop increased fellows' identification with the clean energy field is simply not possible to know without further research. In sum, fellows least connected to the clean energy field before the CEI Fellowship made the most gains with respect to identification with the clean energy field, but not necessarily because of the PLV Design Workshop.

Integration of Results for RQ3

One of my goals for this action research study was to determine if participation in the PLV Design Workshop strengthened CEI Graduate Fellows' identification with the clean energy field. Both the PLV Workshop Survey and the focus group interview suggest that many fellows identify with the clean energy field. Quantitative results from the PLV Workshop Pre-Survey demonstrated that most fellows already identified with this field with a few exceptions. Qualitative results from the focus group corroborate this evidence, with two participants sharing that they had felt connected to this field even before the fellowship and deliberately pursued research in the clean energy field. Without post-surveys, it is not possible to quantify if any changes were made because of the PLV Design Workshop. Yet, results from the focus group suggest that little changes would have been observed. The fellows who came into the fellowship with a strong connection to the clean energy field reported that their views had only been confirmed, not changed. And the two fellows who did report changes in their identification with the field attributed this change to other fellowship experiences. While many insights were gained about this topic, a clear answer to RQ3 (Identification with Clean Energy) is not possible with that data collected for this study.

Summary

This chapter presented data collected for this concurrent mixed methods action research study. Results and analysis were organized by research questions. First,

quantitative results from the PLV Rubric were presented in relation to RQ1 (PLV Quality). Second, quantitative and qualitative data from the PLV Workshop Pre-Survey were presented along with qualitative results from the focus group as evidence for RQ2 (BI Knowledgeability). Finally, quantitative results from the PLV Workshop Pre-Survey and qualitative results from the focus group were presented in light of RQ3 (Identification with Clean Energy). In Chapter 5, findings related to all three research questions will be discussed in light of the theoretical and conceptual frameworks that guided this action research study. The limitations and future implications of this study will also be addressed.

CHAPTER 5

DISCUSSION

The overarching purpose of this mixed methods action research study was to support the professional development of University of Washington (UW) Clean Energy Institute (CEI) Graduate Fellows and to support the development of high-quality educational products focused on clean energy research. Through three cycles of research, I reviewed one of the CEI Graduate Fellowship requirements, the Product of Lasting Value (PLV), to better understand its ability to positively contribute to these goals. The purpose of this last cycle of research was to evaluate the impact of an innovation, the PLV Design Workshop, on the quality of PLVs and the CEI Graduate Fellows' perspectives on the Broader Impacts (BI) of research. The specific research questions that guided this cycle of research were:

RQ1: How does the PLV Design Workshop increase the quality of PLVs?

RQ2: How and to what extent does participation in the PLV Design Workshop increase CEI Graduate Fellows' knowledgeability of the broader impacts of their research?

RQ3: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field?

In this chapter, these research questions are discussed in light of results from this last cycle of research as well as the theoretical and conceptual frameworks that guided this study. I then discuss the limitations of this study, the implications it has for practice, and future iterations of this workshop. Finally, I share some personal lessons learned throughout the action research process.

Discussion of Results

This mixed methods action research study employed several instruments and types of data to address its guiding research questions. For RQ 1 (PLV Quality), quantitative data was collected with the PLV Rubric and these scores were informed by the qualitative data collected from the PLV Check Ins. Both quantitative and qualitative data were collected through the PLV Workshop Survey for RQ2 (BI Knowledgeability). The qualitative data helped to elaborate on the quantitative findings during the interpretation of data. The meta-inferences from the PLV Workshop Survey were then integrated with qualitative results from the focus group interview which also collected data for RQ2 (BI Knowledgeability). Finally, quantitative data collected from the PLV Workshop Survey was elaborated on with qualitative data from the focus group interview to inform conclusions related to RQ3 (Identification with Clean Energy). Overall, the qualitative data collected for this study served to elaborate on quantitative data. It provided more specific and personal understandings of CEI Graduate fellows perspectives of the BI of their research and their identification with the clean energy field. In this section, the findings for each research question will be shared and discussed in light of the theoretical frameworks that informed this study.

Research Question 1

One of the main goals of this cycle of research was to determine if a PLV Design Workshop could increase the quality of PLVs. Since the PLV requirement is designed to support fellows' understanding of the BI of research, I wanted to align the metrics used to measure quality with the *Broader Impacts Review Document for National Science Foundation Proposals* (ARIS, 2020). This document informed the analytic rubric I designed to assess each PLV. Overall, PLV Rubric results showed a positive, strong, and significant relationship between workshop attendance and PLV quality. As attendance at

workshop sessions increased, mean rubric scores also increased. While this correlation was a positive indication of the merits of the PLV Design Workshop, it should not be interpreted as causation.

The workshop was designed as a semi-structured opportunity for CEI Graduate Fellows to reflect on the BI of their research and their impact identity (Risien & Storksdieck, 2018). The design was rooted in a social theory of learning. Significant time was built into the workshop for fellows to interact through giving and receiving feedback on PLVs. Because fellows come from many different disciplines and lab groups, I see them as members from several different communities of practice. Interaction among fellows, then, is a positive opportunity to expand their understanding of their landscape of practice. Further, because PLVs are intended to share clean energy research with audiences beyond fellows' communities of practice (COP), I view PLVs as boundary objects (Wenger, 1998; Wenger-Trayner & Wenger-Trayner, 2015). By inviting fellows to consider the target audience for their PLVs and how to effectively communicate and design for this audience, I am offering fellows an opportunity to practice the skills needed to work with other COPs and to engage in the broader impacts of one's research.

Research Question 2

This action research study also set out to learn how participation in the PLV Design Workshop increased CEI Graduate Fellows' knowledgeability of the broader impacts of their research. The concept of knowledgeability (Wenger-Trayner & Wenger-Trayner, 2015) was included in this study because I find it directly related to CEI's goal of increasing fellows' ability to engage effectively with the BI of their research. Engaging in BI activities requires an understanding of other communities of practice (COP), crossing disciplinary boundaries, and "translating this complex experience of the landscape, both its practices and their boundaries, into a meaningful moment of service" (Wenger-

Trayner & Wenger-Trayner, 2015, p. 23). I created the PLV Workshop Survey to measure fellows' knowledgeability of the BI of research. This instrument invited fellows to rate their knowledgeability of 10 different BI activities. A pre- and post-survey were both administered in order to demonstrate changes that took place during the PLV Design Workshop. Unfortunately, no post-surveys were returned and the data collected from the PLV Pre-Workshop Survey and the focus group interview do not provide the type of evidence needed to answer RQ2 (BI Knowledgeability).

Yet, one important meta-inference was made from the results of the pre-survey and the focus group that should be mentioned. Despite showing a fairly high interest in a diversity of BI activities, CEI Graduate Fellows generally struggle to connect their research with BI. Based on results from the focus group, some fellows may also struggle to connect the PLVs with BI. One reason for this disconnect could be that many of these students are doing such fundamental research that applications for their research may not yet exist. Fellows may have the misunderstanding that BI must be directly related to applications of one's research. As Fellow 4 explained in the focus group, their PLV was "not exactly a direct ... broad impact" such as the development of technology. Yet, they went on to say that the goal of their PLV was "to try to inspire people to sort of find that curiosity. ... And that's kind of how you started to become a scientist" (Focus Group Interview, 2022). While I understand this sentiment, I also interpret this goal as an important BI of research. If curiosity is an important attitude for scientists, then cultivating this in youth is a valuable outcome of outreach.

These findings made me wonder if the STEM community inadvertently has created a false dichotomy between research and the BI of research, or, what the National Science Foundation refers to as the "Intellectual Merit criterion" and "Broader Impacts criterion" (NSF, 2020, p. III-2). In the pre-survey for this study, CEI Graduate Fellows

identified many strengths and skills that could support their BI activities. Yet, few identified their disciplinary expertise as skills that could support these activities and few related their research to BI activities. To me, this suggests that the disconnect between one's research and the BI of their research may come from the university or research setting. As Risien and Storksdieck (2018) argue, engaging in the BI of one's research from an integrated identity can serve both the scientist and the public and may encourage a more diverse STEM field. They describe that "impact identity results from a thoughtful and intentional integration of a scientist's multi-dimensional self-concept" (p. 58). This framework and the results from this action research study suggest that more explicit support is needed to help scientists develop knowledgeability of the BI of their research. In addition, universities and the STEM community at large need to ensure that graduate STEM students are encouraged to bring their whole selves to their practice.

Research Question 3

The last research question for this study was: How and to what extent does participation in the PLV Design Workshop strengthen CEI Graduate Fellows' identification with the clean energy field? The CEI Graduate Fellowship is awarded to doctoral students to support their ability to conduct clean energy-related research. Yet, clean energy-related research is not necessarily the primary focus of CEI Graduate Fellows' doctoral studies. One of my hopes is that through this fellowship, UW doctoral students learn about the clean energy applications of their research and want to continue to contribute to this field. As Wenger-Trayner and Wenger-Trayner (2015) state, "identification is a key factor in shaping knowledgeability because it implies accountability" (p. 24). When I consider the complexity and urgency of decarbonization, I want all STEM professionals to feel accountability to clean energy research and equitable solutions to climate change.

To explore fellows' identification with the clean energy field, the PLV Workshop Survey included three questions aligned with the three modes of identification (Wenger-Trayner & Wenger-Trayner, 2015) and was administered at the beginning and end of the PLV Design Workshop. Because no post-surveys were returned, there was no way to quantify any changes that took place with respect to fellows' identification with the clean energy field. Yet, results from the pre-survey demonstrated that most CEI Graduate Fellows identified with the clean energy field at the beginning of the workshop. Through the Focus Group Interview, I learned that the two interviewees who least identified with the clean energy field before the CEI Fellowship made the most gains with respect to identification with the clean energy field, but it was not possible to claim this was only due to the PLV Design Workshop. Several other opportunities related to the CEI Fellowship seemed to have an impact on their identification with the clean energy field, such as connecting with CEI's Entrepreneur-In-Residence, participating in a K-12 Outreach Lunch & Learn, and even filling out the fellowship application. It could be argued that this research question was too optimistic for the scope of this project. Yet, the fact that two fellows who had little prior experience with the field of clean energy had some transformative experiences during their year-long fellowship suggests that this question is important, but perhaps better suited for a review of the CEI Graduate Fellowship program as a whole rather than one aspect of the curriculum.

Summary of Results

With respect to RQ 1 (PLV Quality), results demonstrated a significant, strong, and positive correlation between attendance at the PLV Design Workshop attendance and PLV quality. Unfortunately, the lack of respondents in the PLV Workshop Post-Survey prevented the ability to quantify any changes that took place in fellows' knowledgeability of the BI of their research (RQ2) and their identification with the clean

energy field (RQ3) due to the innovation. However, results from the focus group interview do show that some fellows experienced increased knowledgeability of the BI of their research and identification with the clean energy field, but these gains were not necessarily due to the PLV Design Workshop.

Study Limitations

There were several limitations with this study that are important to note. These can be categorized into themes of time constraints, instrumentation, and participation. One of the biggest challenges in this study was the short window of time that I had to develop and implement PLV Design Workshop. At the time that I began conducting initial cycles of research for this action research study, I had worked at the UW CEI for less than one year. Because the CEI Graduate Fellowship typically runs from September through June, I was constrained to this period to implement the PLV Design Workshop. This limited the amount of time that I had to develop instruments, content, and recruit focus group participants. The timing of development impacted the start date of the innovation. Further, data from the Focus Group Interview suggested that facilitating the PLV Design Workshop throughout the academic year rather than only during the Spring Quarter would have provided more support for participants.

Time constraints also may have contributed to a few instrumentation issues. As mentioned in previous sections, I had originally intended to share the PLV Rubric with fellows and the community representatives who participated in the third session of the workshop. Yet, condensing the PLV Design Workshop into the quarter that PLVs were due increased the urgency of helping fellows solidify their PLV ideas and receive general feedback rather than adding another layer of requirements for the PLVs. Additionally, receiving no PLV Workshop Post-Surveys prevented the ability to draw conclusions for RQ3 (Identification with Clean Energy). Finally, according to Wenger-Trayner and

Wenger-Trayner (2015), “knowledgeability is a complex achievement” (p. 23). It is not easily measured and likely developed over a lifetime. While insights were made about CEI Graduate Fellows’ perspectives on this topic, further research on how to best assess one’s knowledgeability of their landscape of practice is warranted.

In addition to the lack of participation on the PLV Workshop Post-Survey, I would have liked to conduct at least one other Focus Group Interview. The interview that I had was so fruitful that it would have been helpful to communicate with more fellows in this way. Along the lines of participation, it is important to remember that participation in the innovation for this study as well as in the surveys and focus groups was voluntary. Those who attended the workshop, gave feedback about the workshop in their PLV Check Ins, and participated in the Focus Group Interviews were likely more engaged than those who did not. This does limit the results of this study.

Implications for Practice

This action research study offers three main implications for practice. First, I learned that scientists conducting fundamental research need opportunities to reflect on the broader impacts of their research. The findings from this action research study confirm the recommendations of the Committee on Revitalizing Graduate STEM Education for the 21st Century (NASEM, 2018). Many doctoral STEM students want to become “well-rounded” (PLV Workshop Pre-Survey, 2022) researchers and gain transferable skills. Many are interested in the BI of their research and are personally motivated by the opportunity to “give back” (PLV Workshop Pre-Survey, 2022) to their communities yet feel less knowledgeable about these activities. Therefore, those of us who support graduate STEM students should consider ways to provide authentic opportunities for them to engage in activities related to the BI of their research and to reflect on other aspects of their identity that could support their BI (Risien &

Storksdieck, 2018). I recommend starting from students' strengths with BI activities to help them see these as assets to bring to these endeavors.

Second, incorporating boundary objects such as PLVs can be valuable learning opportunities, but they should be directly connected to their target audience and transformed from a 10-hour, add-on to an authentic opportunity to engage in the BI of one's research. Through PLV Check Ins and the focus group interview, I learned that CEI Graduate Fellows really valued feedback and connecting with the actual audience for their PLV. Artifacts designed to bridge the gap between COP are not guaranteed success, especially if they do not accurately "capture multiple meanings and perspectives" (Akkerman and Bakker, 2011, p. 141). While the inclusion of content about the BI of research and feedback from community representatives in the PLV Design Workshop was a step in the right direction, I believe CEI fellows need to engage directly with the audience for their PLVs to make this a more authentic experience. With respect to knowledgeability, Wenger-Trayner and Wenger-Trayner (2015) argue that it is critical to bring people together.

...it is difficult for communities of practice to be deeply reflective unless they engage with the perspectives of other practices. Combining multiple voices can produce a two-way critical stance through a mutual process of critique and engagement in reflection. (Wenger-Trayner & Wenger-Trayner, 2015, p. 19)

I believe this "two-way critical stance" (Wenger-Trayner & Wenger-Trayner, 2015, p. 19) is an essential element of equitable and effective BI activities. Therefore, providing authentic opportunities for fellows to engage directly in discussions with the target audience for their PLVs is important element to include in future iterations of this project.

Finally, those of us who support the professional development of STEM graduate students might benefit from thinking of ourselves as brokers. In addition to boundary objects, brokers are people who can connect communities and facilitate dialogue between COP. Often brokers help to coordinate, manage conflicts, and align perspectives (Wenger, 1998). When I reflect on the feedback from CEI Graduate Fellows during this study, I realize that one of the most important things that I can do is to connect students with other communities and to facilitate opportunities for effective dialogue across boundaries. With support, this could also provide an opportunity for students to “understand and learn to consider ethical and cultural issues surrounding their work, as well as the broader needs of society” (NASEM, 2018, p. 4).

Lessons Learned

The above implications for practice will be lessons that I incorporate into my practice moving forward. In addition, I have learned several other lessons through the design and implementation of this action research study that are worth acknowledging. First, I have learned that action research provides a rich opportunity to get to know just one’s context and community. Throughout the data collection process, I had an opportunity to get to know CEI Graduate Fellows much better than I did before. Not only did I learn that many fellows are contributing new knowledge to their disciplines, but many are also passionate about advancing justice, clean energy solutions, and science literacy. I now better understand how to provide support for their learning journey. In many ways, I have come to see my role as facilitating opportunities for them to engage with communities beyond the lab and then getting out of their way!

There are lessons I have also learned with respect to my growing identity as an action researcher. First, I have learned to appreciate the strengths of both quantitative and qualitative data and the need to clearly align one’s research questions, design, and

instruments. Second, similar to the participants in this study, I better understand the value of feedback and the need to cultivate a community of critical friends who can provide external perspective when needed. Third, I better appreciate the cyclical nature of action research and the value of systematically inquiring into an aspect of one's practice. Conducting multiple cycles of inquiry is a way to build in reflection to a practitioner's busy schedule and allows for a richer, deeper understanding of one's context than one cycle of research would allow.

Finally, I also have learned that this action research study is not quite finished. One of the criteria that can be used to assess the quality of action research is future action. "Outcome validity" refers to the action that follows a study and the impact of a study on a researcher's framing of an issue "in a more complex way" (Ivankova, p. 271). I can confirm that the insights that I made from this action research study will have a direct impact on future iterations of the PLV requirement and the PLV Design Workshop. This year, the three sessions of PLV Design Workshop will be offered throughout the year with the first occurring in the Fall Quarter. To support authenticity of projects and the ideation phase of this process, I intend to constrain options for PLVs to either K-12 lessons or webpage research explainers — unless a fellow has a specific idea. Fellows will also be asked to use or share one's PLV during the Spring Quarter with its intended audience. I plan to make the most of the PLV Design Workshops by increasing the time for dialogue, feedback, and work time while decreasing the length of my own presentations.

Summary

The goal of this action research study was to evaluate the effectiveness of a workshop created to support UW CEI Graduate Fellows' professional development and the design of high-quality educational products related to clean energy. While the data

collected in relation to the research questions guiding this study do not provide conclusive evidence about the impact of the innovation, many insights were learned about the importance of providing STEM doctoral students the opportunity to work toward knowledgeability of BI. CEI Graduate Fellows are interested in BI activities, and they bring incredible skills and strengths to outreach, including their deep disciplinary knowledge. As an educator supporting STEM doctoral students who conduct clean energy research, I have a responsibility to ensure these future energy leaders can communicate across disciplines and with diverse stakeholders so that others have equitable and timely access to emerging science and technologies. When I think about the complexity and gravity of the climate crisis, I do find hope in the incredible skill and passion that these students bring to their work and the world.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD: CYCLE 1



EXEMPTION GRANTED

[Steven Salik](#)
[Division of Educational Leadership and Innovation - West Campus](#)
602/543-6442
shsalik@asu.edu

Dear [Steven Salik](#):

On 11/17/2021 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Graduate Student Preparation for the Design of Products of Lasting Value (PLV)
Investigator:	Steven Salik
IRB ID:	STUDY00014866
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	<ul style="list-style-type: none">• Hendrickson Consent Letter 11.10.21, Category: Consent Form;• Hendrickson Interview Questions 10.22.21, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);• Hendrickson Protocol 11.3.21, Category: IRB Protocol;• Hendrickson Recruitment Communication 10.27.21, Category: Recruitment Materials;• UW CEI Letter of Support, Category: Other;• UW IRB Approval, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc);

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 11/17/2021.

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

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

REMINDER - All in-person interactions with human subjects require the completion of the ASU Daily Health Check by the ASU members prior to the interaction and the use of face coverings by researchers, research teams and research participants during the interaction. These requirements will minimize risk, protect [health](#) and support a safe research environment. These requirements apply both on- and off-campus.

The above change is effective as of July 29th [2021](#) until further notice and replaces all previously published guidance. Thank you for your continued commitment to ensuring a healthy and productive ASU community.

Sincerely,

IRB Administrator

cc: DANICA HENDRICKSON



DETERMINATION OF EXEMPT STATUS

November 10, 2021

Dear Danica Hendrickson:

On 11/10/2021, the University of Washington Human Subjects Division (HSD) reviewed the following application:

Type of Review:	Initial Study
Title of Study:	Graduate Student Preparation for the Design of Products of Lasting Value (PLV)
Investigator:	Danica Hendrickson
IRB ID:	STUDY00014408 <
Funding:	None

Exempt Status

HSD determined that your proposed activity is human subjects research that qualifies for exempt status (Category 2).

- COVID NOTE: See the [HSD website](#) for the latest COVID guidelines for conducting human subjects research.
- This determination is valid for the duration of your research.
- This means that your research is exempt from the federal human [subjects](#) regulations, including the requirement for IRB approval and continuing review.
- Depending on the nature of your study, you may need to obtain other approvals or permissions to conduct your research. For example, you might need to apply for access to data or specimens (e.g., to obtain UW student data). Or, you might need to obtain permission from facilities managers to approach possible subjects or conduct research procedures in the facilities (e.g., Seattle School District; the Harborview Emergency Department).
- HSD does not make determinations on behalf of other institutions. Arizona State University will need to make its own determination for your researcher role related to your doctoral program there, or they may decide to be guided by our determination.

If you consider changes to the activities in the future and know that the changes will require IRB review (or you are not certain), you may request a review or new determination by submitting a Modification to this application. For information about what changes require a Modification, refer to the [GUIDANCE: Exempt Research](#).

Thank you for your commitment to ethical and responsible research. We wish you great success!

Sincerely,

Deborah Dickstein, MSPH
Human Subjects Review Administrator, Team B
206-543-5971 dickstei@uw.edu

4333 Brooklyn Ave. NE, Box 359470 Seattle, WA 98195-9470
main 206.543.0098 fax 206.543.9218 hsdinfo@u.washington.edu www.washington.edu/research/hsd
Implemented 08/30/2021– Version 1.12 - Page 1 of 1

APPENDIX B

RESEARCH CYCLE 1: INTERVIEW PROTOCOL

Graduate Student Support for the Design of Products of Lasting Value

Cycle 1 Interview Questions for Graduate Fellows

1. Please share a little about your academic and research background (e.g., your discipline, when you began your doctorate, etc.).
2. What unique or important contributions does your research have for the field of clean energy?
3. As you know, CEI Graduate Fellows are required to design a Product of Lasting Value (PLV) as part of their fellowship. PLVs are educational products designed to share some aspect of your research with an external audience such as K-12 teachers, other lab groups, or the public audience who view CEI's website.

New Fellows:

- a. What ideas, questions, or concerns, if any, do you currently have about this project?
- b. What growth opportunities do you think this project could encourage in graduate fellows?

Previous Fellows:

- a. What did you design for your PLV?
- b. What was your overall experience of this project?
- c. What growth opportunities do you think this project could encourage in graduate fellows?

4. What type of preparation and support would you like [Previous Fellows: have liked] for this project?
 - a. What strengths do you think you bring to this project? What weaknesses?
5. Is there anything else you would like to share? Any questions you have for me?

APPENDIX C
INSTITUTIONAL REVIEW BOARD: CYCLE 2



EXEMPTION GRANTED

[Steven Salik](#)
[Division of Educational Leadership and Innovation - West Campus](#)
 602/543-6442
 shsalik@asu.edu

Dear [Steven Salik](#):

On 3/10/2022 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	The Impact of a Design Workshop on Doctoral Students Knowledgeability of the Broader Impacts of Their Research
Investigator:	Steven Salik
IRB ID:	STUDY00015547
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	<ul style="list-style-type: none"> • Focus Group Consent Form, Category: Consent Form; • Focus Group Interview Protocol, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • PLV Check In Questions, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • PLV Design Workshop Consent Letter, Category: Consent Form; • PLV Design Workshop Outline, Category: Other; • PLV Design Workshop Protocol 3.6.22, Category: IRB Protocol; • Pre and Post Survey, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • UW CEI Letter of Support, Category: Other;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 3/9/2022.

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

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

REMINDER - - Effective January 12, 2022, in-person interactions with human subjects require adherence to all current policies for ASU faculty, staff, students and visitors. Up-to-date information regarding ASU's COVID-19 Management Strategy can be found [here](#). IRB approval is related to the research activity involving human subjects, all other protocols related to COVID-19 management including face coverings, health checks, facility access, etc. are governed by current ASU policy.

Sincerely,

IRB Administrator

cc: DANICA HENDRICKSON

DETERMINATION OF EXEMPT STATUS

March 10, 2022

Dear Danica Hendrickson:

On 3/10/2022, the University of Washington Human Subjects Division (HSD) reviewed the following application:

Type of Review:	Initial Study
Title of Study:	The Impact of a Design Workshop on Doctoral Students Knowledgeability of the Broader Impacts of Their Research
Investigator:	Danica Hendrickson
IRB ID:	STUDY00015146
Funding:	None

Exempt Status

HSD determined that your proposed activity is human subjects research that qualifies for exempt status (Category 101). This determination may or may not be based on the Limited IRB Review process.

- COVID NOTE: See the [HSD website](#) for the latest COVID guidelines for conducting human subjects research.
- This determination is valid for the duration of your research.
- This means that your research is exempt from the federal human subjects regulations, including the requirement for IRB approval and continuing review.
- **Depending on the nature of your study, you may need to obtain other approvals or permissions to conduct your research. For example, you might need to apply for access to data or specimens (e.g., to obtain UW student data). Or, you might need to obtain permission from facilities managers to approach possible subjects or conduct research procedures in the facilities (e.g., Seattle School District; the Harborview Emergency Department).**
- HSD does not make determinations on behalf of other institutions. If other institutions are involved in the research, they may need to make their own determination or they may decide to be guided by our determination.

If you consider changes to the activities in the future and know that the changes will require IRB review (or you are not certain), you may request a review or new determination by submitting a Modification to this application. For information about what changes require a Modification, refer to the [GUIDANCE: Exempt Research](#).

Thank you for your commitment to ethical and responsible research. We wish you great success!

Sincerely,

Deborah Dickstein, MSPH
Human Subjects Review Administrator, Team B
206-543-5971 dickstei@uw.edu

APPENDIX D

PLV DESIGN WORKSHOP OVERVIEW

Products of Lasting Value: Curriculum Overview

Project Purpose

One of the requirements of the Clean Energy Institute (CEI) Graduate Fellowship is to create a product of lasting value (PLV). A PLV is an educational product that communicates your research to a broader audience. The purpose of this project has been designed to contribute to CEI's overall mission "to accelerate the adoption of a scalable clean energy future that will improve the health and economy of our state, nation, and world" (CEI, Our Mission) and "to prepare and empower the next generation of clean energy leaders and innovators to have broader impacts on society" (CEI, CEI Graduate Fellowship: Objective and Focus). Specifically, our goal is that through participation in the PLV curriculum, you will:

- Build community with other CEI Graduate Fellows.
- Gain a deeper understanding of the broader impacts of your research and your own impact identity.
- Increase your ability to communicate your research across disciplinary boundaries.
- Develop the ability to design and evaluate broader impact activity proposals.

Project Overview

The media you use to communicate is up to you but should be appropriate for the audience one is hoping to reach. Past media that have been used include videos, lesson plans, a science demo, and participation in an event.

Session 1: Building Teams and Generating Ideas

Overview

The purpose of this 2-hour workshop is to provide CEI graduate fellows with an overview to the product of lasting value (PLV) requirement, to help students identify a project and team, and to provide an opportunity for students to reflect on the broader impacts of their research and their own impact identity.

Objectives

Fellows will:

- Build community with other fellows.
- Identify commonalities and distinctions between their research and their peers.
- Gain a deeper understanding of the broader impacts of their research and their own impact identity.

Time

2 hours

Communication

Email date, time, and things to bring (computer, notebook)

Materials

Collective Clean Energy Map (Large white board or poster board), 1 per whole group

Impact Identity handout, 1 per participant

Poster Paper

Post-its

Raffle Prizes

PowerPoint

Survey:

Plan

<i>Introduction (4 - 4:35 pm)</i>	NAN 181
<ol style="list-style-type: none"> 1. Welcome, Roadmap, Objectives (5 min) 2. Administer Pre-Survey (20 min) (Review PLV resources when finished) 3. Introduce the Collective Clean Energy Map (a concept map generated from CEI's mission). Give students time to add their name/research phrase to the concept map to show where their research fits into CEI's mission. It is okay to write this multiple times. (10 min) 	<ul style="list-style-type: none"> ● PPT ● Comp. station ● Survey link ● White board with map ● White board markers ● PLV resources digital share ● Music

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<i>PLV Overview and Reflection (4:35 - 5 pm)</i>	
<ol style="list-style-type: none"> 1. Purpose of PLVs (disseminate research (professional development - interdisciplinarity, communication, opportunity to consider the broader impacts of your research, climate change & urgency). 2. Introduce Impact Identity 3. Reflection activity with broader impacts: Venn diagram with the “five critical elements” (personal preferences, capacities/skill sets, institutional context, scientific discipline, scholarship & research). Review, THEN consider societal needs or opportunities. 4. Invite table groups to share insights with each other, then invite a few volunteers to share with the whole group. 	<ul style="list-style-type: none"> ● PPT ● Impact ID wksht

<i>Short Break (5 - 5:05 pm)</i>

<i>Idea- and Team-Building Activity (5:05 - 5:50 pm)</i>	
<ol style="list-style-type: none"> 1. Warm-up: 1 - 2 rounds of Impromptu Networking (pairs, 2 min per person, 4-5 minutes per round; 3 rounds): What big challenge do you bring to this educational project? What do you hope to get from and give to this project? (5 min) 2. Discuss PLV timeline, requirements, constraints. Encourage teamwork to practice across discipline boundaries and to generate a higher quality project. communication PLV requirements; The purpose and increasing importance of broader impacts requirements and its connection to professional skills, broader impacts 	<ul style="list-style-type: none"> ● PPT ● Comms/Education ideas on

<p>skills, and impact identity. Remind students about the difference these products can make and show video views. Discuss appropriate scale for the PLV - think small for high quality. (7 min)</p> <ol style="list-style-type: none"> 3. Share CEI and Comms ideas that are posted around the room based on audience. Invite others to share ideas. (8 min) 4. Mingle 1: Invite students to move to the area of the room with an audience they are interested in. Post-its on areas of interest. (15 minutes) 5. Questions? Clarifications? 6. Mingle 2: Invite students to move to a poster with a pitch of interest (including both CEI staff ideas and graduate fellow pitches). Introduce yourself, your research, contributions you could make for this PLV. 7. Break time and networking. 8. Write down top 3 ideas and potential team members. 	
---	--

<p><i>Wrap Up (5:50 - 6 pm)</i></p>	
<ol style="list-style-type: none"> 1. Questions? 2. PLV timeline and next steps 3. PLV Check In 1 by Monday: https://forms.gle/B3HAsKSR8853CEDq5 	<ul style="list-style-type: none"> ● PPT ● PLV Check In Link

Session 2: Peer Feedback

Overview

The purpose of this 2-hour workshop is to provide fellows with an opportunity to give and receive peer feedback on their current PLV proposal or draft. Using a semi-structured feedback format, students will give and receive constructive feedback on PLV ideas in small groups.

Objectives

Fellows will:

- Identify strategies for engaging different audiences.
- Get feedback on your current PLV design.
- Communicate constructive feedback for peers about their PLVs.
- Build community with other fellows.

Time

2 hours

Materials

PLV Rubric

Student PLV visuals or prototypes, as deemed necessary by students

Evaluation

Plan

<i>Introduction (4 - 4:20 pm)</i>	NAN 181
<ol style="list-style-type: none"> 1. Welcome, Roadmap, Objectives 2. Collective Brainstorm of Engagement Strategies (use PLV Check-In) <ol style="list-style-type: none"> a. Share resources on strategies b. Short intro of backwards design 	<ul style="list-style-type: none"> ● PPT ● Comp. station ● White board with map ● White board markers ● PLV resources digital share ● Music

<i>Peer Feedback Activity (4:20 - 5:20 pm)</i>	
<ol style="list-style-type: none"> 3. Introduce Peer Feedback goal and format: <ol style="list-style-type: none"> a. Gather in small groups of 3 PLV teams 	<ul style="list-style-type: none"> ● PPT ● Comp.

<p>b. Identify a presenter, timekeeper, and facilitator</p> <p>c. Presenting team provides brief overview of PLV (share visuals as desired)</p> <p>d. Peers ask clarifying questions only</p> <p>e. Presenter provides more detailed description of PLV/answers questions</p> <p>f. Peers provide constructive feedback, presenter asks clarifying questions</p> <p>6. Share presenter and peer roles:</p> <p>a. Presenter's Brief Overview:</p> <ul style="list-style-type: none"> · What is your topic? · What is your intended audience? · What is the purpose of your PLV? · What type of feedback would you like (general, appropriate level of science for audience, visual, etc.)? <p>b. Peers' Constructive Feedback:</p> <ul style="list-style-type: none"> · Specific · Descriptive · Relevant · Helpful · Respectful · Suggestions rather than Commands (Don't be bossy) <p><i>Peer Feedback Activity (60 min)</i></p> <ol style="list-style-type: none"> 1. Gather in small groups and identify PLV teams as 1, 2, and 3 2. Small group feedback session for PLV 1 conducted (15 min) 3. Small group feedback session for PLV 2 conducted (15 min) 4. Bio Break (10 min) 5. Small group feedback session for PLV 3 conducted (15 min) 	<p>station</p> <ul style="list-style-type: none"> ● White board with map ● White board markers ● PLV resources digital share ● Music
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<p><i>Wrap Up (5:20 pm - 6 pm)</i></p>	<p>NAN 181</p>
<ol style="list-style-type: none"> 8. Debrief activity as a whole group 9. Discuss next steps and workshop 10. Time for PLV teams to work together (if desired) 11. Reminder: PLV Check In form Resources for 2021 - 2022 PLVs 	<ul style="list-style-type: none"> ● PPT ● Comp. station ● White board with map ● White

	<p>board markers</p> <ul style="list-style-type: none">● PLV resources digital share● Music
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Additional Resources:

Liberating Structures, <https://www.liberatingstructures.com/>

Session 3: Community Engagement

Overview

The purpose of this 1.5-hour workshop is to provide fellows with an opportunity to engage in dialogue with representatives of their target audience and gather feedback on the effectiveness of their PLV drafts. Audience representatives will be recruited after Sessions 1 and 2 of this workshop as fellows home in on a specific target audience.

Objectives

Fellows will:

- Increase their ability to communicate their research across disciplinary boundaries.
- Develop the ability to design and evaluate broader impact activity proposals.
- Gain awareness of their own disciplinary norms, values, and blind spots.
- Gain a deeper understanding of the broader impacts of their research and their own impact identity.

Time

1.5 hours

Materials

Student PLV visuals or prototypes, as deemed necessary by students
Evaluation

Plan

<i>Introduction (4 - 4:20 pm)</i>	NAN 181
<ol style="list-style-type: none"> 1. Welcome, Thank you to guests, Intro to CEI, Roadmap & Objectives for today 2. Icebreakers in Small Groups <ol style="list-style-type: none"> a. Name, Preferred Pronouns (if comfortable), Favorite thing about Spring b. Provide a brief description of your professional discipline or field; as a group identify a commonality among all of your disciplines c. Identify a difference among all of your disciplines; try to focus on the norms or how you practice your discipline (Prompts if needed: How do you define a problem? How do you work toward a solution? How do you measure success?) 	<ul style="list-style-type: none"> ● Sign In ● Name Tags ● Music ● PPT ● Comp. station ● White board markers ● Music ● PLV Check In ● Post Survey ● Eval for

	comm members?
--	----------------------

<i>Feedback Activity (4:20 - 5:20 pm)</i>	
<ol style="list-style-type: none"> 1. Intro to PLVs & Broader Impacts 2. Introduce Peer Feedback goal and format: <ol style="list-style-type: none"> c. Gather in small groups of 3 PLV teams d. Identify a presenter, timekeeper, and facilitator e. See Session 2 4. Groups with 3 PLVs <ol style="list-style-type: none"> a. 15 minutes per group b. Group Discussion (if time): c. Any insights, patterns, questions that you noticed about PLVs? about working with others outside your lab, discipline or field? About giving/receiving feedback? d. Thank your group! 	<ul style="list-style-type: none"> ● Rubrics ● PPT

<i>Wrap Up (5:20 - 5:30 pm)</i>	
<ol style="list-style-type: none"> 3. Whole Group Share Out 4. Fellows: On a scale of 1 - 5, how clear are you about your next step. Volunteers to share their next steps for PLVs? 5. Guests: Any insights? 6. Thank you ALL for participating! 7. Post-Survey 8. Final Seminar: <ol style="list-style-type: none"> a. PLV Check In: I will print these on a template b. Other tangible products or objects to bring c. Guest evals 	<ul style="list-style-type: none"> ● Rubrics ● PPT

Additional Resources for Students

- Potential Products: <https://www.cei.washington.edu/education/uw-graduate-students/graduate-fellowship/>
- Existing Products of Lasting Value: <http://www.cei.washington.edu/education/uw-graduate-students/graduate-fellowship/products-of-lasting-value/>
- Types of Broader Impacts:
- National Science Foundation: Chapter II - Proposal Preparation Instructions: https://www.nsf.gov/pubs/policydocs/pappg22_1/pappg_2.jsp
- Broader Impacts Project Evaluation <https://www.colorado.edu/researchinnovation/research-development/other-resources/broader-impacts-network/broader-impacts-project-evaluation>

APPENDIX E
PLV RUBRIC

CEI PLV Rubric v4 Informed by CEI's purpose for PLVs and "Broader Impacts Review Document for National Science Foundation Proposals: Guiding Principles 2.0" https://researchinsociety.org/resource/guiding-principles-2/				
	1	2	3	4
Purpose of PLV	Purpose and desired outcomes of PLV is not communicated or unclear; PLV medium is not aligned with purpose; Purpose not aligned with CEI's mission or outreach goals.	Purpose and desired outcomes of PLV is implicitly communicated and general; PLV medium is somewhat aligned with purpose; Purpose tangential to CEI's mission or outreach goals.	Purpose and desired outcomes of PLV is communicated and somewhat specific; PLV medium aligned with purpose; Purpose aligns with CEI's mission or outreach goals.	Purpose and desired outcomes of PLV is explicitly communicated and specific; PLV medium strategic for purpose; Purpose advances CEI's mission or outreach goals.
Target Audience	PLV's target audience is unclear or very general; PLV classified as advantaged/status quo based on Inclusive-Immediacy Criterion; PLV medium is inappropriate for target audience.	PLV's target audience is somewhat clear and general; PLV classified as universal or status quo based on Inclusive-Immediacy Criterion; PLV medium is somewhat appropriate for target audience;	PLV's target audience is explicitly communicated and somewhat specific; PLV classified as universal (benefits all) or inclusive (benefits marginalized communities) based on Inclusive-Immediacy Criterion; PLV medium is aligned with target audience;	PLV's target audience is explicitly communicated and specific; PLV classified as universal (benefits all) or inclusive (benefits marginalized communities) based on Inclusive-Immediacy Criterion; PLV medium is appropriate and engaging for target audience.

Design Strategy	Design does not use effective strategies to encourage audience learning and/or measure outcomes; Value-add is unclear; Scale of PLV resulted in poor quality, incomplete, or overly superficial product PLV is unlikely to reach target audience.	1 or 2 strategies to encourage audience learning and/or measure outcomes; Value-add is unrelated to other outreach or educational efforts; Scale of PLV resulted in fair quality product or incomplete; PLV is somewhat likely to reach target audience	Some effective means of engagement, representation, and action/expression* to encourage audience learning and/or measure outcomes; Value-add is supportive of other outreach or educational efforts; Scale of PLV resulted in quality, complete product; PLV leverages existing infrastructure or suggests new mechanism for reaching target audience;	Multiple, effective means of engagement, representation, and action/expression* to encourage audience learning and/or measure outcomes; Value-add is creative with potential to be transformative; Scale of PLV and resources used resulted in high quality, complete, thorough product; PLV leverages existing infrastructure in an enhanced way or suggests new, sustainable mechanisms for reaching target audience.
Communication	PLV did not use language appropriate for target audience (jargon was used without support); Disciplinary assumptions/ blind spots of were apparent; Inadequate background information was provided; Communication exclusive	PLV used somewhat appropriate language for target audience; Disciplinary assumptions/ blind spots were somewhat mitigated; Some background information was provided; Communication was inclusive	PLV used appropriate language for target audience (jargon was not used or was defined); Disciplinary assumptions/ blind spots were mitigated; Appropriate background information was provided; Communication was inclusive	PLV bridges the gap between disciplinary and target audience language (strategic use of jargon); Disciplinary assumptions/ blind spots were well-mitigated; Background information was strategically provided; communication was inclusive and engaging.

*<https://udlguidelines.cast.org/>

APPENDIX F
PLV CHECK IN

PLV Check In

Please complete the following questions based on your current ideas about your product of lasting value (PLV). It is okay (and expected) that your ideas will change over time! This check in will help to document ideas about your PLV and to Danica know if you need any support or resources to help you with this project.

1. Email *
2. Your Name *
3. Team Members' Names
4. What is the title of your PLV?
5. What is the purpose of your PLV?
6. Who is your main audience for your PLV?
7. What are the desired outcomes or goals of your PLV?
8. What strategies will you use to reach your PLV goals?
9. What was most valuable about today's session? Please share at least one strength of today's session.
10. What was least valuable about today's session? Please share at least one improvement you would suggest for today's session.
11. Are there any resources or support you need from CEI or Danica to advance your PLV?
12. How would you like to showcase (e.g., printed poster, physical prototype, video, etc.) your PLV at the End of the Year Seminar?

Action Research Study Participation

As a reminder, I am also inviting your voluntary participation to use your PLV Check Ins as data for my action research study. These check ins will help me to evaluate the impact and value of this PLV Design Workshop. If you choose not to participate or to withdraw from the study at any time, there will be no penalty and it will not affect your CEI Graduate Fellowship. Results from this study will be used in my dissertation and may be used in reports, presentations, or publications but no names nor titles of PLVs will be used. If you have any questions concerning the research study or this check in, please contact the research team – Danica Hendrickson at -- or or Dr. Steven Salik at --

13. Will you allow your answers to be included in the data set for the study PLV Design Workshop? Yes/No

APPENDIX G

PLV CHECK IN – WORKSHOP VALUE CODING AND ANALYSIS

Qualitative Results for PLV Check Ins - Workshop Value

The PLV Check In was a digital, non-anonymous survey administered after each session of the PLV Design Workshop. All fellows, including those who did not attend a session were invited to complete the open-ended questions on this survey. While most questions were related to their PLVs, two questions specifically asked fellows to provide feedback on what was most and least valuable about each session of the PLV Design Workshop. These data were collected to support future iterations of the workshop. After removing responses from fellows who did not want to share their data and responses such as “N/A” or “I was unable to attend because I was sick,” there were 21 PLV Check Ins from 11 different fellows. There were 20 comments about the most valuable aspects of a session and 18 comments about the least valuable aspects of a session. One important thing to note is that it is not possible to confirm the session to which the fellows are specifically referring. Because each survey response had a timestamp, I can associate many — but not all — comments with a specific session.

PLV Check In — Workshop Value Results

Descriptive coding was first employed to explore the data and identify the main topic or topics of each comment (Saldaña, 2021). This initial cycle of coding resulted in 21 unique codes for the most valuable aspects of workshop sessions and 20 unique codes for the least valuable aspects of workshop sessions. Descriptive Codes similar in content were then grouped into larger categories and updated into six Pattern Codes for workshop strengths and eight Pattern Codes for workshop improvements. Table 1 summarizes the Pattern Codes that synthesize comments about the most valuable aspects of the PLV Design Workshop.

Table 1*Pattern Codes, Descriptions, and Data Related to Fellows' Ideas about Workshop Value*

Pattern Codes with Frequency Counts	Pattern Code Description and Examples
Feedback, 14	<p>Codes in this category referred to constructive feedback shared by peers or community members. Some fellows noted that even hearing other fellows' ideas was helpful.</p> <p>“Getting feedback from educators, especially since my knowledge is so limited. I was able to get good feedback on what was done well as well as what could be improved”</p> <p>“The group feedback sessions were really helpful!”</p> <p>“Just hearing different people's perspectives on our ideas was useful since they could point out holes or other things that we may have missed.”</p>
Clarity and Support for Development, 5	<p>This code describes aspects of the workshop that gave fellows clarity on the development of their PLV or other types of support like content about techniques.</p> <p>"Pushing us to take time to actively strategize and plan"</p> <p>“Having a clear idea of expectations for the PLV and areas of need”</p>
Collective Clean Energy Map, 2	<p>Two fellows appreciated a Session 1 activity that invited fellows to add their research to a map of CEI's research areas. “It was cool seeing how everyone's research fits into different areas of CEI.”</p>
Brainstorming, 1	<p>One fellow wrote that “The Brainstorming Session!” was a strength of the first session.</p>
Connections with Fellows, 1	<p>After the first session, one fellow who already knew what they were doing for their project valued connections made with other fellows.</p> <p>“Knowing what I wanted to do before this, I thought the best part were the connections I made with my fellow CEI fellows.”</p>
Impact Identity, 1	<p>One fellow expressed value for the content presented in Session 1 on impact identity.</p> <p>“I really enjoyed the discussion of impact identity. That will be very valuable in the future for me.”</p>

Eight different Pattern Codes emerged from PLV Check In responses about the least valuable aspects of the PLV Design Workshop. See Table 2 for a summary and description of the Pattern Codes for the least valuable aspects of the PLV Design Workshop.

Table 2

Pattern Codes, Descriptions, and Data Related to Workshop Improvements

Pattern Codes with Frequency Counts	Code Description and Examples
More effective use of time, 6	<p>Codes in this category relate to using time more effectively during the PLV Design Workshop. A few fellows wanted more time to work with their community members or to incorporate the feedback they received. Others wanted shorter presentations from me, the facilitator.</p> <p>“I think making some of the slides from the presentation more concise would have helped get the information across in a more digestible way.”</p> <p>“Some more time for introductions for the people providing us with feedback. It felt rushed. Perhaps the initial table group introductions (at the start, not our assigned groups) could be removed to allow for more time”</p>
Improve Brainstorming Activities, 4	<p>A few fellows made suggestions for ways to improve the brainstorming sessions. The trend was that more time for brainstorming would be helpful and some ideas for how to sequence these activities were shared.</p> <p>“The only improvement I can think of would be to perhaps give the brain storming session a little bit more time.”</p> <p>“It'd be helpful to start workshopping ideas collectively instead of putting people on the spot to state their ideas. Brainstorming collectively on what is a good place to start and look into would be helpful.”</p>
More support for BI and Impact Identity, 4	<p>A few fellows responded that an activity around the Broader Impacts of research or impact identity was the least valuable aspect of a workshop session.</p>

	<p>“I felt like there was not enough time to really delve into the deeper philosophical questions about broader impacts and the goals of our research and fields. Perhaps an activity that walks us through each of those questions step by step would be more useful in the future.”</p>
Positive Comment, 3	<p>Three fellows included positive comments despite the question asking for improvements.</p> <p>“I think it overall went really well and felt productive!!”</p>
Collective Clean Energy Map, 1	<p>One fellow identified the Collective Clean Energy Map as the least valuable part of Session 1.</p> <p>“Writing our names under the branch of the CEI mission that applied to our research”</p>
Commonality/Difference Icebreaker, 1	<p>One fellow identified the Commonality/Difference Icebreaker as the least valuable part of Session 3.</p> <p>“The introduction discussion about commonalities and differences among table members”</p>
Content Not Applicable, 1	<p>One fellow commented that “I already have a bit of a head start, therefore some of the information didn't feel applicable”</p>
Lack of Participation, 1	<p>One fellow’s comment suggested that more participation from peers would improve the session.</p> <p>“Several participants in my group seemed unenthusiastic about brainstorming, generally speaking up, and providing a wide range of constructive criticism.”</p>

Analysis of PLV Check In – Workshop Value Results

Feedback collected from the PLV Check In about the workshop proved invaluable for future iterations of this innovation. From this data, four assertions were made in and are listed and described in more detail below.

Assertion 1: Interaction with peers and community members should be prioritized at the PLV Design Workshop to facilitate constructive feedback and build connections among fellows. First and foremost, many

fellows valued the interactions they had with peers and community members. While much of this was due to the constructive feedback they received, even “talking with others about their ideas” (PLV Check In, April 1) was helpful. While only one person commented on “the connections I made with my fellow CEI fellows” (PLV Check In, April 4), it seems obvious now that in order to facilitate community among CEI Fellows, interaction is required. Since time is such a valuable resource for busy graduate students, prioritizing dialogue with peers and community members should be a goal for future iterations of this workshop. This could also contribute to the objectives of the PLV curricula, which include building community among fellows and increasing their ability to communicate their research across disciplinary boundaries.

Assertion 2: While some fellows valued the impact identity (Risien & Storksdieck, 2018) content, the presentation and support for this content should be reevaluated and revised to increase support. I found feedback on the BI and impact identity activities really useful. Two separate comments suggested that more time was needed to deliver this content effectively. For instance, one fellow wrote, “I would have loved to have had a bit more time with the impact identity, we didn't really have time to delve into it” (PLV Check In, April 7). Reflecting on my experience facilitating the workshop, I agree that the content felt rushed and could have had a session of its own. It is also important to consider how experiential learning through the design and delivery of the PLV could support a deeper understanding of BI and impact identity than a presentation. For instance, prioritizing dialogue with community members and the development of a quality PLV during the workshop might facilitate greater learning with respect to these concepts than a PowerPoint presentation.

Assertion 3: Prioritize “need to know” content and activities and use workshop time effectively. Feedback received via the PLV Check Ins suggested that

fellows want content and activities that will directly benefit the development of their PLVs such as strategies for engaging their audience or clarifying project guidelines. This feedback encouraged me to reflect on how I could shift some teacher-centered pedagogy to more student-centered pedagogy in the PLV Design Workshop. Fellows' requests for more time brainstorming or incorporating feedback during the session suggest that using time to design their PLVs during the workshop might be helpful. The takeaway is that I should identify and prioritize content and activities that fellows need in order to progress their PLVs. And that my PowerPoints are not always concise.

Recall that the overall learning objectives for this project are to build community with other CEI Graduate Fellows, to gain a deeper understanding of the BI of their research and their own impact identity, to increase the ability to communicate their research across disciplinary boundaries, and to develop the ability to design and evaluate broader impact activity proposals. Unfortunately, the PLV Check In comments that were analyzed in this section do not explicitly address these objectives. While some comments suggested the potential for this workshop to build community and interest among fellows to learn more about BI and impact identity, there were many comments that suggested there is much room for improvement. As noted above, however, the feedback that I did receive provides invaluable support for redesigning future iterations of this workshop.

APPENDIX H
PLV WORKSHOP PRE-SURVEY



Dear CEI Graduate Fellows:

I am inviting your **voluntary participation** to complete this survey. This 11-question survey which will be administered at the beginning and end of the PLV workshop will help me to evaluate the impact and value of this PLV Design Workshop. It is part of an action research study to explore the ability of the PLV Design Workshop to support the objectives of the Product of Lasting Value CEI Graduate Fellowship requirement. I am conducting this study as part of my doctoral studies under the direction of Professor Steven Salik in the in the Mary Lou Fulton Teachers College (MLFTC) at Arizona State University (ASU).

Your participation in this study is voluntary and you must be 18 or older to participate. If you begin the survey, you have the right skip any question, stop the survey any time, and to not submit the survey. The benefit to participation is the opportunity to reflect upon this project and the broader impacts of your research. There are no foreseeable risks to your participation, except for the possibility of discomfort associated with reflection on the broader impacts of your research. **By submitting the survey, you are agreeing to be part of the study.**

Your responses will be anonymous and no identifying information is being asked. The results of this study may be used in my dissertation, reports, presentations, or publications but your name will not be collected or used. If you have any questions concerning the research study or this survey, please contact the research team – Danica Hendrickson at dlhendr2@asu.edu or (206) 920-3560 or Dr. Steven Salik at shsalik@asu.edu.

Thank you so much for considering!

Sincerely,
Danica

Danica Hendrickson, Doctoral Student
Dr. Steven Salik, Clinical Assistant Professor

Background Information

Your Unique ID:

In order to pair pre- and post-surveys and maintain anonymity, please create a unique code. Pick the first 3 letters of your favorite animal and the last 3 digits of your phone number. For example, if my favorite animal is an elephant and my phone number is 123-4567, I would write ele567.

Section 1. Perspectives on Broader Impacts

According to the National Science Foundation (NSF), broader impacts are the potential for science to benefit society. "Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to the project" (NSF, Proposal & Award Policies & Procedure Guide II.C.2.d.1.). Even beyond STEM disciplines, agencies that fund research often require proposals to incorporate activities and assessments related to the broader impacts of their research (Harvard University, Broader Impacts).

The questions in this section invite you to reflect on your ideas and perspectives about the broader impacts of research.

The NSF's Proposal & Award Policies & Procedure Guide notes that the foundation "values the advancement of scientific knowledge and activities that contribute to the achievement of societally relevant outcomes." This guide lists the following as examples of these broader impacts or outcomes. Note that this is not an exhaustive or prescriptive list of broader impacts.

- full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM);
- improved STEM education and educator development at any level;
- increased public scientific literacy and public engagement with science and technology;
- improved well-being of individuals in society;
- development of a diverse, globally competitive STEM workforce;
- increased partnerships between academia, industry, and others;
- improved national security;
- increased economic competitiveness of the U.S.;
- use of science and technology to inform public policy;
- enhanced infrastructure for research and education. (NSF, Proposal & Award Policies & Procedure Guide II.C.2.d.1.).

The following questions invite you to evaluate each type of broader impact. If you are not conducting research in a STEM discipline, please replace STEM with your own disciplinary field.

How interested are you in exploring each type of broader impact?

	Not interested at all	Slightly interested	Somewhat interested	Interested	Very interested
A. full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

B. improved STEM education and educator development at any level	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C. increased public scientific literacy and public engagement with science and technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
D. improved well-being of individuals in society	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
E. development of a diverse, globally competitive STEM workforce	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
F. increased partnerships between academia, industry, and others	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
G. improved national security	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
H. increased economic competitiveness of the U.S.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I. use of science and technology to inform public policy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
J. enhanced infrastructure for research and education	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How related to your research is each broader impact?

	Not related at all	Slightly related	Somewhat related	Related	Very related
A. full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
B. improved STEM education and educator development at any level	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C. increased public scientific literacy and public engagement with science and technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
D. improved well-being of individuals in society	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

E. development of a diverse, globally competitive STEM workforce	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
F. increased partnerships between academia, industry, and others	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
G. improved national security	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
H. increased economic competitiveness of the U.S.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I. use of science and technology to inform public policy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
J. enhanced infrastructure for research and education	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

How knowledgeable do you feel about each broader impact?

	Not knowledgeable at all	Slightly knowledgeable	Somewhat knowledgeable	Knowledgeable	Very knowledgeable
A. full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
B. improved STEM education and educator development at any level	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
C. increased public scientific literacy and public engagement with science and technology	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
D. improved well-being of individuals in society	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
E. development of a diverse, globally competitive STEM workforce	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
F. increased partnerships between academia, industry, and others	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
G. improved national security	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
H. increased economic competitiveness of the U.S.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

- I. use of science and technology to inform public policy
- J. enhanced infrastructure for research and education

Please describe any other broader impacts that you are interested in exploring.

What personal skills and strengths do you have that could support broader impact activities?

How might you benefit from engaging in broader impact activities?

Section 2. The Clean Energy Field

The questions in this section relate to your ideas about the clean energy field and your research.

How do you define clean energy?

How engaged do you feel with the field of clean energy?

- 1 = Not engaged at all

- 2 = Slightly engaged
- 3 = Somewhat engaged
- 4 = Engaged
- 5 = Very engaged

How likely is it that you will be involved in the clean energy field in the future?

- 1 = Not likely
- 2 = Slightly likely
- 3 = Somewhat likely
- 4 = Likely
- 5 = Very likely

How aligned is your research with the field of clean energy?

- 1 = Not aligned at all
- 2 = Slightly aligned
- 3 = Somewhat aligned
- 4 = Aligned
- 5 = Very aligned

Is there anything else you would like to share?

APPENDIX I
FOCUS GROUP INTERVIEW PROTOCOL

Focus Group Interview Protocol

Materials:

ASU Zoom, Owl
Phone as back up

Introduction:

- Thank you for participating in this focus group interview. The purpose of this focus group is to learn about your experience with the PLV Design Workshop and your perspectives on the broader impacts of your research. I am also hoping to gain some perspective on some questions that came up for me during this study (member checking).
- I've prepared for a semi-structured interview which means I have some open-ended questions to ask, and also plan to allow space for discussion. I anticipate this interview will take about 75 minutes and I would like to record it, with your permission. We will retain only the audio track for analysis. The interview will not be recorded without your permission; you can also change your mind after the interview starts.
- **Your participation in a focus group is voluntary.** If you choose not to participate or to withdraw from the study at any time, there will be no penalty. Choosing not to participate in the study does not affect your standing at the University of Washington's Clean Energy Institute.
- I do request that we agree to maintaining appropriate confidentiality after interviews such as not sharing others' stories or feelings without permission. Because we are in a group, and hybrid, I ask that we be sure others are finished speaking before starting to speak. I also hope that you enjoy this discussion and get something out of it!
- Always happy to follow up if you have any questions or would like to add something.
- Any questions? Okay, I will begin recording.

Questions:

1. Introductions. Would you please share your name, pronouns if you are comfortable, and a short description of your current research focus.

2. What was your PLV and describe your experience of designing a product of lasting value.

3. Did any of the PLV Design workshops support the development of your PLV? As a reminder, you were invited to an ideation workshop, peer feedback workshop, and a community engagement workshop.
4. Did your participation in the PLV Design Workshop have any effect on your ideas about the broader impacts of research? the field of clean energy?
5. To what extent do you identify as a researcher in the clean energy field, or a clean energy researcher?
6. Would you suggest keeping the PLV requirement? If so, do you have suggestions for improvement? If not, do you have other suggestions for ways to support graduate fellows' engagement with the clean energy field and learning how to engage with the broader impacts of research?

APPENDIX J
INNOVATION CONFIGURATION MAPS

IC Map - Session 2 Evaluation and Notes				
Student Outcome 1 - Build Community				Post-workshop Reflection
Engaging others during breaks; learning new names; make connections for later; create PLV teams	X Engaging others during activities and breaks; learning names	Engaging those already known; Engaging others during activity only	Not engaged with anyone new; multitasking	
Student Outcome 2 - Engaged				Post-workshop Reflection
Critically thinking during workshop; making decisions and progress on PLV; fully participating in reflective and active; personally meaningful PLV	X Fully participating in all activities; critically thinking	Making progress on PLV; active participation; progress on PLV; PLV not personally meaningful	Selective or little participation; going through motions of PLV; selecting easy project	Students seemed tired! And it seemed that not too much progress on PLVs had been made since last time. Some students still didn't have a solid idea, while other had some content to share with others. One issue I see is that some students are making assumptions about audience that may not be true, or they don't know the research that already exists on educating a particular audience.
Facilitator Outcome 1 - Encourages community & engagement				Post-workshop Reflection
Seating, Layout, Structured & Non-structured time foster engagement with students; encourages student contribution and expertise; points out meaningful connections	X Seating, Layout, Structured & Non-structured time foster engagement with students;		Seating, layout, activities discourage interaction or prioritize expertise of facilitator over students	I had a VERY short intro, so I left tables in rows knowing that students would be asked to move into small groups after this intro for peer feedback.
Facilitator Outcome 2 - Fosters Learning				Post-workshop Reflection
Offers adequate worktime/ reflection; facilitates active work with content; gives specific feedback and guidance; probing questions are pointed and fruitful	X Offers adequate worktime/ reflection; facilitates active work with content; provides support for students (though may not be specific)	Adding post workshop: Offers a balance between individual/group work time, though content is not supportive or responsive to student needs with respect to the project	Questions unhelpful or not specific; does not connect with student needs	This is a busy time of year. I had planned for students to have the last 30 minutes to work and thought about offering them time to leave early. When one of the first students to arrive said they might need to leave early, I made the call to end at 5:30 pm rather than 6 pm. This ended up being adequate time for all.

IC Map - Session 2 Evaluation and Notes				
Student Outcome 1 - Build Community				Post-workshop Reflection
Engaging others during breaks; learning new names; make connections for later; create PLV teams	X Engaging others during activities and breaks; learning names	Engaging those already known; Engaging others during activity only	Not engaged with anyone new; multitasking	
Student Outcome 2 - Engaged				Post-workshop Reflection
Critically thinking during workshop; making decisions and progress on PLV; fully participating in reflective and active; personally meaningful PLV	X Fully participating in all activities; critically thinking	Making progress on PLV; active participation; progress on PLV; PLV not personally meaningful	Selective or little participation; going through motions of PLV; selecting easy project	Students seemed tired! And, it seemed that not too much progress on PLVs had been made since last time. Some students still didn't have a solid idea, while other had some content to share with others. One issue I see is that some students are making assumptions about audience that may not be true, or they don't know the research that already exists on educating a particular audience.
Facilitator Outcome 1 - Encourages community & engagement				Post-workshop Reflection
Seating, Layout, Structured & Non-structured time foster engagement with students; encourages student contribution and expertise; points out meaningful connections	X Seating, Layout, Structured & Non-structured time foster engagement with students;		Seating, layout, activities discourage interaction or prioritize expertise of facilitator over students	I had a VERY short intro, so I left tables in rows knowing that students would be asked to move into small groups after this intro for peer feedback.
Facilitator Outcome 2 - Fosters Learning				Post-workshop Reflection
Offers adequate worktime/ reflection; facilitates active work with content; gives specific feedback and guidance; probing questions are pointed and fruitful	X Offers adequate worktime/ reflection; facilitates active work with content; provides support for students (though may not be specific)	Adding post workshop: Offers a balance between individual/group work time, though content is not supportive or responsive to student needs with respect to the project	Questions unhelpful or not specific; does not connect with student needs	This is a busy time of year. I had planned for students to have the last 30 minutes to work and thought about offering them time to leave early. When one of the first students to arrive said they might need to leave early, I made the call to end at 5:30 pm rather than 6 pm. This ended up being adequate time for all.

IC Map* - Session 3 Notes Only				
Student Outcome 1 - Build Community				Post-workshop Reflection
Engaging others during breaks; learning new names; make connections for later;	Engaging others during activities and breaks; learning names	Engaging those already known; Engaging others during activity only	Not engaged with anyone new; multitasking	No true breaks
Student Outcome 2 - Engaged				Post-workshop Reflection
Critical dialogue during workshop; insights made; students actively listening; community members and students fully participating; personally meaningful PLV	Fully participating in all activities; good dialogue; some learning	Participating but not actively listening; holding on to assumptions or initial ideas even after conversation	Disrespectful interactions; lack of participation	Happy with student, target audience participation; a couple groups (education team) seemed more engaged than others?
Facilitator Outcome 1 - Encourages community & engagement				Post-workshop Reflection
Seating, Layout, Communication Guidelines, Structured & Non-structured time foster engagement among students and community; encourages student and community contribution and expertise; points out meaningful connections	Seating, Layout, Communication Guidelines, Structured & Non-structured time foster engagement with students;	Seating, layout, activities discourage interaction or prioritize expertise of some over others	Lack of clarity or poor layout results in disrespectful engagement	Didn't actually have much non-structured time since I shortened this workshop
Facilitator Outcome 2 - Fosters Learning				Post-workshop Reflection
Activities encourage critical thinking and dialogue as well as learning from peers and community members; facilitator and activities provide specific feedback and guidance; probing questions are pointed and fruitful	Offers adequate worktime/ reflection; facilitates active work with content; provides support for students (though may not be specific)	Offers a balance of activities, though content is not supportive or responsive to student needs with respect to the project	Activities unhelpful or not specific; does not connect with student needs; community members feel a waste of time	Shortening seemed like a good idea, though I regret not having students stay to complete the post survey *Updated rubric in advance of Community Engagement Workshop

APPENDIX K

PLV WORKSHOP PRE-SURVEY CODING

1. Please describe any other broader impacts that you are interested in exploring.		
Descriptive Codes 10/10 Reviewed 10/11	Pattern Codes	Pattern Code Description (Frequency)
Specific Audience	"Personal Preferences"	The pattern code, Personal Preferences, comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their "personal identities and intrinsic motivators" (p. 62). Codes included in this category for this question relates to fellows' interest or experience working with specific audiences. (3)
Specific Audience	"Personal Preferences"	
specific audience	"Personal Preferences"	
longitudinal educational improvements for a student	Education	This code refers to interests in education. It included both "public literacy" and concern for improving "education throughout a student's life." (2)
public literacy	Education	
"Our net carbon neutral future"	Energy	Codes in this category are specifically related to energy in some way such as energy resiliency of communities, carbon neutrality, and the "global materials supply." (4)
Energy resiliency	Energy	
Global Materials Supply	Energy	
Renewable Energy	Energy	
Environmental Justice	Justice	This pattern code incorporates descriptive codes associated with justice and the goal of "improvement of people's lives." The arena and approach to working toward justice differed from science policy and infrastructure to more

environmental justice	justice	"equitable and accessible STEM education for public K-12 schools." This also incorporated comments specific to environmental justice. (6)
improving lives through sci policy and infrastructure	Justice	
JEDI in STEM	Justice	
JEDI in STEM	Justice	
just government and economic systems	Justice	
policy	policy	The pattern code includes interest specifically related to policy. (1)
no other interest		

2. What personal skills and strengths do you have that could support broader impact activities?		
Descriptive Codes 10/10 Reviewed 10/11	Pattern Codes	Pattern Code Description (Frequency)
interest in nexus of science, culture, policy	"Personal Preferences"	The pattern code, Personal Preferences, comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their "personal identities and intrinsic motivators" (p. 62). Codes included in this category relate to fellows' interest or experience working with specific audiences, their passion for improving STEM culture, or topics that are of interest to them. (8)
passion	"Personal Preferences"	
passion	"Personal Preferences"	
passion	"Personal Preferences"	
passion	"Personal Preferences"	
specific audience	"Personal Preferences"	
specific audience	"Personal Preferences"	
specific audience	"Personal Preferences"	
bilingual	Communication Skills	Several fellows included communication skills as strengths. This pattern code incorporates many different communication skills such as writing, graphics, general communication, and science communication more specifically. (9)
Comm	Communication Skills	
communication	Communication Skills	
Graphics	Communication Skills	
Sci Comm	Communication Skills	
Sci Comm	Communication Skills	
sci comm	Communication Skills	
sci comm	Communication Skills	
Writing	Communication Skills	

CE literacy	Content Knowledge	Two fellows listed a type of content knowledge as a strength such as "clean energy literacy" or a critical understanding of green capitalism." (2)
critical understanding of green capitalism	Content Knowledge	
Data Science	Disciplinary Skills	This pattern code describes strengths related to disciplinary skills or expertise such as data science or research skills. One fellow called out the fact that they are a scientist as a skill. (3)
research skills	Disciplinary Skills	
scientist	Disciplinary Skills	
identification with UR in STEM	representation in STEM	While this pattern code could fall under the concept of "Personal Preferences," I wanted to call out this strength specifically. Several fellows noted their social identification with non-dominant groups in STEM as strengths. These fellows described insights related to the power of representation in STEM, the ability to communicate and identify with underrepresented groups in STEM. (3)
representation in STEM	representation in STEM	
representation in STEM	representation in STEM	
teaching	Teaching	Two fellows felt that teaching and/or lesson planning were strengths or skills that they bring to BI. (2)
teaching	teaching	

event planning	Transferable Skills	This pattern code incorporates transferable skills such as leadership, event planning, or interdisciplinary knowledge that align with industry's interest. (4)
Interdisciplinary Knowledge	Transferable Skills	
interpersonal skills	Transferable Skills	
leadership	Transferable Skills	

3. How might you benefit from engaging in broader impact activities?		
Descriptive Codes	Pattern Codes	Pattern Code Description (Frequency)
connections within field	Connections	The pattern code Connections refers to the benefit of BI activities facilitating connections with new people whether this was in one's field or with students. (2)
direct connections with students	Connections	
support current research efforts	Disciplinary Expertise	Disciplinary Expertise refers to the ability of engaging in BI activities to deepen one's one expertise. (1)
increased awareness of diversity	Intercultural Awareness	Intercultural Awareness describes the ability of BI activities to help fellows learn about "people from different areas of life." (2)
increased awareness of others	Intercultural Awareness	
"more well-rounded researcher"	Knowledgeability of BI	One pattern I observed were benefits that I interpreted as directly related to the Knowledgeability of BI. This included benefits such as better understanding and ability to engage in different BI activities. It also included better understanding of others' needs and becoming a "more well-rounded researcher." (5)
increased knowledgeability of BI	Knowledgeability of BI	
increased knowledgeability of BI	Knowledgeability of BI	

increased awareness of others	Knowledgeability of BI	
bidirectional research	Knowledgeability of BI	
"Doing good makes you feel good"	Personal Preferences	The pattern code, Personal Preferences, comes directly from Risien and Storksdieck's (2018) work on Impact Identity. This dimension of one's impact identity refers to their "personal identities and intrinsic motivators" (p. 62). With respect to the benefits of engaging in the BI of research, fellows expressed some intrinsic motivators such as "doing good makes you feel good" and a desire to "give back to those who have helped me." (4)
"give back"	Personal Preferences	
"Doing good makes you feel good"	Personal Preferences	
"the world is broken, we all benefit from working to fix it"	Personal Preferences	
sci comm	sci comm	
sci comm	sci comm	Three fellows felt that engaging in BI activities would make them "a better science communicator" (3)
sci comm	sci comm	
sci comm	sci comm	
interpersonal skill building	Transferable skills	One other theme that came up from one fellow's comments was that of transferable skills. They identified some benefits as developing "interpersonal skills" and making them "more competitive" for future applications. This comment seemed directly related to transferable skills which will help one to secure a job. (1)

APPENDIX L
FOCUS GROUP INTERVIEW CODING

Pattern Codes	Final Concept Codes	Interview Question
Are PLVs worth the effort?	Are PLVs worth the effort?	Final Thoughts
Are PLVs worth the effort?	Are PLVs worth the effort?	Final Thoughts
Are PLVs worth the effort?	Does CEI value PLVs?	Final Thoughts
Are PLVs worth the effort?	individual-based enthusiasm vs. sustainable systems	Final Thoughts
Are PLVs worth the effort?	individual-based enthusiasm vs. sustainable systems	Final Thoughts
Are PLVs worth the effort?	individual-based enthusiasm vs. sustainable systems	Final Thoughts
Are PLVs worth the effort?	individual-based enthusiasm vs. sustainable systems	Final Thoughts
Are PLVs worth the effort?	Transparency about PLVs	Final Thoughts
CEI Fellowship offers multiple opportunities for growth.	"It was the Lunch and Learn. And, everyone should do it"	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	application, technology	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: EIR	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: EIR	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: fellowship	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: fellowship	helpfulness of workshops? experience of PLV?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: Lunch and Learn	helpfulness of workshops? experience of PLV?
CEI Fellowship offers multiple opportunities for growth.	other supportive opportunities: Lunch and Learn	helpfulness of workshops? experience of PLV?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: Lunch and Learn	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: more social events	helpfulness of workshops? experience of PLV?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: more social events	helpfulness of workshops? experience of PLV?

CEI Fellowship offers multiple opportunities for growth.	other supportive opportunities: Opportunity for Reflections	helpfulness of workshops? experience of PLV?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: Sci Comm Workshops	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	Other supportive opportunities: tours	Constrain PLV to either K12 product or research explainer?
CEI Fellowship offers multiple opportunities for growth.	timing of new insights	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	Fellow 1 Background: interdisciplinary, clean energy- focused research	Current Research?
Fellows least identified with clean energy stand to gain the most.	Fellow 2 Background: interdisciplinary, clean energy- focused research	Current Research?
Fellows least identified with clean energy stand to gain the most.	Fellow 3 Background: disciplinary, theoretical research	Current Research?
Fellows least identified with clean energy stand to gain the most.	Fellow 4 Background: disciplinary, experimental research	Current Research?
Fellows least identified with clean energy stand to gain the most.	increased connection to clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	increased connection to clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	increased connection to clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	increased connection to clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about career: "maybe I don't want to do academia after all"	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about career: from curiosity to career strategies, or from science to application	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about clean energy	Constrain PLV to either K12 product or research explainer?

Fellows least identified with clean energy stand to gain the most.	new perspectives about clean energy	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about peers	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	new perspectives about peers	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	no change in CE connection for those already engaged	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	no change in CE connection for those already engaged	Constrain PLV to either K12 product or research explainer?
Fellows least identified with clean energy stand to gain the most.	Theorist vs Experimentalist	Current Research?
Gains in Broader Impacts, but Questions Remain	growth in BI	Constrain PLV to either K12 product or research explainer?
Gains in Broader Impacts, but questions remain	growth in BI	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	Growth in BI	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	growth in BI	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	growth in BI	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	growth in BI	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	growth in BI?	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?

Gains in Broader Impacts, but questions remain	Imposter syndrome mitigated	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	PLV/Research Disconnect	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	PLV/Research Disconnect	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	PLV/Research disconnect	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	PLV/Research disconnect	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	What's the relationship between BI, PLVs, and Research?	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
Gains in Broader Impacts, but questions remain	What's the relationship between BI, PLVs, and Research?	Any thoughts on, like, did the PLV design workshops encourage any growth or learning about your broader impacts?
PLV Background & Context	Diversity of PLVs: Largescale PLV	PLV and general experience of developing PLV?
PLV Background & Context	Fellow 1 Background: New to PLVs	PLV and general experience of developing PLV?
PLV Background & Context	Fellow 2 Background: Knew about PLVs	PLV and general experience of developing PLV?
PLV Background & Context	Fellow 3 Background: Knew about PLVs	PLV and general experience of developing PLV?
PLV Background & Context	Fellow 4 Background: New to PLVs	PLV and general experience of developing PLV?
PLV Background & Context	PLV Development: "A lot of troubleshooting"	PLV and general experience of developing PLV?
PLV Background & Context	PLV Development: TBC	PLV and general experience of developing PLV?

PLV Background & Context	PLV Development: TBC	PLV and general experience of developing PLV?
PLV Background & Context	PLV Development: team effort	PLV and general experience of developing PLV?
PLV Background & Context	Variety of Products: Largescale PLV	PLV and general experience of developing PLV?
PLV Background & Context	Variety of Products: Small scale PLV	PLV and general experience of developing PLV?
Target Audience.	Actual Audience	PLV and general experience of developing PLV?
Target Audience.	Actual Audience	PLV and general experience of developing PLV?
Target Audience.	Actual Audience	helpfulness of workshops? experience of PLV?
Target Audience.	Actual Audience	helpfulness of workshops? experience of PLV?
Target Audience.	Actual Audience	Constrain PLV to either K12 product or research explainer?
Target Audience.	Formative Feedback	helpfulness of workshops? experience of PLV?
Target Audience.	Formative Feedback	helpfulness of workshops? experience of PLV?
Target Audience.	Formative Feedback	helpfulness of workshops? experience of PLV?
Are PLVs worth the effort?	Timing: 10 hours not conducive to quality product	helpfulness of workshops? experience of PLV?
Are PLVs worth the effort?	Timing: 10 hours not realistic	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Valued PLVs	helpfulness of workshops? experience of PLV?
More Structured Support Needed	fellow 3 notes that this would make feedback cycles with peers a more efficient use of time since not everybody was prepared	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Timing: Session Dates	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Timing: Session Dates	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Timing: Session Dates	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Timing: Session Dates	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Suggestion: community generated PLV Ideas	helpfulness of workshops? experience of PLV?
More Structured Support Needed	suggestions for improvement: "set deadline" with flexibility	helpfulness of workshops? experience of PLV?

More Structured Support Needed	suggestions for improvement: more specific deadlines for specific deliverables	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Suggestions for Improvement: reference materials for fellows	helpfulness of workshops? experience of PLV?
More Structured Support Needed	suggestions for improvement: timing	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Ideation support	PLV and general experience of developing PLV?
More Structured Support Needed	Ideation support	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Ideation Support	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Ideation support	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Ideation Support	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	Ideation Support	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	Ideation Support	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	Ideation Support	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	"More structure"	helpfulness of workshops? experience of PLV?
More Structured Support Needed	"More structure"	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	"More structure"	
More Structured Support Needed	"More structure"	
More Structured Support Needed	"Vastly different" amounts of effort	helpfulness of workshops? experience of PLV?
More Structured Support Needed	waste of time	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	waste of time: unprepared peers	helpfulness of workshops? experience of PLV?
More Structured Support Needed	conflicting emotions about deadlines	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Interdisciplinary dilemmas	helpfulness of workshops? experience of PLV?

More Structured Support Needed	Interdisciplinary dilemmas	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Interdisciplinary dilemmas	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Networking	PLV and general experience of developing PLV?
More Structured Support Needed	problem of background knowledge	PLV and general experience of developing PLV?
More Structured Support Needed	The problem of background knowledge	PLV and general experience of developing PLV?
More Structured Support Needed	the problem of scientific background knowledge	Constrain PLV to either K12 product or research explainer?
More Structured Support Needed	Valued PLVs	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Workshop Value: "pretty" useful	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Workshop Value: techniques	helpfulness of workshops? experience of PLV?
More Structured Support Needed	Workshops Useful	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	workshop encouraged fellow connections	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	workshop encouraged fellow interactions	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	workshop encouraged fellow interactions	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	leveraging other partnership/project	PLV and general experience of developing PLV?
"I did think the workshops were useful."	Sci Comm	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	Science Communication	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	not all workshop sessions created equal	helpfulness of workshops? experience of PLV?
"I did think the workshops were useful."	Workshop Value: no lasting interactions	helpfulness of workshops? experience of PLV?

APPENDIX M

SUMMARY OF ALL FOCUS GROUP INTERVIEW ASSERTIONS

Focus Group Interview Codes and Assertions

Pattern Codes with Corresponding Concept Codes	Assertions
<p>PLV Background and Context</p> <ul style="list-style-type: none"> ● Fellow 1 Background: New to PLVs ● Fellow 2 Background: Knew about PLVs ● Fellow 3 Background: Knew about PLVs ● Fellow 4 Background: New to PLVs ● PLV Development: "A lot of troubleshooting" ● PLV Development: TBC ● PLV Development: team effort ● Variety of Products: Large-scale PLV ● Variety of Products: Small-scale PLV 	<p>The background and context that drives the development of each PLV is unique.</p>
<p>“I did think the workshops were useful.”</p> <ul style="list-style-type: none"> ● leveraging other partnership/project ● workshop encouraged fellow connections ● workshop encouraged fellow interactions ● Science Communication ● not all workshop sessions created equal ● Workshop Value: no lasting interactions 	<p>The PLV Design Workshop should continue to be offered to CEI Graduate Fellows after some revisions.</p>
<p>Formative Feedback to Target Audience</p> <ul style="list-style-type: none"> ● Actual Audience ● Formative Feedback 	<p>Fellows need formative feedback and want to work directly with the target audience for their PLVs.</p>
<p>More Structured Support Needed</p> <ul style="list-style-type: none"> ● conflicting emotions about deadlines ● Ideation support ● Interdisciplinary dilemmas ● “More structure” ● Networking ● problem of background knowledge ● suggestions for improvement ● timing ● Valued PLVs ● "vastly different" amounts of effort ● waste of time ● Workshop value 	<p>Begin workshops during fall quarter, add formal deadlines for deliverables, and increase support for the ideation phase of design.</p>

<ul style="list-style-type: none"> • Workshop useful 	
<p>Are PLVs worth the effort?</p> <ul style="list-style-type: none"> • Are PLVs worth the effort? • Does CEI Value PLVs? • Individual-based enthusiasm vs. sustainable systems • Transparency about PLVs 	<p>More transparency and sustainable infrastructure are needed for PLVs to be worth the effort.</p>
<p>Gains in Broader Impacts, but Questions Remain</p> <ul style="list-style-type: none"> • Growth in BI • Imposter syndrome mitigated • PLV/Research Disconnect • What's the relationship between BI, PLVs, and Research? 	<p>While some fellows have increased understanding of the BI of their research, it is unclear to what extent this increase was related to the PLV Design Workshop.</p>
<p>Fellows least identified with clean energy stand to gain the most.</p> <ul style="list-style-type: none"> • Fellow 1 Background: interdisciplinary, clean energy-focused research • Fellow 2 Background: interdisciplinary, clean energy-focused research • Fellow 3 Background: disciplinary, theoretical research • Fellow 4 Background: disciplinary, experimental research • New Perspectives about Career • New Perspectives about Clean Energy • New Perspectives about Peers • No Change in CE Connection for those already engaged • Theorist vs. Experimentalist 	<p>Fellows least connected to the clean energy field before the CEI Fellowship made the most gains with respect to identification with the clean energy field, but not necessarily because of the PLV Design Workshop.</p>
<p>CEI Fellowship offers multiple opportunities for growth.</p> <ul style="list-style-type: none"> • "It was the Lunch and Learn. And, everyone should do it" • application, technology • Other Supportive Opportunities • Timing of New Insights • increased connection to clean energy 	<p>"It was the Lunch and Learn. And, everyone should do it."</p>

PLV Background & Context

Assertion 1: The background and context that drives the development of each PLV is unique. This Pattern Code is a fairly explicit categorization of codes and data related to each fellow's background knowledge of PLVs and general experience of developing a PLV. This category also includes some codes about the scale of their projects and whether the interviewees were still working on their PLVs. All codes and their respective data in this category emerged from my request for interviewees to share about the PLV they developed and their general experience of developing a PLV. In the following discussion, interviewees will be referred to as Fellow 1, Fellow 2, Fellow 3, and Fellow 4 to maintain confidentiality and consistency of narrative.

Two of the four fellows interviewed knew about the PLV requirement before they started the fellowship while the other two fellows did not. One fellow had heard "older students in our lab" talking about it, but they didn't have a "good idea of it until" (Fellow 2, July 1) the CEI Graduate Onboarding. Fellows 1 and 2 worked together to develop a PLV. At this time of the focus group, this team and Fellow 3 had not completed their PLVs but intended to continue to develop them. These three fellows had PLVs that were of larger scale than Fellow 4's "pretty simple" PLV. Listening to each fellow describe their PLV gave the impression that the context and motivation for each PLV is unique.

"I did think the workshops were useful."

Assertion 2: The PLV Design Workshop should continue to be offered to CEI Graduate Fellows after some revisions.

This theme, represented with an In Vivo code, reflects some positive outcomes that fellows attributed to their participation in the PLV Design Workshop. Three interviewees said that the sessions or an aspect of a session were "useful" (Fellows 2 and 3) or "helpful" (Fellow 1). Some things they found helpful included receiving constructive

feedback, gains in science communication, and techniques for designing PLVs. While Fellow 4 said that the workshop was “pretty useful,” they did not share any specific gains or evidence. For Fellow 1, these outcomes included “direct input” from educators at Session 3: Community Engagement that informed their final product. Fellow 3 found the techniques presented via PowerPoint “super useful” as well as getting “constructive criticism” from others on their ideas. When asked if the workshop allowed fellows to meet new people or fostered any connections with other fellows, Fellow 3 said they “met a lot of people from chemistry that I would not have otherwise talked to or had any interaction with.” On the other hand, Fellow 4 said they did not make any lasting connections or interactions beyond the workshops with people they met. Finally, one fellow recruited a couple of other fellows from the PLV Design Workshop to help with the implementation of their PLV.

Formative Feedback to Target Audience.

Assertion 3: Fellows need formative feedback and want to work directly with the target audience for their PLVs. All four fellows interviewed expressed explicit interest in working directly with the audience for their PLVs and, in many cases, the reason was to get formative feedback. For instance, Fellow 1 said that “the workshop I found most helpful was when we got feedback from other people outside of here.” They noted that this impacted the final design of their product. Fellow 2, Fellow 1’s PLV partner, was hopeful that in the continued development of their PLV they would get to work with “actual teachers” to complete the product and thought that working with “an educator who ... we can almost partner with to kind of be like to get that feedback at different stages.” This sentiment seems to support the idea that one motivation for working with an audience is to get formative feedback to create a better product.

In addition to the opportunity for feedback from the target audience, Fellows 3 and 4 seemed genuinely interested in working directly with students and teachers. Fellow 3 expressed excitement that “a high school teacher offered three of her students as guinea pigs” to pilot their PLV. Finally, Fellow 4 wondered if preparing a lesson or Lunch and Learn for a specific audience could count as one’s PLV.

As the following quote suggests, even the opportunity to receive formative feedback from me seemed helpful: “I think the thing that got ... me through the most was having these discussions with you, the short ones, and those really helped me make the most of the workshops” (Fellow 3, July 1). This is helpful fodder for me to consider my role during the workshop and how I might best provide support for students.

More Structured Support Needed

Assertion 4: Begin workshops during fall quarter, add formal deadlines for deliverables, and increase support for the ideation phase of design. While fellows said that the workshop was useful or “pretty useful,” they also explicitly and implicitly shared several suggestions for improving the PLV Design Workshop in the future. This theme synthesizes the main interrelated, recurring suggestions that were brought up: earlier timing, support for the ideation phase of development, and increased structure. Fellows agreed that the sessions “would have been more useful if they were a little bit earlier” (Fellow 2, July 1). Fellow 2 also said that spreading these sessions throughout the year would have helped them with PLV development. This would have likely helped Fellow 4 whose quarter was “so busy that there were a few that I just couldn’t attend” (July 1).

Three fellows expressed that more structure for the PLV requirement would be helpful and could mitigate issues that came up during the development of PLVs. They suggested that setting deadlines for specific deliverables would have helped fellows

better prepare for workshops and motivate them to get started earlier with the project. As Fellow 3 noted, "I feel like having more structure overall would help — I don't know — push things further." The fourth fellow also agreed that "maybe more structure, like people are saying" would be helpful but preferred informal deadlines and flexibility for those with busy quarters. This provided insight into the disadvantage of hosting all sessions of the workshop in one quarter. If a particular quarter is too full for a fellow, then they may not be able to participate or have a difficult time completing a quality PLV.

While a few fellows acknowledged the general deadlines that I provided, they continued to recommend increased structure for the PLV requirement and mainly seemed to be asking for more formal deadlines for deliverables. Fellow 2 admitted that even though fellows are told about the PLV during onboarding day "I'm maybe not gonna think about it that hard until I started having ... 'By this time, you should have ... an idea. [By] this time, you should get a draft.'" Fellow 3 liked the idea of deadlines, noting that this might make feedback cycles with peers a more efficient use of time. During Session 2: Peer Feedback, they were grouped with peers who did not have a clear idea of their PLV, making their discussions a "waste of time." Fellow 4 also agreed that more structure and deadlines would be helpful, but should also have flexibility for busy doctoral students:

I think it helps to have flexibility because everybody has different periods, like grad schools a — such a time when you have periods of really intense, intense research work. But then there are also periods where it's like less like that. Everybody has different schedules like that at different times of the year. So, it has to be flexible, but also so yeah, maybe earlier helps. (Fellow 4, July 1)

Some of these requests for earlier sessions or firmer deadlines were in support of the ideation phase of the PLV design process. For instance, Fellow 1 would have preferred to meet earlier with the educators they met at Session 3: Community Engagement since the feedback they received helped them to finalize their product. Fellow 4 was stressed when spring quarter came around and they had not started their project. This and similar comments reminded me that earlier and firmer deadlines for PLV ideas can be supportive for students and encourage them to begin their projects with ample time to complete them. Fellow 2 said that “not really having a firm idea of the PLV kind of made it hard to ... really want to ... connect and work with other people on the PLV.”

In addition to firmer deadlines, the interviewees were in favor of narrowing the possibilities of PLVs or soliciting project ideas from the community or faculty. Fellow 2 suggested that I invite educators to share ideas for PLVs and said that a lot of time was wasted on their effort to identify a PLV idea that related to their research. Yet, “having ideas that are put forward that you could maybe pick off of or get inspiration from, rather than just having something so open-ended” (Fellow 1, July 1) could be helpful.

Are PLVs worth the effort?

Assertion 5: More transparency and sustainable infrastructure is needed for PLVs to be worth the effort. This theme incorporates a few concepts that arose at the very end of the interview. Toward the end of our focus group interview, Fellow 3 wondered about the “worthwhileness” of the PLVs. They noticed “a disconnect between fellows and the amount of enthusiasm you [Danica] had” and felt bad that I exerted so much effort, especially because most “PLVs get tossed away.” Fellow 2 noticed a disconnect, but also appreciated my “enthusiasm, too, because it ... gave me more motivation.” Additionally, there seemed to be a lack of information about who uploaded

PLVs to the website and what happened to them once they were complete. Fellow 2 reiterated the value of working with an audience, saying, “I think that's part of where, like, working with people, like your community members, beforehand would be really useful, because then we're actually like doing a project that fills in need.”

This part of the interview was incredibly valuable as it highlighted the crux of this action research study — are PLVs worth the effort? In particular, it highlighted my responsibility in ensuring that this project is a worthwhile endeavor through the development of infrastructure and systems that fully bridge the gap between fellows and the target audience for their PLVs. As Fellow 3 (July 1) suggested, the fellowship requirement to develop a PLV may benefit from “less individual-based leadership.” Ironically, the main focus of my action research study was CEI Graduate Fellows and identifying the impact of my intervention on their perspectives about clean energy, BI, and their PLVs. However, more attention should be focused on my role in disseminating these products to a broader audience. Transparency around this part of the PLV process is critical to making them worth the effort.

Overall, I did hear insightful comments to suggest that this project made an impact. As Fellow 2 said,

I don't think that the PLV should be thrown out. Because as annoyed as I sometimes was about it [laughs], I still think like I learned so much more about, like, science comm education kind of thing than I would have any other way.

(Fellow 2, July 1)

Gains in Broader Impacts, but Questions Remain

Assertion 6: While some fellows have increased understanding of the broader impacts (BI) of their research, it is unclear to what extent this increase was related to the PLV Design Workshop. This theme consists of the

concept codes related to fellows' understanding or questions about the BI of their research: Growth in BI, Imposter Syndrome Mitigated, PLV/Research Disconnect, and What's the relationship between BI, PLVs, and Research? During the interview, I asked the interviewees if they had any thoughts on whether the PLV Workshop encouraged any growth or learning about the BI of their research, reassuring them that it was fine to say no. There were two patterns that I observed from this discussion about the BI of research. One was that three of the four interviewees believed they learned more about BI this year, but only Fellow 2 attributed this to Session 3, when I introduced BI as a concept and provided examples. The other two fellows mentioned other opportunities provided by the CEI Fellowship that contributed to new insights about the BI of their research such as a Lunch and Learn they participated in as part of this fellowship's outreach requirement. Incidentally, these two fellows both work in a specific disciplinary field conducting fundamental research, and their responses to their growth in BI of their research was really positive. In fact, Fellow 3 stated that they felt "like I had impostor syndrome before — I still do — but, like, I didn't feel like a ... scientist who was worth ... or like ... helpful to society." They explained that now they understood how their research could "impact society positively," even if the BI was not a direct step from their research (Fellow 3, July 1). It was exciting to learn that a few fellows had experienced growth with respect to their understanding of the BI of their research. Yet, to what extent the PLV Design Workshop itself had any gains in the understanding of BI as compared to other aspects of the CEI Graduate Fellowship is a question that remains unanswered.

The other question that fellows in this focus group wondered was how connected the PLVs need to be to the BI of one's research. Fellow 1, who did not explicitly say they developed a greater understanding of the BI of their research, said "it's easy for us to see ... this is a broader impact. But taking that final thing and turning it into a PLV was kind

of tricky.” The other fellows also seemed to struggle with connecting their PLV to the BI of their research. Fellows 3 and 4 ultimately chose something very fundamental to their research that could be turned into an educational product or workshop. Fellow 4 explained that their PLV was “not exactly a direct ... broad impact” such as the development of technology, but the goal was “to try to inspire people to sort of find that curiosity. ... And that's kind of how you started to become a scientist.” I found this such a delightful motivation for a PLV and also interpret this as an important BI of research. However, I am not sure that this fellow thought of it as a BI.

Fellows least identified with clean energy stand to gain the most.

Assertion 7: Fellows least connected to the clean energy field before the CEI Fellowship made the most gains with respect to identification with the clean energy field, but not necessarily because of the PLV Design

Workshop. This Pattern Code incorporated concept codes related to each fellow’s disciplinary background and research topic as well as concepts related to new perspectives about career, clean energy, and their peers in the fellowship. Toward the end of the focus group, I asked fellows about the impact of the workshop or the CEI Fellowship on their connection to the field of clean energy, inviting them to reflect on what they know now versus at the beginning of the year. The group was evenly divided; Fellows 1 and 2 saw no change in their connection to clean energy while Fellows 3 and 4 felt more connected to the field of clean energy. Fellows 1 and 2 are currently working in clean energy research and went on to share that they already were committed to the clean energy field before the CEI Fellowship. As Fellow 2 said, “I don't think it really changed for me. If I'm honest. It was just kind of ... really confirmation.” Yet, Fellow 3 had a very different experience. They said:

Well, it changed everything for me. Like, we're used to being like, very core, like fundamentals [science] usually clueless about what's happening outside in the [world]. I also learned that ... there's a lot of money in clean energy.

Fellows 3 and 4, who do not conduct clean energy research, felt a much stronger connection to the field of clean energy after the CEI Fellowship. Fellow 4 told the group that their lab “could have clean energy like applications, but I didn't really think about those as much before I joined the program. And so I've had to think about those a lot more.” Fellow 3 admitted they had “never really cared about” the “clean energy aspect” but had realized over the course of the year the economic opportunities that exist in this field. They have new perspectives on their career trajectory, noting that “maybe I don't want to do academia after all.” After Fellows 3 and 4 shared about their experience, both Fellows 1 and 2 noted appreciation for hearing about their peers’ perspective changes. As Fellow 1 put it, “I completely agree with [Fellow 2] ... I also came to this having more or less an idea of where I'm heading, and it's clean energy. So I had never considered...not having that background. And I didn't see that perspective.”

Similar to the question about the BI of research, however, the two participants that seemed to have increased their identification with the clean energy field did not attribute this increase to the PLV Design Workshop, citing several other aspects of the CEI Fellowship that contributed to this gain such as conversations with CEI’s Entrepreneur-In-Residence, Interdisciplinary Seminars, and even filling out the CEI application.

CEI Fellowship offers multiple opportunities for growth.

Assertion 8: "It was the Lunch and Learn. And everyone should do it." This Pattern Code was based on several concept codes related to supportive aspects of the CEI Graduate Fellowship program other than the PLV Design Workshop such as outreach

experiences, science communication workshops, and CEI's Entrepreneur-In-Residence program. It also included suggestions that CEI could add to the fellowship program that would be beneficial for fellows, such as more social events where students could more organically mingle and network as well as facilitating tours of the research testbeds. This theme is less relevant to this action research study; however, the experience of the Lunch and Learn on Fellows 3 and 4 seemed so impactful that it is worth considering how to integrate it more fully into the fellowship or aspects of the PLV Design Workshop. As Fellow 3 said:

I found preparing the presentation for the — yeah, it was a lunch and learn probably one of the most useful things in the whole fellowship ... and I would even go on like to say that maybe everyone should do it. Because it really forced me to, like, put my research into perspective, because until this CEI Fellowship actually, I didn't know what my research was good for. I just knew that I was doing it. And like ... by the end, I'm like ... “Oh, cool. This is actually really useful.”

BIOGRAPHICAL SKETCH

Danica Hendrickson is the Associate Director of Education & Workforce Engagement at the University of Washington's (UW) Clean Energy Institute (CEI) and the Education Director at the UW Molecular Engineering Materials Research Center (MEM-C) where she directs STEM educational programs for K-12, undergraduate, and graduate students. In these roles, she draws from her diverse experience in the educational field as a middle school science teacher, curriculum developer, and program director for instruction for adult apprenticeship in the advanced manufacturing industry. Danica earned a Master's in Education from Harvard Graduate School of Education's Mind, Brain, and Education program and is currently a doctoral candidate in the Education in Leadership and Innovation program at Arizona State University's Mary Lou Fulton Teachers College where she is using action research and mixed methods to explore the graduate students' knowledgeability of the broader impacts of their research and their identification with the clean energy field. Danica Hendrickson is interested in the theory of situated learning, and more specifically, the learning that occurs at the boundaries of disciplines and through interdisciplinary work on boundary objects. She believes in asset-based, student-centered programming and is inspired by critical pedagogy, critically compassionate intellectualism, and an ethic of care. Outside her professional life, she loves to read about educational theory, play outside, and update her puppy's Instagram account.