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LETTER

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Abstract

A major barrier to achieving wide-spread progress on planning for impacts from climate change is the lack of trained scientists skilled at conducting societally-relevant research. Overcoming this barrier requires us to transform the way we train scientists so they are equipped to work with a range of different societal partners and institutions to produce the science needed to address climate change and society's other pressing environmental challenges. As researchers at climate research organizations that work directly with decision-makers and stakeholders to produce decision-relevant science, we are entrenched in advancing actionable climate science. Based on our experience preparing scientists for similar careers, we offer a perspective on a path for the academy to better develop, train and support scientists to conduct societally relevant research. We emphasize the need for science training that builds collaborative science skills at different career stages to develop a strong community of practice around actionable climate science. We offer insights from our training and capacity-building programs to demonstrate this transformation, and point to strategies that can be adopted at other universities to grow the capacity of scientists to support society in achieving rapid progress on climate action.

1. Introduction

The unprecedented urgency and magnitude of response demanded by climate change and other environmental threats has led to calls for transformation across social, economic, technological, and political realms (IPCC 2018, IPBES 2019). While the burden for transformation is often placed on these societal dimensions, we in the scientific community must also critically self-reflect and transform the way we produce scientific knowledge to better support this work (Moss *et al* 2013). Echoing Lubchenco's (1998) call for a new social contract between science and society, there has been growing demand for the scientific enterprise to expand its core values and

practices to enable the massive mobilization necessary to reach global sustainability goals (Mach *et al* 2020, Norström *et al* 2020). The IPBES Global Assessment Report on Biodiversity and Ecosystem Services (2019), for example, calls for assessments and solutions that incorporate diverse knowledge systems and identifies the critical importance of engaging with local decision-makers and stakeholders in examining human-environment interactions for policy and action (Diaz *et al* 2018). But such engagement remains elusive within the scientific enterprise, and while scientists have advanced society's understanding of the climate and land-use challenges driving biodiversity loss (IPCC 2018, IPBES 2019), society continues to fall short of taking the necessary

action needed to address these threats. Though science is only one of many factors influencing decision-making, the science that is available is often produced in ignorance of the concerns and contexts of the decision-makers it could inform (Moss *et al* 2013), resulting in scientific knowledge with limited relevance and utility for policy and management (Lemos *et al* 2012, Díaz *et al* 2018). This ignorance can also result in harm to local communities in how science is generated and applied (Klenk *et al* 2015, Lacey *et al* 2015, Ford *et al* 2015), as has been seen in past Western science engagement with Indigenous knowledges and communities (David-Chavez and Gavin 2018). Addressing these short-comings to meet the need for science that serves society has often emphasized the need for a new type of *science* (Lubchenco 1998, Van Kerkhoff and Lebel 2006, Lemos *et al* 2012, Kirckhoff *et al* 2013, Moss *et al* 2013); far fewer calls have examined pathways for developing a new type of *scientist* (but see Rapley and De Meyer 2014, Rapley *et al* 2014, Lozano *et al* 2019). Here we focus on one course of action needed to ensure that the scientific enterprise is actively engaged in meeting society's pressing environmental challenges: changing how we train and support scientists so they can do the kind of societally engaged research shown to increase the ability of decision-makers to apply climate science to policy and management (Reed and Meagher 2019, Mach *et al* 2020).

Collectively, we refer to non-academic partners in scientific research—those who will be applying the research most directly to solve problems—as societal partners. There are several reasons why societal partners have often been excluded from the scientific process, including in the production of use-inspired climate science. These reasons include a lack of diversity and inclusion in science (Klenk *et al* 2015, Brondizio and Le Tourneau 2016), institutional rigidity surrounding science production (Shanley and Lopez 2009) and tensions within science culture (Wynne 1992, Jasanoff 2003). Within scientific culture, scholars point to the way in which scientists distinguish and promote scientific knowledge at the expense of other forms of knowledge in society (Gieryn 1983, Fischer 2000, Bocking 2004). The drive for universality embedded within the scientific enterprise also promotes a disconnect from context (Dupré 1995; Cartwright 1999). The result is that, too often, scientific research has limited applicability for addressing sustainability and climate change issues (Lubchenco 1998, Díaz *et al* 2018). These constraints are often reinforced in the way we train scientists to equate unbiased and objective truth with scientific credibility, and centering that scientific credibility on processes that are seemingly divorced from societal values and non-science communities (Gieryn 1983, Stirling 2010). While maintaining scientific rigor and quality is critical to ensuring that decisions are informed by defensible

information, scholarship over the past several decades demonstrates science is not value-free (Gieryn 1983, Fischer 2000; Sarewitz 2004, Bocking 2004) and expands the view of scientific credibility in relation to the involvement of non-science communities in the production of science (Stirling 2010). Despite the growing recognition that scientific credibility can be related to its societal relevance and co-development with societal actors (Funtowicz and Ravetz 1993; Stirling 2010, Moss *et al* 2013), science training falls woefully behind in fostering the skills and attitudes needed to support this work. This is partially why the science usability 'gap' is perpetually reproduced (Lemos *et al* 2012).

Several scholars point to the usability gap to draw attention to transforming the way scientific knowledge is produced, claiming a new social contract for science, in which science is conducted in service to society (Lubchenco 1998, Lang *et al* 2012, Lemos *et al* 2012). This new approach emerging at the end of the 20th century has different names and characteristics, including co-production, transdisciplinary, actionable science, and others. Collectively, we take these to mean science that is produced in collaboration with decision-makers and stakeholders to address relevant decision-making contexts, which helps close the usability gap (Cash *et al* 2003; Lang *et al* 2012, Lemos *et al* 2012, Goodman and Thompson 2017, Knapp *et al* 2019). Here we use the term 'engaged science' to refer to scientific research that has been conducted with the engagement and participation of the societal actors who are affected by the issue or will use the research findings in policy or practice. Scientists and scholars have argued that engaged science still allows for the production of sound research (Moss *et al* 2013), but the path to developing this new science requires a new kind of scientist, with a new set of skills and cultural orientation (Segalas *et al* 2010, Sprain and Timpson 2012, Leshner 2018).

Here we offer a perspective on a path for the academy to better develop, train and support scientists across career stages to engage in societally relevant climate change research. We begin by reviewing the sustainability and higher education literature to articulate key core competencies and pedagogy that can be applied to train societally engaged scientists. We then identify institutional barriers to producing engaged scientists, and, based on our experience preparing scientists for careers in engaged science, identify successful approaches for overcoming these barriers to transform scientific training in the academy. We offer examples from our own training and capacity-building efforts at climate research organizations working directly with decision-makers to suggest specific strategies that can be adopted for different career stages to grow scientists' capacity to work with societal partners to produce the kind of engaged climate science so critical to achieving rapid progress on climate and sustainability goals.

2. Producing societally engaged scientists

For nearly twenty years, sustainability scholars have been researching ways to train students to develop the applied and collaborative skills needed to solve complex environmental challenges (Steinemann 2003, Rowe 2007, Wiek *et al* 2011). Because this research points to approaches to help students gain the skills needed to work in a non-academic context, we can draw on lessons from sustainability scholars to aid our understanding of how to produce societally engaged scientists. Similar to training sustainability professionals, carrying out engaged science requires a new type of scientist capable of working across and integrating different types of knowledge and facilitating knowledge exchange in the context of multiple, sometimes competing perspectives (Cvitanovic *et al* 2019, Norström *et al* 2020). This new knowledge has been described by others as core competencies, or desired educational outcomes related to key knowledge, aptitudes, skills, and abilities to perform a task, summarized in table 1 (Wiek *et al* 2011, Lozano *et al* 2017). For example, Wiek *et al* and the National Research Council both identify systems, anticipatory, values and strategic thinking as well as normative and interpersonal aptitudes as necessary for pursuing a career in sustainability work (Wiek *et al* 2011, NRC 2015). Brundiers *et al* (2020) expand upon this initial set of aptitudes to include intrapersonal and implementation competencies. Lozano *et al* offer 12 learning objectives that further articulate values and social emotional competencies, suggesting that sustainability competencies include: systems thinking; interdisciplinary work; anticipatory thinking; justice, responsibility and ethics; critical thinking and analysis; interpersonal relations and collaboration; empathy and change of perspective; communication and use of media; strategic action; personal involvement; assessment and evaluation; and tolerance for ambiguity and uncertainty (Lozano *et al* 2017). These sustainability competencies extend beyond a traditional disciplinary education by emphasizing cross-disciplinary and applied thinking, as well as inter- and intra-personal perspectives so that sustainability professionals are better prepared to advance sustainable development goals in real-world settings with multiple tradeoffs (Wiek *et al* 2011, Brundiers *et al* 2020).

In addition to research in sustainability higher education, lessons can also be learned from science communication training because communication skills are a fundamental component of producing engaged science (Lang *et al* 2012). Rapley *et al* (2014) build on Pielke's (2007) 'honest broker' concept to suggest that in order for climate scientists to foster dialogue with non-scientists, they need communication skills that support multi-way communication and a deeper understanding of the different forms of reasoning. Acquiring these skills

requires that scientists value and recognize other forms of knowledge; doing so can help them foster public discourse, build trust and support non-scientist participation in the climate science process (Rapley *et al* 2014). Despite recognition of these learning goals for science communication, a review of science communication education efforts shows that most training programs emphasize the one-way communication of translating science content to different audiences (Baram-Tsabari and Lewenstein 2017). While this is indeed a skill needed to engage with societal partners, it falls short of the two-way communication skills one also needs. When science communication training does include skills needed for comprehensive public engagement activities, scientists are unsurprisingly better equipped to interact with non-scientists in more meaningful ways (Stylinski *et al* 2018). Effective multi-way and frequent communication is regularly pointed to as key to developing engaged science (Lang *et al* 2012, Pohl 2017) and appropriate science communication education can help scientists develop those skills. For example, training can be developed to help scientists learn how to foster relationships with decision-makers and stakeholders to build trust and engage in joint decision-making around research framing, methodology, data collection and analysis (Lang *et al* 2012, Leshner 2018).

Many of the competencies and skills identified in the sustainability education and science communication literature are interdependent (Wiek *et al* 2011, Rapley *et al* 2014, Vare *et al* 2019; Roy *et al* 2020, Brundiers *et al* 2020). For example, several researchers suggest that developing intrapersonal competencies (i.e. self-awareness of one's values, position, and assumptions) is central to developing the other competencies and skills needed to be an engaged scientist (Dlouhá *et al* 2019, Brundiers *et al* 2020). This observation is also reflected in the literature on conducting engaged science, in which many argue that scientists need to be capable of self-reflexivity (Pohl *et al* 2017), or the ability to continually reflect on their epistemic values and position in the world while remaining open and responsive to diverse community perspectives (Wals and Jickling 2002, Segalas *et al* 2010, Sprain and Timpson 2012, Reid 2020). The ability to self-reflect is considered key to scientists' ability to respect and value other knowledge systems and recognize that science is only one source of information within a complex decision arena (Wals and Jickling 2002, Segalas *et al* 2010, Sprain and Timpson 2012, Rapley *et al* 2014, Reid 2020).

The literature on core competencies for sustainability is linked to the development and implementation of sustainability and interdisciplinary education programs around the world (e.g. Vare *et al* 2019, Lozano *et al* 2019, Brundiers *et al* 2020, Redman *et al* 2020). The experiences of these different programs

Table 1. Literature on sustainability higher education and science communication education offer skills and pedagogical approaches for training students to work in non-academic settings, which can be applied to training engaged scientists.

Summary of training components that can help produce societally engaged scientists	
Core Competencies	<ul style="list-style-type: none"> • Systems, anticipatory, values, strategic, normative, and interpersonal aptitudes (Wiek <i>et al</i> 2011; National Research Council 2015). • Intrapersonal and implementation (Brundiens <i>et al</i> 2020) • Systems thinking; interdisciplinary work; anticipatory thinking; justice, responsibility and ethics; critical thinking and analysis; interpersonal relations and collaboration; empathy and change of perspective; communication and use of media; strategic action; personal involvement; assessment and evaluation; and tolerance for ambiguity and uncertainty (Lozano <i>et al</i> 2017)
Pedagogical Practices	<ul style="list-style-type: none"> • Constructivist pedagogy (Biggs 1996) • Experiential learning and critical self-reflection (Wals and Jickling 2002; Sprain and Timpson 2012; Lozano <i>et al</i> 2019) • Project-based learning and case studies (Wals and Jickling 2002; Sprain and Timpson 2012)
Skills Development	<ul style="list-style-type: none"> • Science communication training that emphasizes multi-way communication (Rapley <i>et al</i> 2014) • Self-reflexivity (Dlouhá <i>et al</i> 2019; Brundiens <i>et al</i> 2020) • Relationship building and joint project management (Lang <i>et al</i> 2012; Leshner 2018)

demonstrate pedagogical practices that have been used to help scientists develop the competencies, skills and self-reflection needed to produce engaged science (Wals and Jickling 2002, Brundiens *et al* 2010, Sprain and Timpson 2012, Díaz *et al* 2018, Lozano *et al* 2019). This literature recognizes that these competencies cannot be adequately developed in a traditional education approach of sharing facts and knowledge in a one-way process with learners, but instead the learner must engage with the material in a deeper context and in relation to the knowledge and experiences they already bring to learning (Biggs 1996, Wals and Jickling 2002, Sprain and Timpson 2012, Rapley *et al* 2014, Lozano *et al* 2017, 2019). This follows along a constructivist pedagogy with an emphasis on experiential learning and critical self-reflection, as a mechanism to transform traditional mental models used by Western scientists to think about and solve problems (Wals and Jickling 2002, Sprain and Timpson 2012, Lozano *et al* 2019). Pedagogical practices rooted in constructivist tradition center on the notion that students learn best when they are given the opportunity to integrate new knowledge into what they already know (Biggs 1996).

Project-based learning and case studies are two recognized approaches for aiding learners to develop many of the sustainability core competencies (Brundiens *et al* 2010; Beard and Wilson 2002, Lozano *et al* 2017, 2019). In these instances, students engage in projects that expose them to the kinds of skills engaged scientists need. These approaches allow learners to interpret and apply new information with their own knowledge and experiences (Wals and Jickling 2002, Sprain and Timpson 2012). This has been shown to result in students' broader recognition of

the importance of integrating diverse community perspectives into research (Díaz *et al* 2018, Leshner 2018). Designing curriculum around project-based learning has also been linked to increased student comprehension and increasingly nuanced understanding of the political processes surrounding environmental issues and the role of science in decision-making (Denham *et al* 2020).

While many of the competencies and pedagogical practices from the sustainability education and science communication curriculum have been implemented in specialized interdisciplinary and sustainability graduate programs, such approaches remain rare in disciplinary science training programs. Though some may emphasize aspects of this training (e.g. one-way communication techniques for science dissemination), most disciplinary programs continue to be limited in supporting training that fosters the competencies needed for producing societally relevant science (Rapley and De Meyer 2014, Baram-Tsabari and Lewenstein 2017). Part of the challenge is that obtaining disciplinary training is by itself a huge undertaking and space has, traditionally, not been made in the curriculum for developing these skills, creating a feedback loop wherein today's disciplinary scholars may not be equipped to teach the necessary skills associated with engaged science practices (Brundiens *et al* 2010; Yarime *et al* 2012, Denham *et al* 2020). Further, scientists have even fewer options for training and support to learn how to do engaged science once they have completed their graduate work and enter academic careers, which often reinforce attitudes and behaviors that work against developing engaged scientists (Lyall and Meagher 2012, Casson *et al* 2018).

3. Institutional resistance to producing societally engaged scientists

Institutional structures in academia can severely restrict the growth and development of engaged scientists at early and more advanced career stages (Shanley and López 2009, Cvitanovic *et al* 2019). Much of the academic inertia surrounding the development of engaged scientists has historical roots in the traditions and frameworks that dictate how research is done and what is considered high-quality research. Some traditional academic structures actively work against efforts to make research more relevant to and usable by non-academics (i.e. policy makers, practitioners or members of the public) (Neylon 2019). For example, despite the fact that most modern environmental problems are known to require transdisciplinary solutions, academia has been slow to change its structure to allow or encourage teaching and degrees to cross disciplinary boundaries (Klein 1990, Lach 2014). Further, promotion processes continue to favor peer-reviewed papers within disciplinary boundaries as opposed to multidisciplinary publications or products designed for societal partners (Adler 2009, Hicks 2015, Alvesson *et al* 2017), although this is beginning to change (Abel and Williams 2019, National Academy of Sciences 2020). The time demands required to do engaged science are often interpreted as inconsistent with the need to accumulate publications and citations at a rapid rate. Further, external research funding, another key academic performance measure, tends to be more available for disciplinary proposals (Bromham *et al* 2016) relative to funding for applied research (Arlinghaus 2014). Such barriers to participating in engaged science can limit academic contributions to solving environmental problems and may ultimately harm the academic enterprise as more and more countries turn evaluation of research funding programs toward the societal impacts of government-funded research, leaving researchers who are not adept at working with societal partners behind the innovation and funding curves⁷.

These and other institutional processes shape the development of a scientist throughout their career, and in this case limit professional growth and skills in the direction needed to produce engaged science (Shanley and López 2009, Cvitanovic *et al* 2019). Despite notable advancements in graduate training programs to encourage interdisciplinary training as described above, the instinct within academia remains to train students to be disciplinary specialists so they can succeed using current metrics

(Leshner 2018). Efforts to prepare the scientific community to successfully conduct engaged science must consider the ways in which different career stages interact with each other and these institutional processes.

4. Efforts to support societally engaged science training and career development

As university-based researchers who work with diverse societal partners to produce decision-relevant and engaged climate science, we view an important part of our role as expanding current institutional capacities within the academy to produce engaged scientists. Below we describe our efforts at the Climate Impacts Group (CIG) at the University of Washington and the Climate Assessment for Southwest (CLIMAS) program at the University of Arizona to innovate within academic training and career development, at four different career stages, to illustrate how this training can be done despite the constraints and disincentives described above. The majority of our efforts have been with graduate students, due to the nature of our programmatic funding. However, we also describe our activities aimed at three other career stages (early career, mid-career, and senior scientists) because we recognize 1) the influence of later career scientists on graduate students or other early career researchers through their roles as instructors, advisors, and mentors, and 2) we do not believe we have time to wait for the necessary transformations in science until today's graduate students control tenure, funding opportunities and editorial decisions in journals. We also touch on efforts to engage university administration in this work for the same reasons. We need to move as many current scientists toward this engaged model as quickly as possible.

4.1. Graduate students

Graduate fellowship programs and seminars can help early career scientists develop the skills, knowledge and experiences needed to have a career as an engaged scientist. Graduate education plays a significant role in shaping scientific careers, making it pivotal to develop skills training and opportunities at this career stage (Wiek *et al* 2011, Leshner 2018). The CIG and CLIMAS have fellowship programs that provide funding and training for graduate students in engaged research. Both organizations also host seminars to reach a broader group of students. These seminars emphasize theories, best practices and case examples of producing societally engaged science.

4.1.1. Fellowship programs.

Our two fellowship programs provide students with funding and support to develop and carry out engaged research projects, giving students the opportunity to connect their knowledge and experiences from their disciplinary field to a new approach of

⁷For examples of other countries integrating societal impacts into evaluation of government-funded research programs see United Kingdom www.ref.acuk/, Europe www.knaw.nl/nl/actueel/publicaties/standard-evaluation-protocol-2015-2021, and Australia www.arc.gov.au/excellence-research-australia.

working with non-academic partners. The goal for both fellowship programs is for students to develop their own relationships with societal partners, practice methods of engagement with those partners, and learn effective ways to communicate their research with audiences outside of academia. The students carry out a research project with their societal partners and reflect on their experience along the way.

Since 2014, CLIMAS has funded 27 graduate fellows through the Environment and Society Fellowship program, including students from natural, physical and social science departments at the University of Arizona. The students' projects must address research and information needs voiced by their societal partners. One fellowship project, for example, dealt with community concerns about the health impacts of untreated wastewater overflows on students and teachers at a nearby elementary school. This fellow developed a soil sampling procedure with school administrators that incorporated students, parents, and teachers as active participants. Another student's project responded to a Tribal commission's request for historical information about a long-standing water conflict in California, which resulted in a digital database of historical documents, an online timeline of federal agency action on Tribal land, and educational materials for local schools and Tribal programs.

As university host for the Northwest Climate Adaptation Science Center (NW CASC), the CIG has supported 32 NW CASC research fellows across six consortium universities from a variety of science disciplines. These fellows are selected based on proposed research projects that demonstrate decision-relevant climate adaptation science that will be produced in collaboration with societal partners (e.g. Federal, state, Tribal and non-governmental organization), covering topics including endangered species, forest ecosystems and aquatic systems. One NW CASC fellow, for example, worked with a Tribal community to create and implement a fish-consumption survey to understand climate impacts on traditional foods. Another fellow worked with the National Park Service to test different monitoring strategies for wolverines, an endangered and climate-sensitive species.

In both programs, fellows receive training on various aspects of societally engaged science, such as project design and methods for engaging partners in the research process; writing for and presenting to non-academic audiences; dealing with interpersonal conflict; or how to develop a professional network that includes non-academic partners. As part of this training, fellows participate in cross-cohort discussions of relevant topics with CLIMAS and CIG staff and faculty who have expertise in engaged research approaches, which helps students problem-solve. For example, one NW CASC fellow, whose proposed research was to collaborate with water district staff to assess the impacts of climate change, urbanization

and other water uses on streamflow, faced apparent resistance to streamflow data collection and sharing from their non-academic partner. CIG staff coached the fellow to use their upcoming partner meeting as an opportunity to learn more about their partners' professional priorities and to identify management questions that could be informed by the streamflow project or other analyses, rather than focusing discussion on the fellow's academic research questions. In their subsequent meeting, the fellow learned about the group's key research questions and was even able to find additional funding to support the analysis necessary to respond to that request. This fellow shared their learning experience with the other fellows, and shared the data sharing agreement document for others to review and adapt as a template for other projects.

The fellows' experiences have helped them develop and apply skills and knowledge they would not have gained in their disciplinary training. Surveys between 2014 and 2019 revealed that CLIMAS fellows gained direct experience in building and maintaining relationships with their societal partners and shifting research design, methods, timing and outputs as the project developed based on shifts in their partners' needs. As one fellow stated, 'Determining the needs of stakeholders and decision-makers can be challenging, and gaining insight into stakeholder needs requires multiple iterations and micro adjustments to the research and the conversation.' Another student said she learned that 'Engaging with stakeholders takes time, a good amount of luck, and development of trust.' Many students also stated that they learned to appreciate and incorporate multiple types of expertise and knowledge. 'Science is only one tool in the toolbox. To be an effective actor in society, scientists have to accept this,' one fellowship student said.

NW CASC fellows have had similar responses over the three years of that program, where students entering the program tended to stress the importance of 'unbiased science' for environmental management and policy in their pre surveys, but not in exit surveys. In reflecting on their fellowship in their final report, one fellow shared, 'I do feel that the development of skills learned from this fellowship has helped me to become a better and more thoughtful scientist, with a larger toolbox to work with and support natural resource managers faced with the complex challenges of climate change.' This student and others stressed the value in practicing communication skills and learning different approaches and strategies to navigate challenges from people who have experience doing this work.

The fellowship experiences may also change the way students think about their disciplinary training. A geoscience graduate student constructed her CLIMAS fellowship project around developing guidance on sustainable sampling of cave formations such as

stalagmites, informed by people who use caves for recreational, educational, and cultural purposes. Cave formations are natural archives of paleoclimate data going back hundreds of thousands of years, but they are slow-growing, so scientists must take care to conserve cave structures while collecting data. Through her project, this student realized how much she valued working with societal partners, but had been discouraged from adding this component to her dissertation research. She reflected that as a student ‘in a purely science field, I became increasingly annoyed at the advice given to scientists these days—wait until tenure to do stakeholder engagement work. Receiving the fellowship gave me enough of a push to recognize it is OK to start early with this kind of work. I only wish I had started even earlier and then my entire PhD could have been in the fun space between science and society.’

4.1.2. Graduate seminars.

In addition to the fellowship programs, both the CIG and CLIMAS have seminars that help students develop competencies needed to become a societally engaged scientist. The CLIMAS seminar was created in 2009 and has attracted over one hundred PhD, masters, and non-degree seeking students since its inception. The CIG seminar started in 2018 and has had over fifty students. Both seminars attract students from a variety of biophysical and social science disciplines as well as non-science programs like law, policy and history. The disciplinary diversity among the students is a hallmark of both courses. The seminars share common goals: to broaden the students’ perspectives on the role of science in society and the value of recognizing and integrating multiple forms of knowledge into the creation of science and policy. The seminar content and discussions emphasize intrapersonal, values, ethics and other competencies related to working on environmental challenges and are often considered central to conducting societally engaged research. Students participate in class discussion to ground the theoretical readings on the role of science in society in their work and experiences. They also participate in different role-playing activities to learn about different ways to collaborate with non-academic communities and hear from different guest experts including non-profit, academic, governmental and Tribal organizations, who provide case examples of societally engaged research from multiple perspectives.

We have observed two main changes among students who participate in our seminars. First, their understanding of the role of science in decision-making appears to deepen and, second, their interest in pursuing a career that allows them to participate in engaged science seems to increase. For example, pre-course surveys of students in the CIG seminar revealed students’ view of science as unbiased and that

it should inform decision making. The vast majority of the responses to the question ‘How do you think science should inform decision-making and/or policy?’ considered the scientific process as occurring external to policy processes and devoid of values, politics and local contexts. We asked them this same question following the course and the vast majority of the responses included a conception of collaboration among scientists, decision-makers and stakeholders in the co-creation of science. One student, who identifies as a physical or natural scientist shared,

‘Before the class, I would have said the science should come first and the decisions should come after. Now that i have taken this course, I would say that in order for science to be most impactful for policy, the research question and design truly need to be a collaborative effort between scientists, policy makers, and other stakeholders.’

Many students in the CLIMAS seminar find the theoretical and practical insights offered in the course useful and applicable to their work going forward. Some, though, have found the course eye-opening in terms of the challenges associated with engaged research, like one student who noted, ‘I was overly optimistic about implementing this kind of work into my own research, and that it takes more time to do that I have at my disposal (right now).’ A course like this can be helpful in revealing both the challenges and opportunities in engaged science, an important factor in bringing about institutional change in academia since these realities are rarely an element of traditional graduate science education. CIG students shared the importance of learning about challenges and opportunities associated with engaged research through the class discussions with invited experts who have experience doing engaged science. This was connected to several students reporting that, after the course, they were interested in having a similar career as several of those experts who shared their experiences. Reflecting back on the course, a student who identifies as a physical or natural scientist shared,

‘This seminar broadened my perspective in collaborative work and provided me with more tangible skills to approach transboundary research. It challenged me to think hard about my work as a scientist and inspired me to move forward in my career toward applied research that has meaning beyond scientific inquiry.’

4.2. Later career stages

In our efforts to introduce more researchers to engaged science approaches, CIG and CLIMAS both seek out postdocs and early career faculty who are interested in and show potential in doing engaged science. The CIG and CLIMAS work to involve these researchers in proposal development, project work and other activities to help them gain experience and skills in conducting and teaching engaged research. Providing opportunities for early career scientists to do engaged science allows them to develop relationships with societal partners and produce actionable science outputs for different audiences (e.g. tools and reports). The NW CASC, for example, funds an Actionable Science Postdoctoral Fellow (one of the authors of this paper), whose position includes facilitating cross-sector dialogue with researchers and practitioners to identify the state of the knowledge and research needs around an emerging climate risk, such as how to manage vegetation changes following fires under climate change. This activity positions the postdoc to develop relationships with resource managers and stakeholders while building experience fostering multiway communication and producing reports for non-academic audiences.

Because mid- and late-career scientists are often responsible for training students and early-career scientists and setting the direction for much of the research that takes place in academia we have consciously worked to engage them in our efforts. One approach we have taken is to engage our graduate fellows' advisors. The CIG has started to do this through a welcome call in which NW CASC fellows' advisors learn how we approach societally engaged research and the mechanisms we use to train their students. Another approach has been to include faculty in the large grants that fund both centers, which can be an attractive proposition, particularly for those seeking support for graduate students. This helps us engage with both senior scientists and students simultaneously. For example, the CIG's NW CASC program has a University Leadership Team composed of early- to late-career scientists to provide opportunities and support for career advancement in this space by helping set the direction for education, training and capacity-building on engaged science.

We have had positive experiences when more late-career scientists have been given the time, space and resources to explore engaged science work themselves. We have noted sustained changes in attitudes about and understanding of engaged science among our research teams. For example, CLIMAS has instituted formal program review processes that help identify the program's impacts and provide opportunities for learning and reflection to its mid- and late-career research team (Owen *et al* 2019). Individual researcher interviews that encourage reflection upon the research processes, accomplishments and

impacts have yielded thoughtful discussions about how the lessons they learned from previous projects will inform their current or future research. The CIG's NW CASC program is newer and will be undertaking more rigorous evaluation in the coming years. However, early observations point to actions on the part of University Leadership Team members as well as advisors of NW CASC research fellows that support engaged science at their institutions. One of the mid-career researchers involved, for example, has been working with CIG and NW CASC leadership to identify ways to develop engaged science research and training at their university.

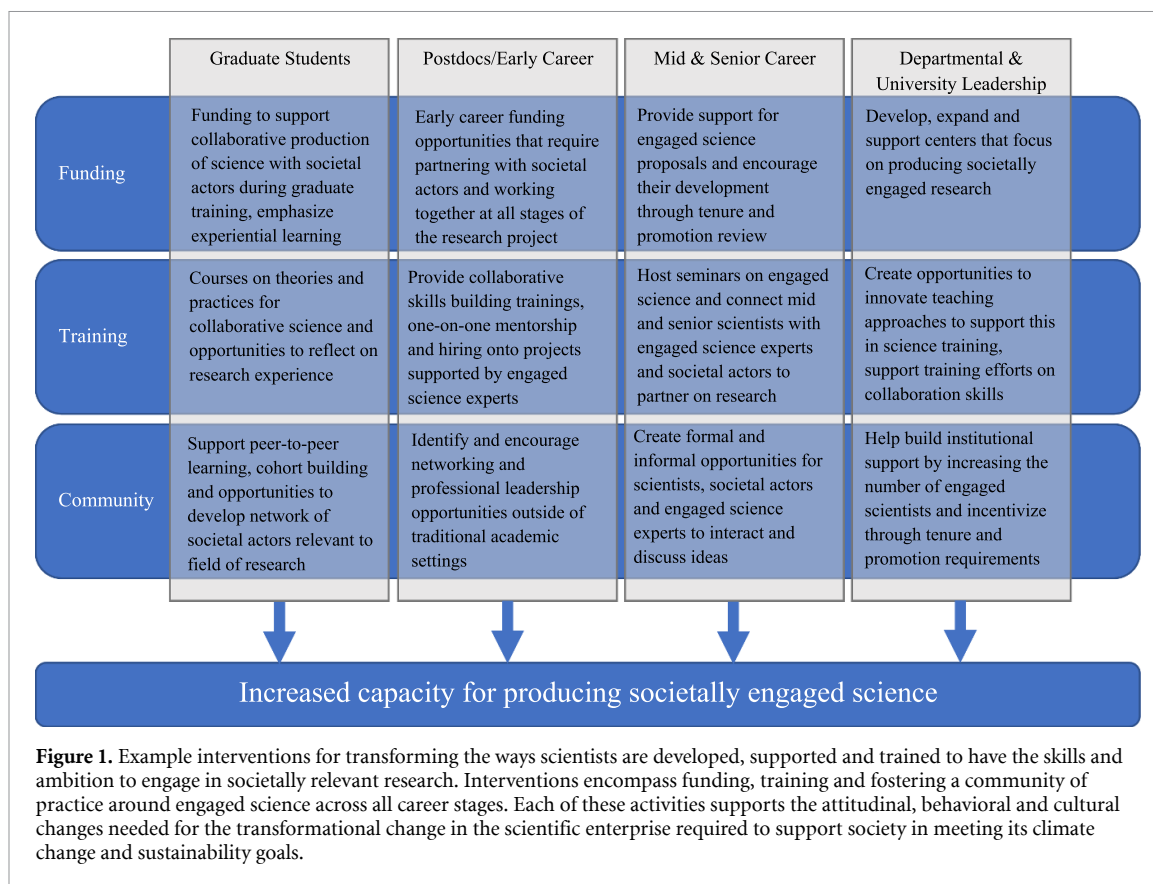
We recognize more work needs to be done to support scientists at different career stages, which could include mentoring programs, training opportunities, facilitating introductions with non-academic partners and other types of support. As our interventions at these career stages continue, we expect to see faculty become more successful in receiving external funding from programs that emphasize societal impacts and to see broader participation in university engagement efforts like Carnegie Community Engagement Classification or The Times Higher Education impacts rankings⁸.

4.3. Departmental and university leadership

Intervention at the level of departmental and university leadership is also crucial to address institutional and cultural barriers to developing and training engaged scientists (Wiek *et al* 2011, Cvitanovic *et al* 2019). Both CIG and CLIMAS make efforts to use our roles as large, federally funded science centers to demonstrate to university leaders what successful, engaged science can bring to our universities in terms of high-quality research and strong community partnerships. We aspire to promote further change in university culture by documenting the societal impacts of research as well as ways to tie such impacts to performance reviews and promotion and tenure evaluations; this would help develop a pathway for academic career advancement to researchers who choose to focus on engaged research projects (Association of Public and Land-Grant Universities 2019, Abel and Williams 2019). We also hope to see upper administration provide professional development opportunities and promote the work accomplished by societally engaged faculty members, as recommended in a recent report by the Association of Public and Land-Grant Universities (Association of Public and Land-Grant Universities 2019).

We see evidence of some of these changes already. For example University of Washington's College of

⁸For more information about the Carnegie Community Engagement Classification see: www.brown.edu/swearer/carnegie and for The Times Higher Education impacts rankings see: www.timeshighereducation.com/rankings/impact/2020/overall#!/page/1/length/25/sort_by/rank/sort_order/asc/cols/undefined.



the Environment (home of CIG) includes a robust statement about the role of engagement outcomes in promotion and tenure reviews that recognize the time commitment of external engagement and suggest faculty candidates include testimonials from societal research partners for tenure review (UW-COE 2020). The University of Arizona, home to CLIMAS, has recently opened an Office of Societal Impact with the mission to help ‘researchers identify benefits, stakeholders and impacts on the larger world’ (Makansi 2020). While we may not be able to claim direct influence on these organizational changes, we see them as key indicators that those at the highest levels of academic leadership at our institutions are recognizing the importance of engaged research as key to their missions.

5. Proposed framework for transforming science training in the academy

Our experiences training students to conduct societally relevant research align with many of the lessons learned from research on sustainability education (summarized in table 1). We agree with the need to cultivate innovative ways of fostering interactive, immersive and real-world learning in science training (Steinemann 2003, Rowe 2007, Sipos *et al* 2008, Duckworth *et al* 2017, Chang *et al* 2020; Denham *et al* 2020) in ways that promote diversity and equity

(Dutt 2020). Project-based learning opportunities, like those offered through the CLIMAS and CIG fellowship programs, can help students unpack the complex systems, values and normative assumptions that permeate their projects while developing the strategic skills and interpersonal aptitudes required for engaged science (Wiek *et al* 2011, National Research Council 2015). We also see that scientists are more able to conduct societally relevant research when they have experience reflecting and integrating multiple perspectives into their science (Brundiers *et al* 2010, Pohl *et al* 2017). While we are beginning to see evidence that our fellowship programs are helping students develop many of these skills, we recognize the importance of developing them at all academic career levels.

To transform science training in the academy, we propose deliberate approaches that address funding, training and building a supportive community of practice at each career stage (figure 1). We see the importance of providing funding opportunities to students and postdoctoral researchers that require partnering with societal actors, coupled with similar incentives at later career stages that allow scientists to continue along this career path. We also see the need for training alongside those funding incentives, to support scientists in developing collaborative science skills through experiential learning and self-reflection. Such learning could be supported by training programs, webinars and

mentorship opportunities for scientists across career stages. The importance of relationship building in engaged science requires support for scientists in developing a community of practice that extends beyond the university setting. This can be facilitated by creating opportunities for formal and informal interactions with both other researchers and societal actors through seminars, working groups and other mechanisms. Applying this system of interventions across an entire academic career; could assist in rapidly building the capacity of the academy to produce societally engaged science. A crucial component in understanding whether we are successful in creating a new kind of scientist is the perspectives of our societal partners regarding whether their needs for information and collaboration are being met (Mach *et al* 2020). While we were not able to systematically include our societal partners in our evaluation efforts in this round of work, we plan to do so as we launch our next fellowship cycles with the goal of using partner feedback to refine and strengthen our training and professional development efforts.

6. Conclusion

There are many transformations that need to take place to prepare human and ecological communities for future climate impacts. We have chosen to examine how we can train and educate scientists to produce the societally engaged scientific knowledge required to inform these transformations. Transforming the scientific enterprise more broadly first begins with transforming the way we train and educate scientists. We recommend that disciplinary science training be expanded to incorporate applied and collaborative research competencies and pedagogies to grow the community of scientists able to engage effectively with communities and decision-makers. These interventions cannot stop with students but require a systems perspective to build the attitudinal, behavioral and cultural transformations needed to develop a scientific community capable of addressing society's most pressing needs. We therefore recommend that universities develop funding, training and institutional support for scientists across career stages to promote rapid development of the skills and knowledge necessary to produce engaged science.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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References

- Abel S and Williams R 2019 *The Guide: Documenting, Evaluating and Recognizing Engaged Scholarship* (Lafayette, IN: Purdue University, Office of Engagement)
- Adler N and Harzing A 2009 When knowledge wins: transcending the sense and nonsense of academic rankings *Acad. Manage. Learn. Educ.* **8** 72–95
- Alvesson M, Gabriel Y and Paulsen R 2017 *Return to Meaning: A Social Science with Something to Say* (Oxford: Oxford University Press)
- Arlinghaus R 2014 Are current research evaluation metrics causing a tragedy of the scientific commons and the extinction of university-based fisheries programs? *Fisheries* **39** 212–5
- Association of Public and Land-Grant Universities 2019 *Public Impact Research: Engaged Universities Making The Difference* (Washington, DC: Association of Public and Land-Grant Universities)
- Baram-Tsabari A and Lewenstein B 2017 Science communication training: what are we trying to teach? *Int. J. Sci. Educ.* **B** 7 285–300
- Beard C and Wilson J P 2002 *The Power of Experiential Learning: A Handbook for Trainers and Educators* Stylus Publishing, Herndon, VA
- Biggs J 1996 Enhancing teaching through constructive alignment *Higher Educ.* **32** 347–64
- Bocking S 2004 *Nature's Experts: Science, Politics, and the Environment* (Rutgers University Press)
- Bromham L, Dinnage R and Hua X 2016 Interdisciplinary research has consistently lower funding success *Nature* **534** 684
- Bronzizio E S and Le Tourneau F M 2016 Environmental governance for all *Science* **352** 1272–3
- Brundiers K *et al* 2020 Key competencies in sustainability in higher education—toward an agreed-upon reference framework *Sustain. Sci.* 1–17
- Brundiers K, Wiek A and Redman C 2010 Real-world learning opportunities in sustainability: from classroom into the real world *Int. J. Sustain. High Educ.* **11** 308–24
- Cartwright N 1999 *The Dappled World: A Study of the Boundaries of Science* (Cambridge: Cambridge University Press)
- Cash D, Clark W C, Alcock F, Dickson N M, Eckley N, Guston D H, Jäger J and Mitchell R 2003 Knowledge systems for sustainable development *PNAS* **100** 8086–91
- Casson N, Whitfield C, Baulch H, Mills S, North R and Venkiteswaran J 2018 A model for training undergraduate students in collaborative science *FACETS* **3** 818–29
- Chang H, Granek E, Ervin D, Yeakley A, Dujon V and Shandas V 2020 A community-engaged approach to transdisciplinary

- doctoral training in urban ecosystem services *Sustain. Sci.* **15** 1–17
- Cvitanovic C, Howden M, Colvin R, Norström A, Meadow A and Addison P 2019 Maximising the benefits of participatory climate adaptation research by understanding and managing the associated challenges and risks *Environ. Sci. Policy* **94** 20–31
- David-Chavez D M and Gavin M 2018 A global assessment of Indigenous community engagement in climate research *Environ. Res. Lett.* **13** 123005
- Denham D, Rozance M, Malone M and Goodling E 2020 Sustaining future environmental educators: building critical interdisciplinary teaching capacity among graduate students *J. Environ. Stud. Sci.* 1–14
- Díaz S et al 2018 Assessing nature's contributions to people *Science* **359** 270–2
- Dlouhá J, Heras R, Mulà I, Salgado F P and Henderson L 2019 Competences to address SDGs in higher education—a reflection on the equilibrium between systemic and personal approaches to achieve transformative action *Sustainability* **11** 3664
- Duckworth O, Andrews M, Cubeta M, Grunden A and Ojiambo P 2017 Revisiting graduate student training to address agricultural and environmental societal challenges *Agric. Environ. Lett.* **2** 1–5
- Dupré J 1995 *The Disorder of Things: Metaphysical Foundations of the Disunity of Science* (Cambridge, MA: Harvard University Press)
- Dutt K 2020 Race and racism in the geosciences *Nat. Geosci.* **13** 2–3
- Fischer F 2000 *Citizens, Experts and the Environment: The Politics of Local Knowledge* (Duke University Press)
- Ford J et al 2015 Community-based adaptation research in the Canadian Arctic *Wiley Interdisciplinary Reviews: Climate Change* **7**
- Funtowicz S O and Ravetz J R 1993 Science for the post-normal age *Futures* **25** 739–55
- Gieryn T 1983 Boundary-work and the demarcation of science from non-science: strains and interests in professional ideologies of scientists *Am. Sociol. Rev.* **48** 781–95
- Goodman M and Sanders Thompson V 2017 The science of stakeholder engagement in research: classification, implementation, and evaluation *Transl. Behav. Med.* **7** 486–91
- Hicks D, Wouters P, Waltman L, De Rijcke S and Rafols I 2015 Bibliometrics: the Leiden Manifesto for research metrics *Nat. News* **520** 429
- IPBES 2019 *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* S Díaz, J Settele, E S Brondízio, H T Ngo, M Guèze, J Agard, A Arneeth, P Balvanera, K A Brauman, S H M Butchart, K M A Chan, L A Garibaldi, K Ichii, J Liu, S M Subramanian, G F Midgley, P Miloslavich, Z Molnár, D Obura, A Pfaff, S Polasky, A Purvis, J Razzaque, B Reyers, R Roy Chowdhury, Y J Shin, I J Visseren-Hamakers, K J Willis and C N Zayas eds. (Bonn, Germany: IPBES secretariat) **56**
- IPCC 2018 Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways *The Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* V Masson-Delmotte, P Zhai, H O Pörtner, D Roberts, J Skea, P R Shukla, A Pirani, W Moufouma-Okia, C Péan, R Pidcock, S Connors, J B R Matthews, Y Chen, X Zhou, M I Gomis, E Lonnoy, T Maycock, M Tignor and T Waterfield ed
- Jasanoff S 2003 Technologies of humility: citizen participation in governing science *Minerva* **41** 223–4
- Kirchhoff C, Lemos M and Dessai S 2013 Actionable knowledge for environmental decision making: broadening the usability of climate science *Annu. Rev. Environ. Resour.* **38** 393–414
- Klein J 1990 *Interdisciplinarity: History, Theory, and Practice* (Detroit: Wayne State University Press)
- Klenk N, Meehan K, Pintel S, Mendez F, Lima P and Kammen D 2015 Stakeholders in climate science: beyond lip service? *Science* **350** 743–4
- Knapp N, Reid S, Fernández-Giménez E, Klein A and Galvin A 2019 Placing transdisciplinarity in context: a review of approaches to connect scholars, society and action *Sustainability* **11** 18
- Lacey J, Howden M, Cvitanovic C and Dowd A M 2015 Informed adaptation: ethical considerations for adaptation researchers and decision-makers *Glob. Environ. Change* **32** 200–10
- Lach D 2014 Challenges of interdisciplinary research: reconciling qualitative and quantitative methods for understanding human-landscape systems *Environ. Manage.* **53** 88–93
- Lang D, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M and Thomas C 2012 Transdisciplinary research in sustainability science: practice, principles, and challenges *Sustain. Sci.* **7** 25–43
- Lemos M et al 2018 To co-produce or not to co-produce *Nat. Sustain.* **1** 722
- Lemos M, Kirchhoff C and Ramprasad V 2012 Narrowing the climate information usability gap *Nat. Clim. Change* **2** 789
- Leshner A 2018 Student-centered, modernized graduate STEM education *Science* **360** 969–70
- Lozano R, Barreiro-Gen M, Lozano F J and Sammalisto K 2019 Teaching sustainability in European higher education institutions: assessing the connections between competences and pedagogical approaches *Sustainability* **11** 1602
- Lozano R, Merrill M Y, Sammalisto K, Ceulemans K and Lozano F J 2017 Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal *Sustainability* **9** 1889
- Lubchenco J 1998 Entering the century of the environment: a new social contract for science *Science* **279** 491–497
- Lyall C and Meagher L 2012 A Masterclass in interdisciplinarity: research into practice in training the next generation of interdisciplinary researchers *Futures* **44** 608–17
- Mach K et al 2020 Actionable knowledge and the art of engagement *Curr. Opin. Environ. Sustain.* **42** 30–37
- Makansi K 2020 New office of societal impacts helps measure the broader impacts of research (University of Arizona) (<https://uatwork.arizona.edu/lqp/new-office-societal-impacts-helps-measure-broader-impact-research>) (Accessed 6 June 2020)
- Moss R et al 2013 Hell and high water: practice-relevant adaptation science *Science* **342** 696–8
- National Academies of Sciences, Engineering, and Medicine 2020 *Re-envisioning Promotion and Advancement for STEM Faculty: Proceedings of a Workshop in Brief* (Washington, DC: National Academies Press)
- National Research Council 2015 *Enhancing the Effectiveness of Team Science*, edited by N J Cooke and M L Hilton. (Washington D.C.: National Research Council)
- Neylon C 2019 Research excellence is a neo-colonial agenda (and what might be done about it) *Transforming Research Excellence: New Ideas from the Global South*, ed E Kraemer-Mbula, R Tijssen, M Wallace and R Mclean (Cape Town: African Minds) 92–115
- Norström A et al 2020 Principles for knowledge co-production in sustainability research *Nat. Sustain. January* **3** 1–9
- Owen G, Ferguson D and McMahan B 2019 Contextualizing climate science: applying social learning systems theory to knowledge production, climate services, and use-inspired research *Climatic Change* **157** 151–170
- Pielke Jr R A 2007 *The honest broker: making sense of science in policy and politics* (Cambridge University Press)
- Pohl C, Krütli P and Stauffacher M 2017 Ten reflective steps for rendering research societally relevant *GAIA Ecol. Perspect. Sci. Soc.* **26** 43–51
- Rapley C G et al 2014 Time for change? climate science reconsidered *Report of the UCL Policy Commission on Communicating Climate Science*

- Rapley C and De Meyer K 2014 Climate science reconsidered *Nat. Clim. Change* **4** 745–6
- Redman A, Wiek A and Barth M 2020 Current practice of assessing students' sustainability competencies—a review of tools *Sustain. Sci.*
- Reed M and Meagher L 2019 Using evidence in environmental and sustainability issues *What Works Now? Evidence-informed Policy and Practice*, ed A Boaz, H Davies, A Fraser and S Nutley (Chicago: Policy Press) 151–170
- Reid B 2020 Positionality and research: 'two-eyed seeing' with a rural ktaqmuk mi'kmaw community *Int. J. Qual. Methods* **19** 1609406920910841
- Rowe D 2007 Education for a sustainable future *Science* **317** 323–4
- Roy S G, de Souza S P, Mcgreavy B, Druschke C G, Hart D D and Gardner K 2020 Evaluating core competencies and learning outcomes for training the next generation of sustainability researchers *Sustain. Sci.* **15** 619–31
- Sarewitz D 2004 How science makes environmental controversies worse *Environ. Sci. Pol.* **7** 385–403
- Segalas J, Ferrer-Balas D and Mulder K 2010 What do engineering students learn in sustainability courses? The effect of the pedagogical approach *J. Clean. Prod.* **18** 275–84
- Shanley P and López C 2009 Out of the loop: why research rarely reaches policy makers and the public and what can be done *Biotropica* **41** 535–44
- Sipos Y, Battisti B and Grimm K 2008 Achieving transformative sustainability learning: engaging head, hands and heart *Int. J. Sustain. High Educ.* **9** 68–86
- Sprain L and Timpson W 2012 Pedagogy for sustainability science: case-based approaches for interdisciplinary instruction *Environ. Commun.* **6** 532–50
- Steinemann A 2003 Implementing sustainable development through problem-based learning: pedagogy and practice *J. Prof. Issues Eng. Educ. Pract.* **129** 216–24
- Stirling A 2010 Keep it Complex *Nature* **468** 1029
- Stylinski C, Storksdiack M, Canzoneri N, Klein E and Johnson A 2018 Impacts of a comprehensive public engagement training and support program on scientists' outreach attitudes and practices *Int. J. Sci. Educ. B* **8** 340–54
- [UW-COE] University of Washington College of the Environment 2020 Promotion and tenure guidelines: candidate responsibility (<https://environment.uw.edu/wp-content/uploads/2013/05/Promotion-and-Tenure-Guidelines.pdf>) (Accessed 6 June 2020)
- Van Kerkhoff L and Lebel L 2006 Linking knowledge and action for sustainable development *Annu. Rev. Environ. Resour.* **31** 445–77
- Vare P et al 2019 Devising a competence-based training program for educators of sustainable development: lessons learned *Sustainability* **11** 1890
- Wals A and Jickling B 2002 'Sustainability' in higher education *Int. J. Sustain. High Educ.* **3** 221–32
- Wiek A, Withycombe L and Redman C 2011 Key competencies in sustainability: a reference framework for academic program development *Sustain. Sci.* **6** 203–18
- Wynne B 1992 Misunderstood misunderstandings: social identities and public uptake of science *Public Underst. Sci.* **1** 281–304
- Yarime M, Trencher G, Mino T, Scholz R, Olsson L, Ness B, Frantzeskaki N and Rotmans J 2012 Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and stakeholder collaborations *Sustain. Sci.* **7** 101–13