The Emergence of the Field of Sustainability Science: Influences on Faculty Behavior Related to Sustainability Work

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DEDICATION

To my talented and creative daughter, Katie, who thinks that I am the smartest woman in the world! You are my light and my motivation.

Your bright future continues to unfold. Be bold. Persevere. Be happy.

ABSTRACT

This study investigates sustainability science as an emerging scientific field and the role of faculty members at higher education institutions as drivers of change in sustainability-science-based research, teaching, and community engagement. Seven factors related to the transdisciplinary field of sustainability science are analyzed for their influence on faculty behavior. This study is based on interviews with faculty members from a broad variety of disciplines at a large, public, research institution. The analysis shows that colleagues from other disciplines, student interests, and stakeholder and citizen interests exert very strong influences on faculty work to address the complex problems of sustainability. The study suggests that faculty members value the ability to develop strong interdisciplinary teams to find solutions to sustainability problems, even with the significant investments of time required and institutional barriers; see students as motivators and well-prepared future researchers in applying sustainability science approaches; and engage non-scientists as essential partners in sustainability research, a key characteristic of sustainability science's transdisciplinary approach.

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CHAPTER 1
INTRODUCTION

Sustainability is a word that has become ubiquitous over the last three decades. It can be described as "a realization that our ability to prosper now and in the future requires increased attention not just to economic and social progress but also to conserving Earth's life support systems: the fundamental environmental processes and natural resources on which our hopes for prosperity depend" (Matson, Clark, and Andersson, 2016).

Sustainability, as it integrates environmental, social, and economic elements, continues to be an issue of increasing consequence locally and globally. Newspaper headlines bring sustainability issues to the general public daily. The *Washington Post* reports that under extreme climate change conditions over time, sea levels in the United States and worldwide could rise by more than eight feet by the end of the century (Harvey, 2017). The story, based on a federal government report (National Oceanic and Atmospheric Administration, 2017), characterized concerns about seacoast conditions, including in Louisiana, where rising sea level combined with coastal land that is sinking due to groundwater extraction and other human activities is a double threat. In a *New York Times* interview (Tugend, 2017), the mayor of Paris, France, describes her efforts to close main thoroughfares and streets to vehicles to make iconic areas of the city pedestrian friendly and reduce the air pollution that is harmful to human health. Mayor Anne Hidalgo, chair of a network of the world's largest cities that are committed to climate change actions, is focused on expanding the bicycle sharing system, electric car

hire system, and other pollution reduction measures. She will ban all diesel vehicles by 2025 to curtail carbon emissions and create more livable spaces for residents of Paris, a step also being enacted by the mayor of Mexico City.

Reports from Somalia portray the advance of disease and famine, not only in that country but also in South Sudan, Nigeria, and Yemen (Gettleman, 2017). Scientific research on climate change has predicted the increasing frequency of droughts which, coupled with local warring factions that seek to control food and water resources, are putting the lives of 20 million people at risk. The massive use of motorized vehicles and the manufacturing of industrialized nations results in the global pollution that causes climate change. In a case of environmental injustice, the people experiencing famine and devastation, however, are in countries that are insignificant contributors to carbon emissions and pollution. Such stories will continue over time, underscoring the relationships of natural resources to daily life, human systems, and environmental systems.

Despite academic differences in the definition of the concept of sustainability, federal agencies (National Science Foundation, 2017a, 2017b; U. S. Environmental Protection Agency, 2014) on down to local units of government (University of Minnesota, Resilient Communities Project, 2017; University of Oregon, 2017a) are taking steps to address energy use, land and water use, agricultural practices, and other environmental issues as they mesh with societal and economic activities.

Institutions of higher education, too, have a role in addressing the problems of sustainability in a variety of ways – for example, through research, teaching and learning,

community engagement, management of campus facilities, and seminars and public lecture series (Association for the Advancement of Sustainability in Higher Education, 2017a; University Leaders for a Sustainable Future, 2017a). Although individual faculty and staff members and students are engaged in a variety of sustainability projects and research, academic institutions are criticized for lack of better coordinated approaches that address sustainability challenges in more coherent, integrated ways (Sterling, 2004; Wals and Jickling, 2002; Velazquez, Munguia, and Sanchez, 2005). Some scholars suggest that new models must be developed within institutions that can advance solutions to sustainability problems without high-level institutional leadership and support (Thompson and Green, 2005). Advancements in sustainability work are lagging without the publicly stated commitment of presidents and chancellors (Shriberg, 2003), and without transformations in the structure of higher education institutions that address ways to overcome disciplinary constraints and incorporate education and training in sustainability research approaches (Dedeurwaerdere, 2013).

The emergence of the new field of sustainability science has the potential to spearhead progress in addressing the range of interconnected problems in sustainability through an array of networks that include professional scientific societies, peer-reviewed journals, and international arrangements and relationships, for example (Fagerberg and Verspagen, 2009). As networks and related developments in sustainability science coalesce, institutions of higher education may be transformed into the interdisciplinary powerhouses that can play a leading role in transitioning the global landscape to environmental, social, and economic sustainability. An increasing focus on sustainability

issues that can make change in institutions might be fueled by the faculty rather than by university leaders (Pittman, 2004; Thompson and Green, 2005). As Kauffman and Arico (2014) conclude:

"…the science that leads to sustainable transitions must necessarily be produced through collaboration among various disciplines and actors within and outside the academy in robust participatory and iterative processes that recognize policies and proposed solutions as experiments and that foster societal as well as scientific learning and advancement" (p. 417).

It is, then, the "actors" within the academy – the faculty – who are the focus of this study. A better understanding of the ways that faculty members are motivated by their scientific networks, external communities in the public and private sector, students, and funders, for example, as sustainability science matures may offer strategies for more coherent approaches to the "wicked problems" (Rittel and Webber, 1973) of sustainability – problems that ultimately touch all regions of the earth (Foley et al., 2005; Foley et al., 2011; Ostrom, 2009; Rockström et al., 2009).

Background

The concept of sustainability is anchored in the 1987 report *Our Common Future* (World Commission on Environment and Development). That report, for the first time, linked the status of the environment and natural resources globally to a generational timeline – not only to the lives and livelihoods of current populations but also to future populations.

The problem of sustainability is of critical importance to current and future generations. Already, about one billion people are chronically malnourished, and global food production must increase, even while agricultural systems are degrading land, water, biodiversity, and climate (Foley et al., 2005; Foley et al., 2011; Rockström et al., 2009). The outcomes of unsustainable natural resource use in the United States include increasing costs of energy and food. The ultimate outcomes of unsustainable natural resource use globally are famine, poverty, declining global health, and civil unrest (Ostrom, 2009).

Although governmental agencies and the private sector have some level of resources and expertise that can be applied to sustainability solutions, the public is skeptical of the politics (Ostrom, 2009) and profit motives (Steelman and Rivera, 2006; Tregidga, Kearins, and Milne, 2013) that might be involved. In general, institutions of higher education are viewed by the public as knowledge-generating organizations that have a commitment to learning and the public good and contribute to quality of life (Leveille, 2006). Many colleges and universities are bureaucratic organizations, however, with internal challenges of priority setting and alignment (Birnbaum, 1988). It is possible for faculty members and students to make contributions to specific issues in sustainability through multiple, discrete projects. Without a call for focus on sustainability from an institution's leader, however, the advantages of an overarching and coordinated approach and potential synergies may not be realized (Shriberg, 2003).

Sustainability science was introduced by 22 preeminent scientists (Kates et al., 2001) as a new field that emphasizes broader engagement of citizens to solve the

challenges of sustaining the environment, societies, and economies over the long term. Within this science of engagement, the new knowledge generated through scientific research is only one part of potential solutions. Sustainability science is based on the transdisciplinary approach that engages stakeholders and policy makers as critical participants in confronting issues in sustainability – issues related to agriculture, biodiversity, climate, economic development, energy and resources, fishery, forestry, health, lifestyle, and water (Kajikawa, 2008).

Sustainability science is founded on disciplinary knowledge and expertise that, once integrated, can address coupled social-environmental concerns. Disciplinary expertise alone is insufficient to reach sustainability solutions (Matson, Clark, and Andersson, 2016). For those researchers who pursue the complex issues of sustainability, strong relationships with colleagues from other disciplines are key to successful interdisciplinary team work. Interdisciplinary and transdisciplinary research and related activities are important yet still small percentages of the work conducted at largely discipline-based academic institutions (Brown, Deletic, and Wong, 2015).

Institutions of higher education commonly include community engagement as a key element of their missions. The Land Grant universities (Smith-Lever Act, 1914), in particular, hold the tradition of extending knowledge to the community. The Cooperative Extension Service and its linkages through the Land Grant universities across the states, has evolved over time from a one-way offering of information from a faculty expert to the community to a two-way discourse between faculty members and community members as they jointly address community-based problems. A subset of faculty

members at many universities have been involved or have actively participated in community engagement as a standard practice. Talwar, Wiek, and Robinson (2011) note that successes in sustainability projects that include community participation often can be attributed to the vision and skills of faculty members rather than the goals of the institution. Sustainability science may offer new and interdisciplinary opportunities for faculty members to engage with communities.

Two key drivers of change, students and funders, could influence faculty behavior, strategic change within institutions of higher education, and sustainability solutions. Student interest in research, learning, and community engagement might influence faculty members as they approach their work. Vincent and Focht (2011) report that student demand for interdisciplinary environmental education, for example, and subsequent growth in these programs has been dramatic. According to self-reported information by member institutions of the Association for the Advancement of Sustainability in Higher Education (2017a), 298 degree programs in "sustainability science and studies," undergraduate through doctoral, are available to meet student demand. Other degrees related to sustainability, such as "environmental studies and sciences," numbering 588, are reported by members. These tallies represent significant increases from those reported just six years prior (Kates, 2011), with eight doctoral programs and 41 master's degree programs at that time. Student interest in sustainability studies can have a notable effect on the teaching, research, and community engagement responsibilities of faculty members.

Grant opportunities to researchers are available through federal agencies (U.S. Department of Transportation, 2015; National Science Foundation, 2017a, 2017b) and private foundations (Calder and Clugston, 2004; Charles Stewart Mott Foundation, 2017; the Rockefeller Foundation, 2017; and the William and Flora Hewlett Foundation, 2017). Other financial support for sustainability research in the United States and abroad can be accessed through corporations (European Commission, Directorate-General for Environment, 2011) such as Wells Fargo (Carlson School of Management, University of Minnesota, 2011) and General Mills (Karnowski, 2017), and local jurisdictions (Schlossberg and Larco, 2014). Guidelines for submission of proposals and applications frequently require partnerships among the public and private sectors and academia.

The sustainability story has unfolded at an increasing pace since the publication of *Our Common Future* (World Commission on Environment and Development, 1987). Initial contributions from European institutions and their researchers (Gardner, 2011) have been expanded by scholars worldwide, and through a growing number of journals. The advent of the field of sustainability science may offer a convergence of research efforts and a more cohesive approach to addressing the challenges of problems in sustainability.

The Research Question

Sustainability is a complex web of human actions and global resource consequences that involves the world's populations and the environment and economies that sustain them. The new field of sustainability science may offer more innovative

approaches to address the challenges of sustainability as it strives to engage the public – stakeholders, communities, policy makers and others – in research toward sustainability solutions. Institutions of higher education are making contributions in research, education, and engagement but largely in a piecemeal rather than coordinated fashion. Contributions come to the fore through the activities of faculty members with strong interest in the disciplinary, interdisciplinary, and transdisciplinary pursuits that are core to their research, teaching, and community engagement. Given the complexities of sustainability, the nascent field of sustainability science, and the challenges of leaders in aligning institutions of higher education, the individual faculty member becomes an important focal point for inquiry.

This study investigates the research question: *How do key factors related to the evolving field of sustainability science affect the behavior of faculty members in addressing problems related to the interactions between human and environmental systems?* Seven factors related to the emergence of new fields of science are analyzed to inform the answer to the research question. These factors are: new journals; associations, organizations, and networks; funders' priorities; colleagues from other disciplines; stakeholder and citizen interests; student interests; and international arrangements.

Summary of the Study

The study focuses on faculty members at a top-tier, public, research university and how factors related to the new field of sustainability science might influence their behavior. The chapters that follow provide context on sustainability and the emergence

of sustainability science and describe the methods, analysis, results, and conclusions of the study. Chapter 2 is a review of the literature relating to sustainability, sustainability science as an emerging field, community engagement, and institutions of higher education and their leaders, students, and faculty members. Chapter 3 is a description of the methodology for this qualitative investigation. It includes presentation of the conceptual framework and descriptions of the research subjects, interview method and protocol, and analytical approach. Chapter 4 presents findings from interviews with 20 faculty members representing a range of disciplines. Findings are described in relation to the seven factors of influence on faculty behavior. The chapter concludes with a discussion of the themes that emerged from the analysis. Chapter 5 presents a discussion of the key findings of the study and responds to the research question. The chapter includes a discussion of the findings, implications for theory and policy, limitations, and directions for further research.

CHAPTER 2

REVIEW OF THE LITERATURE

Issues of sustainability affect people worldwide: drought, crop failure, loss of income and poverty, greenhouse gas emissions from the burning of fossil fuel, degradation of natural areas and wildlife habitat, chronic disease such as asthma, waste management, and safe and affordable housing, for example. With the accelerated rate of human activity during the past 30 years, "today, no ecosystem on earth is free of pervasive human influence" (Kauffman and Arico, 2014, p. 414).

What is unclear, however, is the meaning of sustainability and the issues and challenges that it encompasses. What is sustainability? How does it relate to university research, teaching, and community engagement? What are the roles of higher education institutions and their faculty or other groups and organizations in addressing sustainability?

A review of the literature informs this discussion of the role of higher education institutions and their faculties in sustainability. The review is presented in four main sections. The first section describes the history, definition, and interpretations of sustainability. The second section summarizes community engagement in higher education from the early traditions of outreach to current practices. The third section describes sustainability science as the new field that works toward sustainability solutions advocates for transdisciplinarity – the inclusion of community engagement broadly in sustainability research. The fourth section reviews the structure of higher education

institutions and the internal and external constraints that can challenge university leaders and faculty members, particularly related to sustainability. The section also includes a description of potential drivers of institutional change.

Defining Sustainability

In 1987, international attention was captured by the World Commission on Environment and Development with the publication of its report *Our Common Future* (World Commission on Environment and Development, 1987). The Commission, established by the United Nations and chaired by Norwegian Prime Minister Gro Harlem Brundtland, describes the need to integrate environment, development, and governance priorities as a practical response to the problems of international development that include Third World poverty, destruction of natural resources, and social inequities (Sneddon, Howarth, and Norgaard, 2006). In the report, development is framed with regard to environmental degradation, and is defined as that which "meets the needs of current generations without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, p. 23). The report signals the underlying interconnections among the environment, economics, and social equity, which came to be characterized as the three-legged stool of sustainable development (Sneddon, Howarth, and Norgaard, 2006).

A predominant characteristic of the term "sustainable development" is the fact that it is interpreted in many different ways by different individuals and organizations. Governments and the private sector have tended to adopt the term as common usage.

Public and non-governmental organizations and the academic community tend to use the term "sustainability" in similar contexts (Robinson, 2004). The term "sustainable development" focuses on continued growth, while the term "sustainability" emphasizes the ability of humans to continue to live within environmental constraints. Those who talk in terms of sustainability suggest that the growth defined as sustainable development would ultimately challenge the limits of natural resources and thus would not be sustainable (Robinson, 2004). Matson, Clark, and Andersson (2016) use the terms sustainable development and sustainability interchangeably.

The components of sustainability are generally recognized as environmental, economic, and social (Lozano, 2008; World Commission on Environmental and Development, 1987; United Nations, 2017). Some propose, however, that the concept of sustainability can be strengthened by freeing it from the traditions of development and recommitting to the definition from the Brundtland report, especially emphasizing scientifically-derived principles from the Laws of Thermodynamics and investigations of humans as a social species (Johnston, Everard, Santillo, and Robért, 2007). For example, Johnston and colleagues advocate that setting goals to eliminate waste and materials generated by society and slow the physical degradation of nature can provide metrics for use by governments and the public and private sectors to strive toward sustainability over time. Others suggest that sustainability needs only to be untangled from the misconceptions, especially on the part of higher education institutions, that it is too abstract, too broad, lacks specialized personnel to address it, presents financial challenges, or has no scientific basis (Filho, 2000). Others advocate re-conceptualizing

sustainability by drawing on a new sustainability science that incorporates the local knowledge of citizens (Kemp and Martens, 2007). Some call for developing a visual that can better inform people about the interrelationships of the environment, economics, and social inequities over shorter and longer periods (Lozano, 2008). The concept of sustainability has been represented visually in multiple ways (Lozano, 2008; Mebratu, 1998; Parkin, 2000). Lozano (2008) analyzes 15 visual representations that strive to communicate the concept of sustainability, and notes that the Venn diagram of three interconnecting circles of environment, society and economy with sustainability at the center intersection, and the graphic of three nested concentric circles, society and then economy set within the larger circle of environment are the two most frequently used and critiqued.

While acknowledging the "ill-defined nature of sustainability," Wals and Jickling (2002, p. 226) argue that the vagueness in definition has a powerful heuristic capacity when applied as an entré to or device for the exchange of ideas. They suggest that the complex facets of sustainability create a potential for education from an emancipatory, or transformative learning perspective (Kitchenham, 2008). The emancipatory perspective is introspective and self-reflective and offers the involvement of institutions, their students, and community partners, to engage actively in sustainability problem solving, according to Wals and Jickling (2002). Robinson (2004) concurs with the lack of rigor in the definition of sustainability, but suggests that refinements to the definition might best emerge from attempts to implement sustainability, a strategy that might offer political and policy making opportunities. He describes sustainability as an integrating concept

that creates synergies among environmental, economic, and social concerns. He suggests that the concept of sustainability can help to bridge the gaps in knowledge that are created by the disciplinary structures within academic institutions.

Over time, a number of local, national and international organizations have focused on one or more issue areas, or principles, within the concept of sustainability. For example, BioRegional (2017) pursues activities associated with sustainability principles that include the interrelated areas of zero carbon (no net release of carbon dioxide into the atmosphere), zero waste (an increase in reuse and recycling of materials while reducing consumption and the generation of waste), sustainable transport, sustainable materials, local and sustainable food, sustainable water, land use and wildlife, culture and community, equity and local economy, and health and happiness. The U.S. Green Building Council (2017a) launched its green building certification system, LEED (Leadership in Energy and Environmental Design), in March 2000 with the goals of encouraging building construction that saves money and resources, has a positive effect on the health of occupants, and promotes renewable energy. A subsequent program, LEED for Neighborhood Development (U.S. Green Building Council, 2017b), was developed to help create more sustainable, well-connected neighborhoods. Elements of the certification include conservation management of wetlands and species habitat, reduced automobile dependence, walkability, affordable housing, transit facilities, access to public spaces, community outreach and involvement, reduced water use, energy efficiency, and waste management.

In addition to issues related to the interaction of humans and the environment, such as global warming, wildlife, water, and pollution prevention, the Natural Resources Defense Council (2017a) also includes sustainable cities as a priority issue. In the United States, more than 80 per cent of the population settles in urban and suburban areas – a significant source of carbon pollution. The Council's current sustainable cities initiatives focus on social equity, carbon dioxide emissions, climate, energy efficiency, storm water pollution, food waste, and transportation (Natural Resources Defense Council, 2017b).

A more tailored set of sustainability goals was exemplified by the Obama administration's federal strategic sustainability performance plan (Obama White House Council on Environmental Quality, 2017), which was established in 2009 under Executive Order 13514. The Executive Order integrated the environmental, economic, and social components of sustainability by requiring federal agencies to develop, implement, and annually updated a plan that prioritized actions based on a positive return on investment for the American taxpayer and met greenhouse gas emissions, energy, water, and waste reduction targets.

For the purposes of this discussion, the concept of sustainability is defined as *the interconnections among society, economy, and environment that interact in an integrated way to maintain the earth's resources and the quality of life and livelihood of its inhabitants for future generations.* Issues in sustainability can include but are not limited to: biodiversity; climate change; cultural, diversity and social fabric; economic opportunities for diverse communities and individuals; energy; food production and

availability; health and wellness; land use; poverty alleviation; waste management; and water quality and availability.

The Problem of Sustainability

The problem of sustainability is of critical importance to current and future generations. Already, about one billion people are chronically malnourished, and global food production must increase, even while agricultural systems are degrading land, water, biodiversity, and climate (Foley et al., 2005; Foley et al., 2011; Rockström et al., 2009). The earth's oceans have lost more than 90 percent of their large predatory fish due to exploitation during the past 50 to 100 years (Myers and Worm, 2005). Dietz, Ostrom, and Stern (2003) warn:

> "In the absence of effective governance institutions at the appropriate scale, natural resources and the environment are in peril from increasing human population, consumption, and deployment of advanced technologies for resource use, all of which have reached unprecedented levels" (p. 1907).

The outcomes of unsustainable natural resource use in the United States include increasing costs of energy and food. The ultimate outcomes of unsustainable natural resource use globally are famine, poverty, declining global health, and civil unrest (Ostrom, 2009).

Sustainability and its interrelated environmental, economic, and societal elements are frequently referred to as a wicked problem (Crow, 2007; Gibbons, 1999; Miller, 2013; Weaver and Rotmans, 2006; Yarime et al., 2012). The term "wicked problem" was first described by Rittel and Webber (1973) as a problem that is ill-defined and

requires a political resolution. One of the key characteristics of a wicked problem is the fact that it has no clear definition. They state that the mission of a wicked problem is unclear, given various stakeholder viewpoints, and it is also unclear at what point the problem is solved. In fact, Rittel and Webber argue that a wicked problem is never solved; rather, it is repeatedly re-solved, at best. They contrast wicked problems to the tame problems of science and engineering whereby a mathematical problem is solved by an equation or the chemical structure of an unknown substance is identified through analysis. Rittel and Webber note that, due to a wicked problem's complexities and the multiple perspectives of stakeholders, multiple possible solutions would need to be formulated in advance in order to define the problem.

The Role of Higher Education Institutions in Sustainability

Scholars and organizations have envisioned multiple roles for higher education institutions in sustainability, including research, student learning, management of campus operations, public facilitation, and community engagement that address society's changing beliefs and values (Association for the Advancement of Sustainability in Higher Education, 2017a; Clugston and Calder, 1999; Rees, 2003; University Leaders for a Sustainable Future, 2017a). A key goal envisioned for colleges and universities is to pursue actions and education that would contribute to a citizenry with an improved understanding of natural resource consumption and its effects on economics and the well-being of people. Analysis of sustainability initiatives outside the United States demonstrates that regional and national governments and stakeholders increasingly expect higher education institutions to play a primary role in addressing sustainability

problems, particularly in collaboration with industry and the public sector (Dedeurwaerdere, 2013).

A critical aspect of the role of higher education institutions is the way in which colleges and universities address sustainability in partnership with local communities, through Cooperative Extension programs within the Land Grant university system and other outreach and engagement mechanisms. For the purposes of this discussion, the term "communities" refers primarily to communities of place, such as villages, towns, and cities. Communities of interest, however, are another important component and can include units of government, governmental agencies, non-profit organizations, and business and industry as well as local community and citizen organizations. The need for higher education institutions to focus on community engagement and contribute to sustainability education and solutions increases as the ramifications of overuse of global natural resources are better understood.

Framing the Issue

A broad literature exists on disciplinary and interdisciplinary research related to aspects of sustainability: climate change, in the *Journal of the Atmospheric Sciences* (American Meteorological Society, 2017a) and the *Journal of Climate* (American Meteorological Society, 2017b); water quality and supply in the *Journal of Soil and Water Conservation* (Soil and Water Conservation Society, 2017); land uses in the *Journal of the American Planning Association* (American Planning Association, 2017) and the *Journal of Environmental Sciences* (Elsevier, 2017a), food and health in

Agroecology and Sustainable Food Systems (Taylor & Francis, 2017), transportation and transit in *Transportation* (Springer, 2017a); and economics in the *Journal of Environmental Economics and Management* (Elsevier, 2017b), to name but a few sources of sustainability-related, peer-reviewed articles. The literature demonstrates the wide-ranging contributions of academic researchers to new knowledge in areas of sustainability.

Community engagement in various forms has been a traditional element of the mission of most higher education institutions, and its evolution is demonstrated in the literature (Boyer, 1990; Brown University, Swearer Center for Public Service, 2017; Kellogg Commission on the Future of State and Land Grant Universities, 1999; New England Resource Center for Higher Education, 2017). Community engagement can be a powerful way to apply new knowledge from academic research and create learning experiences for students, faculty, and community members as community-identified problems of sustainability are addressed (Borden, Cline, Hussey, Longsworth, and Mancinelli, 2007; Shandas and Messer, 2008).

The framework for sustainability science demonstrates that issues that arise in communities and local, national, and international issues of sustainability can be addressed within colleges and universities. The new field of sustainability science has the potential to integrate sustainability and community engagement into higher education institutions. It is important to note that, in certain circumstances, sustainability science may have the potential to make contributions in arenas outside of higher education.

Sustainability science (Kates et al., 2001) may provide a unique integrator between sustainability and community engagement for higher education institutions.

It is important to note that the literature includes examples from institutions outside the United States. Institutions in the European countries, in particular, are generally regarded as more advanced in the theory and practice of sustainability than those in the United States (Gardner, 2011).

The Evolving Dimensions of Sustainability

Historically, a milestone in the higher education sustainability timeline occurred in October 1990, when the *Talloires Declaration*, a 10-point action plan for incorporating sustainability and environmental literacy into teaching, research, and outreach, was created (University Leaders for a Sustainable Future, 2017b). The *Halifax Declaration* followed in 1991, formulating commitments from higher education institutions prior to the 1992 United Nations Conference on Environment and Development meetings in Rio de Janeiro. These were followed by the *Kyoto Declaration of 1993*, which included a call to the International Association of Universities' (2017) then-650 institutional members, and by a number of other international declarations with higher education signatories from an array of countries that are described (Lozano, Lukman, Lozano, Huisingh, and Lambrechts, 2013; Wright, 2002) and compared (Grindsted and Holm, 2012).

In parallel with other efforts to emphasize the role of colleges and universities in sustainability, the United Nations Educational, Scientific and Cultural Organization (2017) launched in 2005 the Decade of Education for Sustainable Development, which

concluded in 2014. The decadal effort strived to mobilize the educational resources of the world – including higher education – to help create a more sustainable future.

At the same time, sustainability scholars were becoming more prominent in the higher education literature (Clugston and Calder, 1999; Rees, 2003; van Weenen, 2000). In addition, U.S. colleges and universities pledged to pursue actions on their campuses that would contribute to an improved understanding of natural resource consumption and its effects on sustainability. The Association for the Advancement of Sustainability in Higher Education (2017a) was launched in January 2006 as the first higher education association for sustainability in North America. The establishment of the American College and University Presidents' Climate Commitment (2017) followed in June 2007, with more than 600 institutional signatories currently.

Emphasis on the role of higher education in sustainability was further anchored through the establishment of Elsevier's (2017c) *Journal of Cleaner Production* in 1993, and the *International Journal of Sustainability in Higher Education* (Emerald Group Publishing, 2017) in 2000. These journals were followed by *Sustainability: The Journal of Record* in 2008 (Mary Ann Liebert, Inc., Publishers, 2017) and the *Journal of Sustainability Education* in 2010 (The Institute for Sustainable Social Change and The Prescott College PhD Program in Sustainability Education, 2017).

Colleges and universities also have indicated their commitment to sustainability through membership in the Association for the Advancement of Sustainability in Higher Education (2017b). The association offers action steps and documentation that institutions can use to shape a sustainability strategy. U.S. higher education institutions

include 1,700 two-year colleges and 3,026 four-year colleges, a total of 4,726 degree-granting institutions (U.S. Department of Education, 2016). Only 665 institutions, or 14 percent, however, have made a public commitment to sustainability goals through their membership in the Association for the Advancement of Sustainability in Higher Education. U.S. membership currently includes 123 two-year institutions and 542 four-year and graduate institutions (Association for the Advancement of Sustainability in Higher Education, 2017c).

There are four key higher education organizations with the potential to foster sustainability as a priority among their combined 1,917 institutional members: the American Association of Community Colleges (2017), the American Association of State Colleges and Universities (2017), the Association of American Universities (2017), and the Association of Public and Land Grant Universities (2017a). The Association of Public and Land Grant Universities does not have initiatives specific to sustainability, however, did release in May 2014 the report *Science, Education, and Outreach Roadmap for Natural Resources,* which urges institutions to address sustainability as a "grand challenge" (Association of Public and Land Grant Universities, 2014b, p. 11).

Although many institutions have made public commitments to sustainability and sustainability education over the past two decades, they have not made the progress earlier envisioned due to organizational and political barriers (Sterling, 2004; Wals and Jickling, 2002), priorities of leaders (Shriberg, 2003; Thompson and Green, 2005), and institutional culture (Velazquez, Munguia, and Sanchez, 2005), among other factors. Subsequently, the network of higher education institutions in the United States remains

underutilized in addressing sustainability. The private sector and governments have the potential to address environmental as well as economic and social sustainability goals. Shifting political priorities in state and federal governments (Ostrom, 2009) and the profit motivation of corporations (Steelman and Rivera, 2006; Tregidga, Kearins, and Milne, 2013), however, have created wariness and frustration among non-profits and the public, with little systematic advancement toward sustainability solutions. It is, thus, of critical importance that institutions of higher education not only conduct research to further knowledge about sustainability, but also educate their students as future leaders, extend knowledge into the broader community, and address sustainability on their campuses (Sharp, 2002). With a more coordinated and cohesive approach, the network of U.S. colleges and universities could begin to address sustainable solutions to energy alternatives, climate change, resource use and food production, community social fabric, and wellness, for example, and the economics that are at play within each arena.

As sustainability research has evolved, so have the approaches to community engagement and the ways that colleges and universities interact with communities.

Community Engagement

The national commitment to a covenant of engagement between institutions of higher education and the people is expressed in the *Morrill Act* of 1862, which gave states public lands, but required that the lands be sold and that the proceeds be used to establish at least one college. The *Smith-Lever Act* of 1914 created the Cooperative Extension Service to extend knowledge to citizens. Inherent in the Extension structure

was the expert model whereby knowledge was extended to citizens by academics. Traditionally, the Land Grant universities were the owners of the tripartite mission of research, teaching, and outreach. In 1996, a National Research Council report recommended that the Land Grant system and the federal government must reinvigorate the tripartite mission through the integration of its three elements. Scholars were also differentiating outreach from a newer concept of engagement that embraced reciprocity and a two-way flow of information between the university and the community, rather than only the extension of knowledge from the university to the community (Byrne, 1998; Ray, 1999; Simpson, 2000; Spanier, 1997).

Sandmann (2008) notes that the term "engagement" has evolved over time and also can be interpreted to mean outreach, public service, civic engagement, community engagement, participatory action research, and community development. Based on an analysis of articles published in the *Journal of Higher Education Outreach and Engagement* over 10 years, Sandmann further documents the ongoing evolution of the scholarship of engagement through four stages. The first stage includes the introduction of bi-directional engagement and differentiates it from outreach. The second stage emphasizes the relationship to research and teaching, and the third stage focuses on engagement as a scholarly expression. The fourth stage describes the institutionalization of the scholarship of engagement within higher education institutions. Sandmann suggests that the scholarship of engagement will further evolve as an interdisciplinary field for academic research.

Ernest Boyer (1990) was a proponent of a renewed vision of scholarship where "theory and practice vitally interact, and one renews the other" (p. 23). With this, Boyer, President of the Carnegie Foundation from 1979 until his death in 1995, reignited the discussion within higher education that continues today. The Kellogg Commission on the Future of State and Land Grant Universities met between 1996 and 2000, and produced six reports on the topics of the student experience, student access, the engaged institution, a learning society, and campus culture. The third report, *Returning to Our Roots: The Engaged Institution* (Kellogg Commission on the Future of State and Land Grant Universities, 1999), laid a foundation for an engagement agenda that included making engagement a priority on every campus.

In February 2006, the Carnegie Foundation for the Advancement of Teaching released its voluntary classification of engaged institutions, following a pilot among 14 institutions (Driscoll, 2008). The pilot study included institutions that the foundation identified as significantly engaged with communities. Representatives from the 14 institutions tested the foundation's framework for the classification for engagement on their campuses and commented on the final design. As defined by the Carnegie Foundation, "community engagement describes collaboration between institutions of higher education and their larger communities (local, regional/state, national, global) for the mutually beneficial exchange of knowledge and resources in a context of partnership and reciprocity" (New England Resource Center for Higher Education, 2017, p. 1).

Even with significant emphasis on engagement as reinvigorated by Boyer (1990), barriers remain to elevating community engagement within institutions, not unlike

barriers to incorporating sustainability into higher education institutions (Stephens, Hernandez, Román, Graham, and Scholz, 2008; Dedeurwaerdere, 2013). Institutional barriers such as promotion and tenure policies can emphasize research over community engagement and sometimes teaching as well (Bridger and Alter, 2006). Even in the case of a policy change, however, a change in the academic culture does not necessarily follow (Sandmann, Saltmarsh, and O'Meara, 2008). Models that synthesize engagement, service-learning, community-based research, public service, institutional policies, and faculty attitudes can help to understand faculty engagement behaviors and subsequently determine effective ways to institutionalize community engagement (Wade and Demb, 2009).

Enhancing Community Engagement

Steps to further integrate engagement into universities can include a focus on the change agents within universities who span university-community boundaries and effectively help to implement engagement strategies (Weerts and Sandmann, 2008). In addition, scholars can infuse engagement into disciplines and scholarly organizations by publishing their research in journals other than those that focus specifically on engagement (Moore and Ward, 2008). A prompt for the systemic integration of community engagement into an institution can come from funding agencies such as the National Science Foundation and the National Institutes of Health (Fitzgerald, Bruns, Sonka, Furco, and Swanson, 2012) as funders focus on society's challenges and demand broad-based partnerships (Savan, 2004). Research suggests that successes are likely to occur when colleges and universities institutionalize engagement in five dimensions:

philosophy and mission; faculty involvement and support; student leadership and support; community partnership, involvement and leadership; and institutional support and infrastructure (Fitzgerald, Burns, Sonka, Furco, and Swanson, 2012; Furco, 2010).

In their analysis of 21 environmental research projects, Phillipson, Lowe, Proctor, and Ruto (2012) conclude that the most pronounced effects on research occur when non-university participants from the community engage in setting research objectives, project design, and knowledge creation. They also note that informal networks and the interchange of individuals between research and practice are most effective in promoting information and idea exchange.

Even with higher education institutions as signatories to sustainability declarations, journals that foster exchanges on aspects of sustainability, and a membership organization that focuses on sustainability in higher education, integrated institutional actions in sustainability have not gained traction and community engagement has taken a back seat to the priorities of research and teaching (Zilahy, Huisingh, Melanen, Phillips, and Sheffy, 2009). The literature suggests that the emerging field of sustainability science may help to integrate sustainability into institutions and subsequently bolster community engagement overall.

Sustainability Science

Given the protracted efforts to define the concept of sustainability, it follows that the new field of sustainability science is also confronted with a lack of clarity of definition. The journal *Sustainability Science* defines the field as “a new academic

discipline which can point the way to a sustainable global society by facing challenges that existing disciplines have not addressed" (Springer, 2017b, p. 1). Ostrom, Janssen, and Anderies (2007) define sustainability science as an applied science that seeks solutions to complex problems, much like engineering and medicine – but in this case, solutions to the complex problems of sustainability. As the field matures, state Ostrom, Janssen, and Anderies, the ability to construct diagnostic and analytical capabilities will come from disciplinary contributions such as anthropology, biology, ecology, economics, environmental sciences geography, history, law, political science, psychology, and sociology, among others. Rapport (2007) characterizes sustainability science as "a transdisciplinary effort to come to grips with one of the most perplexing issues of our time: how to achieve a symbiotic relationship between biological and social-cultural systems so that future options are not foreclosed (p. 77)." Rapport notes that it is not a science by the standard definition, but rather a set of principles that guides the compilation of knowledge to address sustainability problems. Martens (2006) includes five elements that are core to his definition of sustainability science: inter- and intra-disciplinary research, co-production of knowledge, co-evolution of a complex system and its environment, learning through doing and doing through learning, and system innovation instead of system optimization.

If sustainability is the ideal, then sustainability science provides the set of tools to integrate science and society (including the policy realm) to create new knowledge and provide solutions. Kajikawa (2008) defines sustainability science as a unique,

transdisciplinary field that creates a distinct body of knowledge to address sustainability problems, while drawing upon its relationships with other disciplines.

The National Research Council report, *Our Common Journey*, (1999) laid the foundation for the development of sustainability science, which it defined as place-based problem solving that values different ways of knowing and emphasizes the need to enhance a bridge between scholarship and practice. Momentum increased with a watershed publication in *Science* (Kates et al., 2001), that articulates three pathways for the advance of sustainability science. Kates and his 22 international co-authors note that, first, the scientific communities in the northern and southern hemispheres should discuss institutional capabilities to address sustainability; second, the scientific community overall needs to be connected to the international political agenda; and third, and most important, they note, research must focus on the interactions between nature and society, the ability of institutions to guide this interaction in sustainable ways, and on ways to promote the learning in society that will be necessary over the long term. Clark and Dickson (2003) follow with an emphasis on the close collaboration between practitioners and scholars that is essential to sustainability science.

Kajikawa (2008) subsequently identifies ten domains of sustainability-related research: agriculture, biodiversity, climate, economic development, energy and resources, fishery, forestry, health, lifestyle, and water, based on articles in the literature. In addition, Kajikawa proposes a research framework for sustainability science that includes the components of goal setting, indicator setting, indicator measurement, causal chain analysis, forecasting, backcasting, and problem-solution chain analysis. Jerneck et

al. (2011) further contribute to the field of sustainability science by developing a research platform that can be used to structure and create new knowledge in sustainability science. (See more detailed discussion below.)

Advances in sustainability science continue, for example, with analyses of transdisciplinary research, a new but growing field essential to sustainability science and as yet with no common terminology or shared research framework (Brandt et al., 2013). Descriptions of integrated, cross-disciplinary processes generally rest on two terms: "interdisciplinary" and "transdisciplinary." Vincent and Focht (2011) describe interdisciplinary processes as those pursued by scientific and technological experts to better understand complex environmental systems and phenomena. Their definition of transdisciplinary processes expands to include environmental practitioners, policymakers, economic sector representatives, and public stakeholders to participate in the policy and governance that guide the management of complex human-nature systems.

As in the other developments specific to higher education's role in sustainability, sustainability science, too, has achieved visibility through the creation of new journals – *Sustainability Science* in 2006 (Springer, 2017b) and *Sustainability* in 2009 (MDPI AG, 2017). The *Proceedings of the National Academy of Sciences of the United States of America* (National Academy of Sciences, 2017) created a section of the journal dedicated to sustainability science, as the emerging field of research dealing with the interactions between the environment, or natural systems, and society's economic, social, and political systems. With the establishment of the section in 2006, associate editor William C. Clark noted that, much like agricultural science and health science, sustainability

science is “a field defined by the problems it addresses rather than by the disciplines it employs” (Clark, 2007, pp. 1737).

New programs also emerged within the National Academies and the American Association for the Advancement of Science. The National Academies Roundtable on Science and Technology for Sustainability, established in 2002, engages academics worldwide and leaders from government, the private sector, and civil society (National Academies, 2017). The roundtable attempts to identify long-term science and technology approaches to sustainability, and then apply these approaches to address sustainability problems. The virtual Forum on Science and Innovation for Sustainable Development was created in 2009 by the American Association for the Advancement of Science (2017a) to highlight the people and programs that are contributing to the advancement of knowledge and practice in sustainability. It functions in collaboration with the American Association for the Advancement of Science Center for Science, Technology and Sustainability.

The developments that are associated with sustainability science – the evolving communications and research networks, conferences, new journals – are consistent with what has been called “the invisible college” (Crane, 1969) and the emergence of new scientific fields (Griffith and Mullins, 1972). Social mechanisms can develop among groups of researchers that result in a response to scientific problems and advocacy around an issue (Griffith and Mullins, 1972) – sustainability, in this case. In some cases, the scientists that coalesce around a scientific issue might have effects on their respective traditional disciplines. Based on an analysis of the literature on sustainability,

Bettencourt and Kaur (2011) find that the sustainability science research network has a broad geographical footprint that includes both developed and developing countries. It also includes small universities as well as well-recognized national centers internationally, and a disciplinary array that includes the social sciences, biological sciences, and engineering.

A Science with Social Engagement

Kates et al. (2001) describe sustainability science as a new field that "seeks to understand the fundamental character of interactions between nature and society" (p. 641), noting that research must encompass scales from local to global. That is, human activities related to growing crops, processing and packaging food, and transporting fresh produce and processed goods, for example, have different effects on soil quality, water availability, carbon emissions from vehicles and factories, and economies depending on geographic location – rural or urban, or in developed or developing countries. Terminology in the relatively new field of sustainability science varies among researchers. The "nature-society" relationships described by Kates and colleagues also are termed "human-environment" relationships by other researchers (Turner and Robbins, 2008). Kates et al. (2001) add that "in a world put at risk by the unintended consequences of scientific progress, participatory procedures involving scientists, stakeholders, advocates, active citizens, and users of knowledge are critically needed" (p. 641). Sustainability is a challenge to be addressed by organizations other than academia alone (McMichael, Butler, and Folke, 2003). The researchers note, however, that

academic institutions must overcome the conventional, university-department model and transition to interdisciplinary and transdisciplinary approaches to sustainability

Since the initial emphasis on the need for co-generation of knowledge through the collaboration of scholars and practitioners, or stakeholders (Clark and Dickson, 2003), the challenge of integration in sustainability science has been explored using scenario analysis (Swart, Raskin, and Robinson, 2004). Scenario analysis can include backcasting (Robinson, 1982), a process that envisions sustainable scenarios for the future, and then works backwards to define the steps in policies and programs that will be needed to attain the vision. Participatory forms of scenario analysis engage stakeholders and can effectively address public involvement in the integration of policy and science (Swart, Raskin, and Robinson, 2004).

Stakeholders.

Swart, Raskin, and Robinson (2004) recommend diverse participant groups in scenario analysis that include experts from different disciplinary backgrounds and stakeholders with varying interests. In general, they describe stakeholders as representatives from the private sector, governments, nongovernmental organizations, and the broader community. Stakeholders vary depending on the dimension of sustainability that is to be addressed, the geographical focus, and time frame. They note that dimensions of sustainability issues that require stakeholder participation include, for example, agriculture, biological diversity, climate change, demographics, energy, international security, poverty, and water. The researchers describe the importance of quantitative analysis, but add that the power of scenario analysis comes from the

compelling stories that can emerge from the experiences of stakeholders as well as experts. Such narratives help to identify critical questions for research that might otherwise be overlooked (Swart, Raskin, and Robinson, 2004).

Stakeholder knowledge and adoption of research results are linked to their involvement in front-end project design and identification of objectives (Garnett et al., 2009). In addition, scholars find that the positive contributions of stakeholders to knowledge creation in a project, as perceived by the scientific researchers, is important to ongoing engagement and the ability to acquire funding support for environmental projects (Phillipson, Lowe, Proctor, and Ruto, 2012). Miller (2013) concludes that sustainability scientists, as they conduct their research at the boundaries between science and society, must avoid the view that analysis is the purview of science only. He proposes a process-oriented approach that goes beyond participatory action research to an active role for scientists in facilitating a process and participating in mechanisms for change rather than providing new knowledge only as an observer.

Waas, Verbruggen, and Wright (2010) note that the field of sustainability science and its focus on the interactions between environment and society and the coproduction of knowledge between science and society can reorient and strengthen university research in sustainability. Dedeurwaerdere (2013), however, describes the institutional and research system barriers to incorporating sustainability science into colleges and universities. He highlights the need to combine different disciplinary perspectives and interdisciplinary work from academic experts with the "actionable knowledge" (p. 3785) from community members, the essence of transdisciplinary work. He describes barriers

that include the disciplinary orientation of universities in describing academic positions, and promotion and tenure; the current lack of sustainability research and training capacities at higher education institutions; the lack of mechanisms for building research partnerships with communities and stakeholder groups; and belief among some researchers that a problem-solving participatory action research approach is overstepping the bounds of scientific inquiry.

Sustainability Science: Research Toward Change

Since the inception of sustainability science in 2001 (Wiek, Withycombe, and Redman, 2011), the debut publication in *Science* (Kates et al., 2001), and the subsequent contributions in the literature to this new field, scholars have been exploring the implications for higher education's role in sustainability. Scholars have emphasized ways to balance the social and natural sciences in research approaches and to integrate the local knowledge of citizens. Research strategies that benefit community engagement, student learning, and the integration of sustainability into the fabric of higher education institutions frequently employ case studies as a methodology. A more detailed discussion follows, based on five investigations that provide a synopsis of academic revolutions over time, the potential for academia as a change agent, and the case study as a tool for research.

Higher education: potential change agent.

Higher education is well positioned to serve as the change agent for sustainability (Stephens, Hernandez, Román, Graham, and Scholz, 2008), particularly with the emergence of sustainability science. Stephens, Hernandez, Román, Graham, and Scholz summarize the role that universities held throughout history in the advancement of the

sciences, from the earliest instructions in theology and philosophy, the "alpha sciences;" to natural sciences, the "beta sciences;" and subsequently to the social sciences, or "gamma sciences," according to their categories of evolution. They suggest that the new science of sustainability – one of the "delta sciences" – could indeed spur change, and subsequently transition society via a new, integrated approach to addressing the complex and long-term challenges of sustainability. Stephens, Hernandez, Román, Graham, and Scholz suggest that academic researchers recognize the structural impediments within higher education institutions that can inhibit progress in addressing sustainability, and that the inception of sustainability science signals interest on the part of researchers to break down institutional barriers. Institutional barriers are described above (Dedeurwaerdere, 2013).

Stephens, Hernandez, Román, Graham, and Scholz (2008) offer a rubric of five critical issues that can be explored by an academic institution, as a change agent, to advance knowledge and practice in sustainability. The issues are designed to prompt responses that are informative despite geographical location, culture, values, and specific sustainability challenges. The issues are dominant sustainability challenges of the region, financing structure and independence, institutional organization, extent of democratic processes, and communication and interaction with society. They conclude that the synthesis of responses in the five issue areas and identification of common themes among institutions can encourage innovative mechanisms for teaching and research in higher education and lead to engagement with external individuals and stakeholder groups.

A number of scholars suggest that the transition management framework is a helpful lens by which to assess a transition to sustainability (see an expanded discussion of transition management below). Transition management, anchored in complex adaptive system theory, strives to incorporate long-term goals with short-term demands in addressing complex, multi-layered societal problems such as sustainability (Loorbach, 2010; Kemp, Loorbach, and Rotmans, 2007). Stephens, Hernandez, Román, Graham, and Scholz (2008) highlight the range of opportunities for universities at multiple levels of interaction. At the strategic level, institutions can work collaboratively with others to help set a vision for the future and describe long-term goals. At the tactical level, institutions can foster engagement among citizens, stakeholder groups, and other organizations. At the operational level, colleges and universities can address sustainability through their teaching, research, community engagement, and campus operations.

The next academic revolution.

Despite the standard process for the establishment of a new field through the launch of new journals, the creation of networks and associations, and emerging research programs, the institutionalization of sustainability science is a challenge (Yarime et al., 2012). The priority challenge to integrating sustainability science into the mainstream of higher education is identifying the core mission of the contemporary research university, according to Yarime and colleagues. Similar to Stephens, Hernandez, Román, Graham, and Scholz, (2008), Yarime and colleagues find that the history of higher education provides context for the discussion of higher education's role in sustainability. They highlight the transition, through the first academic revolution of the 1800s, to incorporate

research into the core of the academy, and then to the second academic revolution that now emphasizes scientific research as it contributes to economic development. The hallmark of the second revolution is the entrepreneurial university (Etzkowitz et al., 2008; Philpott, Dooley, O'Reilly, and Lupton, 2011). Yarime and colleagues emphasize that the entrepreneurial university paradigm targets economic growth, but not necessarily the wicked problems of society and the environment.

Yarime and colleagues anticipate, beyond the university-industry focus on the economy, the unfolding of the third academic revolution that might integrate sustainability as the guiding principle. They reference this institutional transformation as the "New American University" (Crow, 2010; Crow and Dabars, 2015). Yarime and colleagues assess the process of institutionalizing sustainability within the University of Tokyo, Japan; the Swiss Federal Institute of Technology, Zurich; Lund University, Sweden; and Erasmus University in Rotterdam, the Netherlands. They conclude that teaching, research, and engagement must be addressed simultaneously. They recommend that active collaboration with various stakeholders is required as the transdisciplinary element that is inherent in sustainability science. In addition, the scholars emphasize the value of employing transdisciplinary case studies to support the transition to sustainability (Scholz, Lang, Wiek, Walter, and Stauffacher, 2006). The engaged collaboration among practitioners and university researchers can achieve research goals while also demonstrating to students that scientific rigor must be linked to the local knowledge of the everyday world.

Bridging the social and natural sciences.

To address research goals more effectively, Jerneck et al. (2011) propose a "research platform" (pp. 69) based on three components within a matrix that can bridge the social and natural sciences. The components are: core themes, such as scientific understanding, sustainability goals, and pathways; cross-cutting critical and problem-solving approaches; and combinations of sustainability challenges that could include land-use change, biodiversity loss, water scarcity, and climate change, for example.

The elements in their research platform that concurrently address nature and society are problem-solving research and critical research. The inclusion of both problem-solving research and critical research is founded on Cox's (1981) distinction between the theories underlying the two approaches. Cox states that problem-solving theory takes into account social and institutional relationships at a given time and attempts to reduce a problem into variables. The variables then can be analyzed for patterns that might better inform tactical actions and efficiencies, based on the status quo. Critical theory, Cox states, questions the basis for existing social and institutional relationships and allows for the exploration of alternatives. Jerneck and colleagues (2011) offer a climate change example to differentiate the two types of research. Problem-solving research might explore ways to optimize emissions trading among manufacturers, for example, whereby a company with insufficient government-issued permits to cover its greenhouse gas emissions can buy permits from a company that has reduced its emissions and has more permits than it requires (Leimbach, 2003). Critical research, for example, would question the very creation of such market-based mechanisms to address climate change. Jerneck and colleagues contend that both are

required for sustainability science and the integration of local knowledge and scientific expertise. They illustrate the combined approach that employs both types of research with an intervention study project undertaken by faculty at Sweden's Lund University Centre of Excellence for Integration of Social and Natural Dimensions of Sustainability, a 10-year integrated effort to study the theory, methodology, and education for sustainability. The study was conducted in conjunction with a community of subsistence farmers in Kenya to address climate change, deforestation and health. Jerneck and colleagues highlight the outcomes that resolved immediate issues of indoor cooking and respiratory health while also creating energy efficiencies and reducing the need for wood.

The case study methodology.

Given the view that sustainability requires the active involvement of a variety of local stakeholders and the need for transparency and reflection, Corcoran, Walker, and Wals (2004) argue that it is not helpful to pursue universal descriptions of sustainability or universal models. They suggest that the critical case study is a valuable approach that can enhance local practice and be applied elsewhere. They view case-study methodology as an ideal tool to investigate sustainability in higher education, one that can accommodate multiple epistemologies. Their analysis of major journals from 1996 through 2001 found that 28 of 54 papers on sustainability in higher education use case-study methodology to describe innovation. Only two papers, however, include an explanation of the methodology and only one provides a critical analysis of the case. Subsequently, Corcoran, Walker, and Wals argue that case-study research must specifically describe the method, state the purpose for conducting the case, and articulate

the foundational objective of exploring sustainability in higher education. Corcoran, Walker, and Wals present a set of 10 considerations to guide a critical case-study model that can engage faculty, students, and the community in participatory action research. The considerations are: the researcher's and institution's goals in conducting the case study, background on the sustainability initiative being studied, nature of the sustainability initiative, questions about the case study, problems and issues to be researched, constraints in implementing the sustainability initiative, implementation strategies, documentation of outcomes, evaluation, and continuation of the initiative.

The transdisciplinary case study.

Scholz, Lang, Wiek, Walter, and Stauffacher (2006) advocate for the use of transdisciplinary case studies. Countering views that sustainability research frequently lacks an epistemological grounding (Fien, 2002; Jerneck et al., 2011; Stephens and Graham, 2009), the transdisciplinary case study approach of Fien and colleagues is organized by a framework that is composed of ontology, epistemology, methodology, and organization. They emphasize, however, that these components must be viewed as a whole and inseparable. A key strength of the approach includes its basis in three paradigms that elucidate aspects of the complex interplay between human and environmental systems. The three paradigms include the case study as a methodology to address real-world issues, the transdisciplinary framework to offer context to the specific issue or problem, and sustainability, to guide potential solutions to real-world problems from a normative perspective. An additional strength, they emphasize, is that the transdisciplinary case study is, by nature, an ongoing inquiry process that accommodates new learnings. Scholz, Lang, Wiek, Walter, and Stauffacher (2006) did, however, raise

the challenge of validating qualitative research in general and of the transdisciplinary case study approach, in particular.

Sustainability, Sustainability Science, and Community Engagement in Practice

Community relationships that are grounded in citizen-identified issues (Borden, Cline, Hussey, Longsworth, and Mancinelli, 2007; Shandas and Messer, 2008), student service learning (VanWynsberghe and Andruske, 2007), and frameworks for an overall commitment to an institutional culture of sustainability (Cortese, 2003; Brinkhurst, Rose, Maurice, and Ackerman, 2011; Levy and Marans, 2012; Moore, 2005; Olson, Arvai, and Thorp, 2011; Sterling, 2004; Wals and Jickling, 2002) can help to identify improved strategies and mechanisms for engagement focused on sustainability.

In addition to the environmental, social, and economic components of sustainability, Chalker-Scott and Tinnemore (2009) urge that community-based research on sustainability must include superior educational quality, clear organizational structure, and continued financial stability. The researchers' case study of a Master Gardener program describes how the absence of an integrated relationship between Extension within a Land Grant university and the academic departments led to a disconnect between the research in landscape horticulture, particularly in urban areas, and research dissemination to volunteers. They conclude that the lack of educational quality and perceived relevance to the community contributed to the financial destabilization of the program. Franz and Cox (2012) also describe factors that contribute to a diminishing role for the traditional Extension approach to community engagement, including

decreased funding, change in livelihoods and lifestyles of community members, and communications methods that may not have kept up with current technology.

It is important to note the potential implications of sustainability science for community engagement around sustainability issues. Sustainability science and its integral transdisciplinary research approach presents a new research paradigm for many scientists. Actionable socio-environmental science, which conceptualizes stakeholder engagement broadly and with a focus on problems rather than disciplines, is influencing academic perceptions of the value of engagement (Palmer, 2012). Savan and Sider (2003) use the umbrella of community-based research – action research, participatory action research, collaborative inquiry, and service learning – in their analysis of a multi-partner sustainable initiative in Toronto, Ontario, Canada. Even with early successes within the project, the researchers identify barriers to productive collaboration via community-based research, including historic hostilities and suspicions among partners, differences in backgrounds and expectations, inequities in the balance of power and control, unrealistic or conflicting goals, and insufficient funding. Allen, Kruger, Leung, and Stephens (2013) analyze stakeholder engagement in a collaborative climate change modeling project. They conclude that learning opportunities must be created for researchers who do not have experience in stakeholder engagement. Learning opportunities can help to address the variations in perceptions that researchers hold of stakeholder contributions toward success.

Case studies also provide insights to best practices for community engagement specific to sustainability issues. Lehmann, Christensen, Thrane, and Jørgensen (2009)

analyze two regional sustainability networks in Denmark that include Aalborg University as a partner. In both cases, university faculty and students were invited to participate with community organizations and businesses, with differing contexts of participation in each. The researchers conclude that universities must be able to adjust their modes of two-way engagement, from the catalyst and lead to a boundary organization that brings knowledge creation and learning opportunities for students and the institution.

A case study of the Community Watershed Stewardship Program in Oregon concludes that program design that involved the Portland State University faculty and students and community partners attracted even more community organizations and residents, expanding the organizational capacities of both the city and the university (Shandas and Messer, 2008). Subsequently, Portland State University has offered 20 senior capstone courses and 12 other undergraduate courses that have involved about 600 students. A second longer-term watershed case study in New England emphasizes the value of community engagement to the institution. The researchers (Borden, Cline, Hussey, Longsworth, and Manncinelli, 2007) note that, in addition to positive environmental and community impacts, achievements of the project include funding for endowed chairs in planning, government and policy, and sustainability and green business leadership. Other outcomes include development of a core faculty around project themes and both problem-based learning and employment opportunities for students.

The community-engaged successes at a small University of Minnesota campus are based on the installation of a wind turbine; a biomass gasification plant; a local foods

initiative that connects growers, students, and the campus food service; a new environmental studies major; and the deepened relationships with community organizations that now draw students directly into community interactions in the town of 5,200 people (Goodnough, Kildegaard, Kuchenreuther, Rasmussen, and Wyckoff, 2009). The authors note that the internal impetus for developments came originally from the campus physical plant department, and was swiftly embraced by the student body. Key faculty members became participants. Last to encourage the set of cohesive efforts was the campus administration.

Replicating Sustainability-focused Community Engagement

In addition to the sustainability-based case studies that appear in the literature, it is important to note the model of sustainability-focused community engagement that was developed at the University of Oregon and is now being replicated elsewhere. The Sustainable Cities Initiative is a cross-disciplinary organization at the University of Oregon (2017a) that promotes education, service, public outreach, and research on the design and development of sustainable cities. A program within the initiative, the Sustainable City Year Program, was established in 2009 to link University of Oregon students with an Oregon city, county, special district, or partnership of governments to work collaboratively on projects for a full academic year. The program has been described as a noteworthy comprehensive effort by higher education to infuse sustainability into curricula, service learning, and the local community (Burnham, 2010; Carlson, 2013, Patz and Vargo, 2015). The Sustainable City Year Program co-directors estimate that during each academic year, more than 400 students from 10 or more

disciplines across 20 to 30 classes could work on 15 to 25 partner-directed projects that focus on a more sustainable future. As of 2016, more than 25 universities have modeled programs on the Sustainable City Year Program (University of Oregon, 2017b). They include Land Grant universities such as Penn State, the University of Maryland, and the University of Minnesota as well as smaller institutions such as Earlham College in Indiana and San Diego State in California. It is important to emphasize the tendencies of institutions toward isomorphism, the process that causes, in this case, a higher education institution to become more like other colleges and universities (DiMaggio and Powell, 1983). Isomorphism potentially can contribute to a more coordinated approach to sustainability solutions from higher education institutions collectively.

As with the college and university initiatives and outcomes that focus on sustainability, similar successes in community engagement most often require the endorsement – if not priority designation – of the institution's president. The attentiveness of the institution's leaders and their reinforcement of cohesive and integrated actions applies to long-standing programs such as Extension (Weerts, 2005), as well as to new programs and institutionally engaged sustainability research, teaching, and outreach (Ferre-Balas et al., 2010).

Strategies for Community Engagement in Sustainability

Aspects of community engagement, specifically related to sustainability and sustainability science, are being addressed in a variety of national and international studies. A closer look at the strategies for engagement such as participatory research and stakeholder analysis methods show that, as in sustainability itself, there is confusion

about definitions of the terms “community” (Head, 2007) and “stakeholder” and their use in different fields (Reed et al., 2009). An additional challenge is the dearth of published empirical research on the outcomes of community-university partnerships. Some research, however, indicates that partnerships result in improved services to communities and an increase in research on a community issue or need (McNall, Reed, Brown, and Allen, 2009). Despite significant challenges, scholars pursue innovation in processes, assessments, and typologies that can fine tune approaches to community engagement and support solutions to sustainability problems. A more detailed discussion follows based on the work reported in three studies.

Engagement through Shared Action Learning.

A process that engages community members, students, and faculty via shared learning experiences has been developed at Worcester Polytechnic Institute in Worcester, Massachusetts, an institution noted for its commitment to project-based learning (Jiusto, McCauley, and Stephens, 2013). The researchers emphasize the opportunities offered by sustainability science and its integration of knowledge and action, the boundary-crossing approaches of transdisciplinary programs, and the need to restructure the academy to facilitate sustainability science and its emphasis on engagement (Kates, 2002). The Shared Action Learning process that Jiusto, McCauley, and Stephens describe follows from participatory action research with the goal of facilitating cooperation among communities, stakeholders, faculty, and students who are jointly engaged in local sustainability projects. Development of curriculum around this process can provide

benefits to students through community-based experiential learning as well as to faculty members and other stakeholders.

Jiusto, McCauley, and Stephens explore the meanings of sustainability and outcomes from the Shared Action Learning process in two different contexts: a Clark University course that grounds curriculum in the physical campus and the surrounding Worchester community, and a Worchester Polytechnic Institute-based sustainable community development program in Cape Town, South Africa. The Shared Action Learning process consists of five stages: project impetus, contextual research and project planning, community engagement and project refinement, action, and reflection and reporting. Jiusto, McCauley, and Stephens conclude that the Shared Action Learning process can address the variety of sustainability priorities at a community level that are context specific, both locally and internationally. They note that the Shared Action Learning process can address the contradictory visions, differing perspectives, creative orientations, and inherent tensions among the range of community members as well as university faculty, staff, and students.

Jiusto, McCauley, and Stephens and others (Head, 2007) emphasize that individuals and organizations within a community do not necessarily share an identity or a commitment to cooperation or inclusiveness. To assume homogeneity would be a failing in community engagement efforts. The Shared Action Learning process can clarify roles, manage expectations, and underscore the importance of communications, relationship building, and the creation of networks based on the discourse that contributes to collaborative sustainability solutions (Jiusto, McCauley, and Stephens, 2013).

Stakeholder engagement in research.

Scholars who study sustainability within the construction industry assess three ways to conceptualize stakeholder engagement: as a management technique, an ethical responsibility, and as a dialogue that can support mutual social learning (Mathur, Price, and Austin, 2008). Although this study addresses the construction industry, the key learnings can be applied to other organizations, including universities. The utilitarian management technique evaluates how a company (or organization) should determine the groups or individuals that it must be attentive to as it carries out projects and activities. Ethical responsibility engagement values broad participation and strives for transparency, fairness, and valuing citizen contributions as part of a democratic process. Engagement as a dialogue involves a multidirectional flow of information among all participants – researchers and community members – and can lead to shared learning, an appreciation of other view points, and consensus building, according to Mathur, Price, and Austin. They emphasize the inherent elements of reflection and mutual learning within dialogue as a social process, based on the work of Innes and Booher (2004). They also emphasize that the dialogue approach to engagement can encompass both management techniques and ethical needs, while providing an opportunity for social learning.

Mathur, Price, and Austin (2008) expand the discussion of stakeholder engagement in sustainability into the process of sustainability assessment. Ideally, a sustainability assessment should not only evaluate whether a project or proposal will achieve sustainability goals but it should also contribute to improved decision making. They apply the definition of sustainability assessment from Weaver and Rotmans (2006)

as a cyclical, participatory process of scoping, envisioning, experimenting, and learning whereby a shared interpretation of sustainability is developed and applied to address a wicked problem.

A typology for engagement.

The focus on community engagement in sustainability research has intensified over the past several years, largely due to the requirements of research funders (Talwar, Wiek, and Robinson, 2011). Although most frequently described in the social science literature, user engagement strategies are cited in land use planning, agriculture, and health research. Stakeholder analysis and strategies for participatory methods in natural resource management research also have been assessed (Reed et al., 2009). Talwar, Wiek, and Robinson use the term "user engagement" broadly to include public participation, stakeholder involvement, extension, outreach, community engagement, and related identifiers. They present a typology that includes two levels of research: unidirectional social research and interactive social research. Unidirectional social research represents the faculty expert model whereby knowledge is transferred to the user as a one-way communication. Interactive social research, can engage users in all segments of the research process, including problem definition and research design. A key criterion in their typology concerns the point in the process when user engagement occurs.

The researchers analyze three sustainability projects that provide an empirical basis for applying their engagement typology. The analysis shows that, even with the intent of strong interactivity, the projects did not achieve higher levels of the typology's

interactive social research. Talwar, Wiek, and Robinson conclude that the barriers to interactive social research are organizational and institutional rather than technical. They note that success in user-engaged sustainability projects often relies on the vision and entrepreneurial skills of individual researchers rather than their institutional environment. Organizational barriers to more robust interactions among academic researchers and users include the increased amounts of time required at each step of the process to collectively engage all participants, and the differences in academic and other timelines among participants. They also find that the ability to manage expectations is a challenge for both researchers and users, given academic research constraints and the potential conflict over expected outcomes. The research publication timeline versus real-time change in a community process or policy is an example of differing viewpoints on priority outcomes. Talwar, Wiek and Robinson note that, although user engagement is the goal of a funder, funders frequently fall back on the traditions of the faculty expert research model in the peer review and award processes for grants.

Each of the three studies summarized above emphasizes the importance of dialogue, or discourse, among engaged participants. Talwar, Wiek, and Robinson (2011) note, however, that the time required for discourse at all stages of a project can be an impediment to the success of collectively addressing sustainability issues.

The preceding discussion highlights the opportunities to enhance institutional advances in sustainability and community engagement through the potentials of sustainability science and its emphasis on stakeholder engagement and problem solving. It is important to review the structure of institutions of higher education as organizations

and their culture to better understand the process of institutional change – and the role of faculty members – that could lead to higher education's contributions toward sustainability locally, nationally, and internationally.

Institutions and Leadership

A key challenge to the integration of sustainability research and community engagement into colleges and universities is inherent in the organization and leadership structures of higher education institutions. Cortese (2003) concludes that the vertical rigor of the disciplinary focus (commonly referred to as "silos") in higher education encourages compartmentalized and competitive views that are contrary to the interdependent nature of sustainability. He suggests a structure and a culture where an equally strong lateral rigor draws students and faculty across disciplines, encourages systems thinking, incorporates sustainable operations and facility design, and engages communities. Using the University of Michigan as a case study, Shriberg (2003) addresses the consequences of lack of sustainability leadership at the highest levels of an institution. Shriberg argues that activities across an institution are piecemeal greening efforts, and concludes that, without leaders at the top who identify sustainability as a priority, there is no driving force to coalesce the many scattered pockets of sustainability activities and disciplinary knowledge into a cohesive whole. Velazquez, Munguia, and Sanchez (2005) also report that the decentralized management, bureaucracy, student and faculty turnover, and many non-standardized processes also are barriers to achieving institutional sustainability goals. Other scholars conclude that there are so few examples of strong institutional leaders who make an active commitment to achieving sustainability

goals for their institutions, that an alternative leadership model is required (Thompson and Green, 2005). They argue that proponents of sustainability within an institution must develop strategies that do not assume a top-down approach.

Leaders and Their Institutions

The challenges that stem from lack of a clearly articulated support for sustainability by the leaders of higher education institutions can apply to other initiatives and opportunities as well. Birnbaum (1988) concludes that leaders in colleges and universities are subject to both internal and external constraints that can limit their effectiveness and render their roles highly symbolic rather than instrumental. Many institutions of higher education, particularly the larger, comprehensive universities, fit the model of an organized anarchy (Cohen and March, 1974; Cohen, March, and Olsen, 1972). They characterize an organized anarchy as having ill-defined or problematic goals, unclear technology or processes toward outcomes, and fluid participation that includes varying degrees of interactions or non-interactions among administrators, faculty, staff, and students. Birnbaum (1988) states that the anarchical qualities of an institution allow the members of the university organization to substitute belief for action. Specific to the case of the role of higher education institutions in sustainability, a university president can sign a national declaration that denotes certain commitments and actions, but without outcomes. As a signatory to a sustainability declaration, the president can reference the institution's commitment to sustainability actions without undertaking the systematic change in institutional behavior that could disrupt but ultimately transform the institution.

The relationships and interactions among the subsystems and elements within the system of an organized anarchy (or other models, such as a bureaucratic institution) are influenced by the ways that the elements are connected, or coupled (Birnbaum, 1988). In the case of sustainability, the loose coupling of elements within a university helps to explain the range of unlinked activities that appear to flourish in many colleges and universities without the support of institutional leaders. Examples might include student sustainability and environmental clubs, the creation of an interdisciplinary major, or a new program with a mission to engage local communities in partnership around sustainability issues.

The Academic Culture

A challenge related to the integration of sustainability into the fabric of colleges and universities is the culture of the academic institution, which also is tied to organization and structure. Bekessy, Samson, and Clarkson (2007) note that non-binding memberships and *ad hoc* projects or pilot programs are ineffective in moving an institution forward in its commitment to sustainability. The researchers conclude that such activities are not persistent and do not create cultural change within the institution. They highlight conservative cultures and an academic autonomy that inhibits multidisciplinary research as key obstacles. Thompson and Green (2005) point to the issue of the failure of university community members to recognize environmental problems due to the use of faulty cultural models of the relationship of humans to the environment. They suggest that sustainability proponents must try to introduce new, accurate models, realizing however, that people do not easily dispense with models that fit with their existing world view. In a study of the cultural perspectives of the faculty,

Wright and Horst (2013) find that faculty members hold the viewpoint that universities should educate about sustainability, conduct research, and organizationally act as models of sustainability. The faculty perspective, however, was that overall leadership on sustainability needs to come from the administration and that demand must flow from the students.

The faculty.

An understanding of the complexities of faculty perspectives and roles can be enlightened by the differences that can arise from a faculty member's relationship to the institution and the relationship to his or her discipline. Gouldner (1957) describes faculty members as cosmopolitans whose sphere can be national and international, based on peer relationships, research interests, and prominence among disciplinary scientific societies. Gouldner identifies, at the other end of the spectrum, faculty members as locals, who are more strongly invested in the university community, participate in institutional committees and activities, and focus on teaching. Birnbaum (1988) notes that the balance of cosmopolitans and locals can affect patterns of activity and influence within an institution. Within the arenas of sustainability, sustainability science, and community engagement, advancement can occur at a national level, via the participation of a university faculty member who has prestige and visibility conferred by a scientific society or a prominent peer network of scholars. Within the campus community, progress can be based on faculty members who are specifically focused on the goal of creating new learning opportunities for their students. Subsequently, the activities of

both cosmopolitan and locally-oriented faculty can result in sustainability initiatives that have successful outcomes but that are unrelated.

Some scholars emphasize the importance of faculty members in motivating change related to sustainability within their institutions. Pittman (2004) argues that top-down approaches to strategic initiatives and transformational change within institutions of higher education are largely ineffective. He notes that institutions are slow to change their use of mechanistic "command and control" (p. 202) strategies to manage their scientific endeavors. Pittman describes the importance of the relationship between the individual faculty member and the institution through the lens of whole systems design. Whole systems design is a design-based strategy for organizational change that begins with individuals – faculty, students, and partners outside of the university – who work together toward a shared and collective vision to address complex problems such as sustainability. Pittman (2004) emphasizes that it is the individuals within an institution who will make change.

Based in part on their analyses of organizational change at Arizona State University and within its School of Sustainability specifically, Miller, Muñoz-Erickson, and Redman (2011) recommend "a mutualism wherein individuals use their influence to encourage their institutions to experience change and that institutions are organized in such a way to encourage and provide support for individuals to go through substantial change and redirection. This relationship can foster epiphanies from the top-down or the bottom-up…" (pp. 185). The School of Sustainability at Arizona State University enrolled an initial set of graduate students in January 2007, and followed with expanded

graduate enrollments and added undergraduates in 2008. A major disruption occurred in Summer 2009 when junior faculty pushed back against the School of Sustainability's approach in addressing the problems of sustainability: bringing multiple disciplines together to work creatively and collaboratively. The junior faculty argued that, to address the wicked problems of sustainability, the disciplinary approach was not effective, even though the intent had merit. They proposed that the faculty develop new conceptual frameworks and methodologies to address sustainability, which was endorsed by the school's senior faculty (Miller, Muñoz-Erickson, and Redman, 2011).

In addition to the roles of presidents, faculty, and students within institutions of higher education, some institutions have created a university sustainability committee, a sustainability officer position, or assigned responsibility for sustainability to an existing vice president or senior leader (Sharp, 2002). There appears to be no systematic accounting of these roles in the literature nor of descriptions, responsibilities, position within the organization, or evaluation procedures. The Association for the Advancement of Sustainability in Higher Education (2017c), however, maintains a section of its website featuring resources for sustainability officers at colleges and universities, and completed a third annual survey of sustainability staff positions among its institutional members (Association for the Advancement of Sustainability in Higher Education, 2015). The analysis was based on 460 responses; however, the authors of the report emphasize that the total number of sustainability staff positions is unknown as is the proportion of individuals who responded and their level of responsibilities.

Drivers of Change

The literature demonstrates that sustainability research, education, and engagement occur in a variety of higher education institutions (Association for the Advancement of Sustainability in Higher Education, 2017b; Crow, 2010; Levy and Marans, 2012), but frequently without the significance and visibility that can come with the priority emphasis of an institution's president, chancellor, and top leaders (Shriberg, 2003; Thompson and Green, 2005). Subsequently, the leadership role of higher education institutions in sustainability has progressed slowly against the challenge of its integration into the structure and culture of colleges and universities. Key drivers of a future integration of sustainability and institutional change could include funders and students.

Funders of sustainability.

Funding from federal agencies and the philanthropic community has the potential to spawn more cohesive approaches to sustainability within institutions. The Obama Administration created the Partnership for Sustainable Communities to break down segmentation among the federal departments of Housing and Urban Development, Transportation, and the Environmental Protection Agency (U.S. Department of Transportation, 2015). The federal agencies, together, were charged to help communities nationwide improve access to affordable housing, provide more transportation options at lower costs, and reduce pollution through the Partnership for Sustainable Communities. The partnership agencies incorporated principles of sustainability into federal funding programs, policies, and future legislative proposals. As of February 2014, the agencies had received more than 9,800 proposals, with requests totaling $122 billion. The

agencies funded 1,066 projects in all 50 states, plus the District of Columbia and Puerto Rico, at a total investment of $4.6 billion. (U.S. Environmental Protection Agency, 2014). Successful applicants were consortia of multiple partners, anchored by a unit of government such as a city. Although not required, several consortium award applicants and recipients included colleges and universities.

The National Science Foundation's Science Engineering and Education for Sustainability program (2017a) was established in 2010 with the related goals of expanding interdisciplinary research and education toward global sustainability, linking projects and partners and adding new participants to sustainability endeavors, and developing the workforce to address sustainability. The initial budget of $70 million in fiscal year 2010 increased to $153 million in fiscal year 2014, and 700 awards were granted during that period. Additional granting programs that address sustainability across multiple directorates include Innovations at the Nexus of Food, Energy and Water Systems, for example (National Science Foundation, 2017b).

South Carolina's Sustainable Universities Initiative is another example of how a funder can drive institutional innovation toward sustainability solutions. In 1999 the University of South Carolina, Clemson University, and the Medical University of South Carolina received $4.5 million from a Danish foundation to focus a five-year project on four major areas: effect change within the faculty, foster student and community programs, enhance campus operations, and share information and manage programs. Calder and Clugston (2004) note that the independent funding provided the impetus to establish the multi-institution initiative and was key to a range of successes. The amount

of the award was small, however, measured against large federal grants that some faculty members received during that time. Calder and Clugston also describe retirements and repositioning of university presidents and other institutional leaders, the lack of acceptance of the legitimacy of sustainability from many academic departments, and institutional budget constraints as contributing to unrealized goals. Although the initiative leveraged an additional $2.27 million in sustainability research grants, Calder and Clugston conclude that such small initiatives, with uncertain long-term funding, can inspire but not translate into comprehensive forces for institutional change regarding sustainability. The statewide network of faculty, staff, and students was most active between 1998 and 2005 and has been replaced by other initiatives (University of South Carolina, 2017).

An increasing number of local, regional, national, and international philanthropic foundations address sustainability in a variety of ways. The Joyce Foundation (2017) focuses on energy efficiencies and the Great Lakes and waterways in the Great Lakes region, for example. The Jessie Smith Noyes Foundation (2017) funding priorities include environmental justice, sustainable agriculture and food systems, and sustainable practices in New York City. Other foundations that fund sustainability priorities are the Charles Stewart Mott Foundation (2017), the Rockfeller Foundation (2017), and the William and Flora Hewlett Foundation (2017), for example.

In the case of the University of Oregon's Sustainable City Year Program, which was described earlier, the selected city itself shapes the projects and invites student and faculty participation. The city also, however, pays project costs to ensure professional

engagement, quality products, and a coordinated approach (Schlossberg and Larco, 2014). The financial commitment by the select cities can be interpreted as an indicator of the need and value of the university's role in sustainability activities, and encourage the institution to continue its sustainability work.

Student goals for education.

The dual outcomes from student participation in community engagement – contributions to the community project and experiential learning outcomes for the student – were referenced earlier in the discussion of community engagement (Borden, Cline, Hussey, Longsworth, and Manncinelli, 2007; Goodnough, Kildegaard, Kuchenreuther, Rasmussen, and Wyckoff, 2009; Savan and Sider, 2003; Shandas and Messer, 2008; VanWynsberghe and Andruske, 2007; and University of Oregon, 2017b). The Association for the Advancement of Sustainability in Higher Education (2017d) also captures self-reported student projects, new curriculum, and learning initiatives.

It is important to note that student interests in research, learning, and community engagement can be important drivers for the creation of new opportunities within colleges and universities. Sandmann, Saltmarsh, and O'Meara (2008) suggest that overall institutional engagement and changes in policy can result from graduate students and junior faculty acting as grassroots agents of change. The National Science Foundation's Advisory Committee for Environmental Research and Education issued key reports (National Science Foundation, 2005, 2009) that emphasize the need for a transformation in environmental education and research. In tandem, student demand for interdisciplinary environmental education and subsequent growth in enrollment in such programs has been dramatic (Vincent and Focht, 2011). A survey of 260

interdisciplinary environmental programs found that two thirds reported a growth trend between 2003 and 2008 (Vincent and Focht, 2009). Brower (2011) reports, in addition, that the interest in sustainability in business schools is growing rapidly in response to the millennial generation and its general interest in social responsibility and making a difference in the world. Technologies that can offer virtual service learning for students who are geographically dispersed or for intensive and collaborative information sharing and writing are addressing student interest in community engagement around sustainability (Pearce, 2009).

In general, sustainability has gained traction in recent years, supported by increasing institutional momentum. European institutions have led the way (Gardner, 2011), but both Arizona State University and Harvard University, among others, are cited as prominent examples of institutional accomplishment and leadership in the field of sustainability (Rowe, 2007; Wiek, Withycombe, and Redman, 2011). Arizona State University president Michael M. Crow describes the reconceptualization of his institution based on commitments to academic excellence, inclusiveness, maximum societal impact, and quality operations and organization – with sustainability at the core (Arizona State University, 2017a; Crow, 2010). Transdisciplinary schools within the university have been created, and some traditional academic departments have been eliminated, including biology, sociology, anthropology, and geology. In envisioning the "New American University," Crow (Arizona State University, 2017b) urges that "scientific research conducted with application and social context in mind – outcome-driven science, or

science with purpose – should be granted equal accord with fundamental research" (Crow, 2010, p. 488).

Summary

Sustainability is a wicked problem of local, national, and global dimensions. The definition that encompasses environmental, social, and economic sustainability has been generally accepted by researchers and practitioners for nearly 30 years. The transdisciplinary character of sustainability lends itself to the goal of an enhanced integration of research, teaching, and community engagement that is a component of the mission of Land Grant institutions and other colleges and universities. Community engagement has not yet achieved the priority status held by research and teaching in many institutions in general, and specifically community engagement that is focused on sustainability issues. Research that focuses more closely on community engagement specific to sustainability emphasizes the discourse, or dialogue, that can support mutual learning among scientists and citizens, and contribute to resolving sustainability issues identified by the community. Inherent in the field of sustainability science is the requirement of citizen involvement in working toward sustainability solutions – solutions that are not purely scientific solutions, but those that incorporate social and political elements as well. The field of sustainability science, with its transdisciplinary emphasis, might be the catalyst that enhances integrated institutional approaches to both sustainability and community engagement.

The organizational structure of institutions of higher education can create barriers to the advancement of sustainability in higher education, sustainability science, and community engagement. In the absence of naming sustainability as an institutional priority by college and university leaders, faculty members might become the change agents that ultimately move institutions toward sustainability solutions. Students and funding organizations can be drivers of actions toward the integration of sustainability into higher education institutions. They, along with other factors such as the networks, professional scientific societies, and journals that have been spawned with the emergence of sustainability science, might have a notable influence on the behavior of faculty members.

CHAPTER 3
CONCEPTUAL FRAMEWORK AND METHODS

The evolution of sustainability science from the earlier conceptual development of sustainability and its interrelated elements of environmental, social, and economic sustainability is a currently unfolding example of the emergence of a new field of study. A number of social and technical elements converge during the emergence of new scientific fields of study. The social interactions and communications among scientists that might lead to new directions in science and new fields of science have been referred to as the "invisible college" (Price and Beaver, 1966; Crane, 1969; Griffith and Mullins, 1972). Loose networks and collaborations eventually can result in group meetings, conferences, new disciplines, and professional scientific societies (Griffith and Mullins, 1972). Pfeffer (1993) notes that the level to which a new field or discipline has achieved paradigm development can influence faculty governance within an academic department, faculty position and pay, relationships to journals, and overall collaborative work. Paradigm development refers to the community of scholars in a field that share a consensus on consistent practices and methods. Fagerberg and Verspagen (2009) suggest that emerging scientific fields constitute attempts to overcome the strictures of traditional ways to organize academic disciplines and innovate in the creation of new knowledge.

Research in the environmental sciences has long addressed the quality of land, water, air, and biodiversity. It was, however, the 1987 publication of the international report *Our Common Future* (World Commission on Environment and Development) that crystalized worldwide attention on the need to address the interconnected environmental,

social, and economic problems through a long-term strategy that ensures quality of life for current and future generations. Even with nearly 30 years of scholarly debate in the literature about the definition of sustainability, its epistemological underpinnings, and approaches, the notion of sustainability has spread into state and federal programs, citizen action at the local level, corporate board rooms, and institutions of higher education. Institutions of higher education can address sustainability through research, student learning, management of campus operations, public facilitation, and community engagement (Association for the Advancement of Sustainability in Higher Education, 2017a; Clugston and Calder, 2000; Rees, 2003; University Leaders for a Sustainability Future, 2017a).

Sustainability science as a field was launched into a steep trajectory with the 2001 publication of the article "Sustainability Science" in the journal *Science* (Kates et al.). In addressing the evolution of sustainability science, Bettencourt and Kaur (2011) state:

> A science of sustainability necessarily requires collaboration between perspectives in developed and developing human societies, among theoretical and applied scientific disciplines, and must bridge the gap between theory, practice, and policy. There is arguably no example in the history of science of a field that from its beginnings could span such distinct dimensions and achieve at once ambitious and urgent goals of transdisciplinary scientific rigor and tangible socioeconomic impact (p. 19540).

From an analysis that included number of publications and authors in the field, intensity of collaborations, and geographic and disciplinary profiles, Bettencourt and Kaur (2011) conclude that sustainability science is an active field of scholarship with an extensive collaboration cluster of researchers and practice. Institutions of higher education can enhance opportunities for research, teaching and learning, and public engagement

through organizational structures that facilitate interdisciplinary research, encourage the transdisciplinary research that engages the public, and ensure that students can participate in community-based learning during their college experience. University faculty members are pursuing research and teaching in areas of sustainability, documented in a *Web of Science* journal analysis (Thompson Reuters, 2017) – with and without the facilitation of their institutions toward removing barriers to interdisciplinary and transdisciplinary work. The activities of individual faculty members in the context of sustainability science offer opportunities for further research on this emerging field.

Conceptual Framework

The present analysis addresses the research question: *How do key factors related to the evolving field of sustainability science affect the behavior of faculty members in addressing problems related to the interactions between human and environmental systems?* The research question is premised on the assumption that faculty behavior is critical to the emergence of a field of science. The responsibilities for research, teaching, and community engagement are borne by the faculty. To understand better the emergence of sustainability science, it is important to determine the key factors that influence faculty behavior and in what ways.

Faculty Behavior

The framework of the study focuses on faculty behavior and the influences that might motivate faculty members as they move through their days of teaching, research investigations, speaking at national meetings, participating in scientific organizations,

serving on faculty governance committees, mentoring and advising students, writing grant proposals, leading centers and programs, engaging with public and private sector stakeholders and partners, and developing new courses and programs. Faculty members encounter opportunities, incentives or disincentives, and rewards in their scholarly work, and may change their behaviors over time through the influences of factors within and outside of their institutions. They are the change agents that lead collectively to a more integrated focus on sustainability within their institutions.

Many institutions in the United States have a stated commitment to sustainability. Many have added new sustainability-related courses, programs, and community-service project emphases at the departmental level, but without an institutionally cohesive approach to sustainability. Fewer U.S. institutions of higher education have identified sustainability as an institutional priority articulated by a president or chancellor. The literature, however, is replete with case studies that characterize the transdisciplinary, sustainability science-oriented research that involves faculty, students, and the community cited earlier and that are found routinely in sustainability journals and other publications (Burnham, 2010; Carlson, 2013; Goodnough, Kildegaard, Kuchenreuther, Rasmussen, and Wyckoff, 2009; Pearce, 2009; University of Minnesota, Resilient Communities Project, 2017). To overcome lack of leadership in the hierarchy of institutions of higher education, Thompson and Green (2005) advocate that members of campus communities need to effect change through a new model that addresses sustainability solutions. Thompson and Green suggest that faculty members, administrators at levels below the executive officers, and students – sustainability

proponents – must recognize barriers to implementing sustainability work and overcome them. Proponents within the institution should also be poised to take advantage of opportunities for change such as the hiring of a new president or dean, developing new curriculum that could incorporate sustainability issues, and creating visible campus locations for sustainability practices that address the local environment, according to Thompson and Green (2005).

Pittman (2004) describes the importance of individual faculty members as agents of change within the institution. Pittman states: "Among the social institutions that structure human systems, those of higher education are uniquely poised to nurture agents who can design and create such change" (p. 199). Miller et al. (2011) also underscore the importance of the individual faculty member as a partner with the institution in dismantling the discipline-oriented framework that inhibits the creation of knowledge to address sustainability challenges.

The literature offers validation for anchoring this investigation in the faculty. Stephens, Hernandez, Román, Graham, and Scholz (2008) suggest that academic researchers recognize the structural impediments within higher education institutions that can inhibit progress in addressing sustainability, and that the inception of sustainability science signals interest on the part of researchers to break down institutional barriers. Institutional barriers include the disciplinary orientation of universities in describing academic positions, and promotion and tenure; the current lack of sustainability research and training capacities at higher education institutions; the lack of mechanisms for building research partnerships with communities and stakeholder groups; and belief

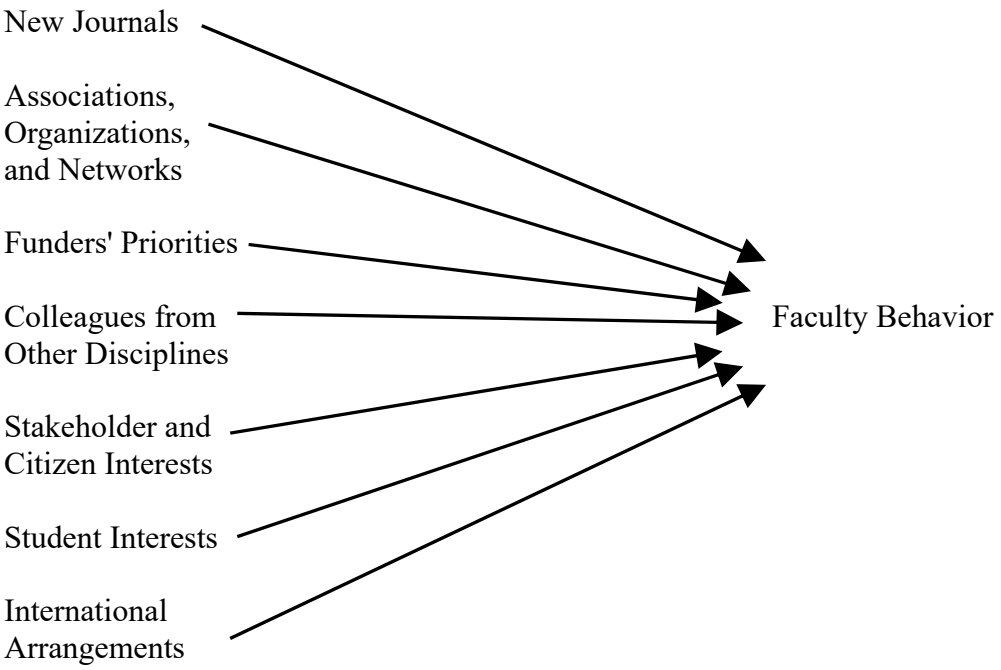
among some researchers that a problem-solving participatory action research approach is overstepping the bounds of scientific inquiry (Dedeurwaerdere, 2013).

The organizational structure of higher education institutions can inhibit interdisciplinary and transdisciplinary work. The silos within institutions encourage compartmentalized and competitive views that are contrary to the interdependent nature of sustainability (Cortese, 2003). In addition, Velazquez, Munguia, and Sanchez (2005) report that the decentralized management, bureaucracy, student and faculty turnover, and many non-standardized processes also are barriers to achieving institutional sustainability goals. Thompson and Green (2005) conclude that there are so few examples of strong institutional leaders who make an active commitment to achieving sustainability goals for their institutions, that an alternative leadership model is required. They argue that proponents of sustainability within an institution must develop strategies that do not assume a top-down approach. Such conclusions from scholars suggest that an investigation based on faculty interviews of individuals with a propensity to engage in sustainability-related activities is an approach that might result in new information about the contributions of faculty to the advancement of sustainability solutions.

Factors that Influence Faculty Behavior

The key factors, shown in Figure 1, that may influence faculty behavior are: *new journals; associations, organizations, and networks; funder's priorities; colleagues from other disciplines; stakeholder and citizen interests; student interests;* and *international arrangements.* The remainder of this section provides rationale for examining these

Figure 1: Conceptual Framework: Key Factors Related to Sustainability Science that May Affect Faculty Behavior in Addressing Interactions between Human and Natural Systems



factors in relation to faculty behavior in the context of the emergence of sustainability science as a field of science.

New journals.

The first factor is *new journals.* Faculty members could prefer publishing in some of the newer journals that focus specifically on sustainability and sustainability science. They might prefer, in contrast, to publish in more traditional disciplinary journals, either as a way to interject sustainability-related research into the discipline or to continue with a publications pathway that might be more familiar to them. Publications choices might be based on the perspectives of all individuals collaborating on an interdisciplinary research team. The range of options for publication offered by newer journals that specifically address sustainability and sustainability science might have an influence on faculty behavior.

As noted in Chapter 2, a broad range of disciplinary and interdisciplinary journals publish peer-reviewed research articles that address aspects of sustainability, but do not necessarily include sustainability as a content focus. Professional scientific societies and publishers cover environmental issues—water quality, climate change and atmospheric sciences, land use and planning, ecology and agroecology, geography, transportation, economics and management, other social sciences and humanities, and engineering, among others. In addition, newer journals that focus specifically on sustainability include the *Journal of Cleaner Production* (Elsevier, 2017c); the *International Journal of Sustainability in Higher Education* (Emerald Group Publishing, 2017); *Sustainability: The Journal of Record* (Mary Ann Liebert, Inc., Publishers, 2017); *Sustainability Science*

(Springer, 2017b); and *Sustainability* (MDPI AG, 2017), for example. A *Web of Science* database (Thompson Reuters, 2017) search conducted in March 2017 identified 947 journals that include articles that address the integration of environmental, social, and economic sustainability.

Publication of research findings is essential to the presentation or validation of new knowledge. The relationship of the factor *new journals* to faculty behavior is important to explore in order to determine how individuals choose to publish new knowledge among their disciplinary colleagues and larger networks of scholars with a priority focus on sustainability – through established journals, newer journals, or both.

Associations, organizations, and networks.

The second factor *associations, organization, and networks* could prompt responses that weigh a balance between disciplinary and interdisciplinary priorities of the individual. The traditions of many professional scientific societies, for example, are founded in the disciplines. Analysis could show consistent participation among faculty interviewees in certain organizations that address sustainability specifically, or with more traditional disciplinary organizations and networks, or a participation in a combination of scientific organizations.

Opportunities for disciplinary-focused memberships and broader networking relationships appear to be vast. For example, the American Association for the Advancement of Science (2017b) alone currently includes 252 professional scientific societies and membership organizations that represent more than 10 million individuals. It is the largest federation of scientific and engineering societies in the world, and many

member organizations include sustainability among their areas of focus. In addition, the American Association for the Advancement of Science (2017a) created the Center for Science, Technology, and Sustainability to promote international scientific cooperation, capacity-building and workforce enhancements, and sustainable development. The effort included compiled information on resources, programs, and research related to sustainability science. The National Academies Roundtable on Science and Technology for Sustainability, established in 2002, engages academics worldwide and leaders from government, the private sector, and civil society (National Academies, 2017). The roundtable attempts to identify long-term science and technology approaches to sustainability, and then apply these approaches to address sustainability problems.

As described above, clusters and networks of researchers and professional scientific societies are core to the evolution and maturation of new fields of study (Griffith and Mullins, 1972; Pfeffer, 1993). The opportunity to interact or collaborate with other researchers through professional scientific societies and networks might motivate individual faculty members to change their behavior and conduct their work in new ways. For example, professors might serve on a committee that is assessing options for new membership sections in the scientific society based on emerging fields of science. They might serve on a task force that is addressing new opportunities to support graduate students. The exposure to new people, new thinking on behalf of the society might prompt an individual to consider new approaches to research and teaching. It is important, therefore, to examine the factor associations, organizations and networks to faculty behavior.

The factor associations, organizations, and networks may have overlapping relationships with other factors. An individual faculty member might participate in an association, organization, or network that also focuses on international activities or links the individual to colleagues in countries outside of the United States, for example. Faculty might also participate in networks related to international declarations that include their institution as a signatory. He or she might become involved in aspects of a professional scientific society's annual meeting that focus on student opportunities or the participation of federal agency or foundation representatives as speakers or sponsors. The opportunity to discuss funding programs in the context of an annual meeting might offer new insights and opportunities to the individual. Many professional scientific societies and associations also publish one or more journals. An individual might be involved on an editorial board or a peer review panel that offers exposure to other researchers and an additional opportunity to exchange ideas that might lead to new collaborations.

Funders' priorities.

The third factor *funders' priorities* might also prompt a range of responses. Some faculty interviewees who work in disciplines related to natural resources and the environment might report that traditional funders have broadened the environmental umbrella to address the social and economic elements of sustainability, or entertain proposals that include the integration of social and economic issues. Given a track record of success, they might continue routinely to secure grant awards from these environmental funders. Other faculty interviewees might describe their process for submitting proposals for grants as following federal Notice of Funds Availability

postings or philanthropic organizations program guidelines related specifically to sustainability. Some might tailor their focus to some extent to meet the requirements of program guidelines.

Funding from federal agencies and philanthropic organizations has the potential to spawn more cohesive approaches to sustainability research, teaching, and community engagement within academic institutions and their partners. The Obama Administration, for example, created the Partnership for Sustainable Communities in 2009 to support integrated sustainability solutions through a grant-making process (U.S. Department of Transportation, 2017). The National Science Foundation (2017a) provides another example of a national grant-making focus for research in sustainability that included a portfolio with several specific programs. The mission of the foundation's Science, Engineering, and Education in Sustainability program was "to advance science, engineering, and education to inform the societal actions needed for environmental and economic sustainability and sustainable human well-being" (National Science Foundation, 2017a, p. 1). Awards in 2010 through 2015 were made through granting programs that addressed the arctic, coastal areas, the dimensions of biodiversity, and dynamics of coupled natural and human systems, for example. Newer strategies through other National Science Foundation directorates and cross-cutting directorates include, for example, the Innovations at the Nexus of Food, Energy and Water Systems opportunity. The program emphasizes a well-integrated, interdisciplinary approach, stating: "Investigations of these complex systems may produce discoveries that cannot emerge from research on food or energy or water systems alone. It is the synergy among

these components in the context of sustainability that will open innovative science and engineering pathways to produce new knowledge, novel technologies and predictive capabilities to solve the challenges of scarcity and variability" (National Science Foundation, 2017b).

A number of private philanthropic foundations – local, national, and international – make grants in sustainability and related areas such as climate change, natural resource management and conservation, ecosystems, and biodiversity. Examples of larger foundations that include sustainability in their funding priorities are the Charles Stewart Mott Foundation (2017), the Rockefeller Foundation (2017), and the William and Flora Hewlett Foundation (2017).

The Mott Foundation's environment program has funded work focused on global natural resources for more than 40 years. The foundation states that "this work has taught us that such grantmaking must seek practical ways to simultaneously build strong economic, environmental and social conditions for all people – in a word, sustainability," (2017). The Rockefeller Foundation has moved from sustainability to the term *resilience* in describing its approach to a global network that strives to overcome disciplinary silos and fragmented approaches to addressing in an integrated way environmental, social and economic issues, among other related issue areas (2017). The Hewlett Foundation, for example, maintains a global focus on climate change while also awarding grants that address clean energy and the environment in the western United States (2017).

Development of grant proposals to state and federal agencies and to private foundations is a routine activity for many faculty members in order to pursue their

research interests and support their graduate students. The availability of funding to advance work on sustainability – and aspects of sustainability including agriculture, biodiversity, climate, economic development, energy and resources, fishery, forestry, health, lifestyle, and water (Kajikawa, 2008) and the special interests of funders – might have an effect on the behavior of faculty.

Colleagues from other disciplines.

The fourth factor *colleagues from other disciplines* relates to complex interactions, particularly related to interdisciplinary and transdisciplinary research. All individuals in the pool of faculty members that I identified as potential interviewees for the study had some experience in conducting sustainability projects and some level of interdisciplinary or transdisciplinary engagement. The interdisciplinary approaches necessary to address issues of sustainability can be challenging due to institutional barriers, development of an interdisciplinary team, and individual temperament. The question related to the influence of colleagues from other disciplines could result in both positive and negative responses.

The factor colleagues from other disciplines could extend well beyond the campus to relationships with colleagues at other U.S. universities and institutions in other countries. Interdisciplinary activities might also develop through relationships with researchers in the private sector. This factor might relate to the influences of the factors international arrangements and informal networks, for example. Colleagues from other disciplines might have a particularly strong influence on the way that faculty members

approach their work, especially given the essential interdisciplinarity that sustainability science demands.

Sustainability science is an emerging field that builds upon interdisciplinary research (Martens, 2006; Ostrom, Janssen, and Anderies, 2007). It advances beyond the integration of the disciplines to achieve footing as a transdisciplinary field, where the co-production of knowledge includes the essential collaboration of practitioners, citizens, and policy makers in concert with scholars (Clark and Dickson, 2003: Kajikawa, 2008; Vincent and Focht, 2011). The interaction of a faculty member with colleagues outside of his or her department and from other disciplines might likely be a key factor in influencing an interest in problem-solving through interdisciplinary collaboration and a pursuit of work in sustainability science.

Scholars suggest that individual faculty members within an institution may have a stronger influence on change than do their institutional leaders (Pittman, 2004). As internal agents of change, the faculty can reorient their work and priorities more nimbly within the institutional structure, even with its disciplinary structures and organizational barriers to interdisciplinary research (Cortese, 2003; Velazquez, Munguia, and Sanchez, 2005). Interviewees collaborating with colleagues from other disciplines – scholars working in other domains who have provided insights or otherwise influenced their work – might have an influence on one another, and ultimately on the institution.

Stakeholder and citizen interests.

The fifth factor *stakeholder and citizen interests* could prompt responses that confirm a long-time focus on community engagement, with positive or negative experiences; no previous engagement with stakeholders; or a circumstance where the interviewee conducts activities that include stakeholders but has not previously considered himself or herself as a practitioner of public engagement.

The engagement of citizens, organizations, and policy makers is a core element of sustainability science through its transdisciplinary emphasis. Nature-society relationships (Kates et al., 2001), sometimes referred to as human-environment relationships (Turner and Robbins, 2008), are essential to the advancement of sustainability science and the outcomes that can benefit the environment, societies, and their economies. The collaboration of scholars and practitioners, or stakeholders, is the pathway to sustainability solutions (Clark and Dickson, 2003; McMichael, Butler, and Folke, 2003). Science alone cannot resolve complex, wicked problems but requires the interactions of citizens and policy makers to effect change. Ongoing dialogue can support mutual social learning among researchers and stakeholders (Mathur, Price, and Austin, 2008). Communication, relationship building, and the creation of networks based on discourse contribute to collaborative sustainability solutions (Jiusto, McCauley, and Stephens, 2013).

Outreach to citizens beyond the campus has long been a tradition of the land grant universities in particular, and other higher education institutions as well. Over time, this extension of knowledge has reinvented itself as “engagement” that can include outreach, public service, civic engagement, community engagement, participatory action research,

and community development (Sandmann, 2008). Engagement is a two-way exchange of research and learning between researchers and the community. At Land Grant institutions, in particular, a percentage of faculty members hold Extension appointments, which carry the responsibility of working in the community to address local problems. Faculty members in the professional schools and other colleges frequently are engaged directly in communities through health care programs, community design charrettes, early childhood learning programs, and other efforts in partnership with the community.

The relationship of the factor stakeholder and citizen interests to faculty behavior is important in the context of sustainability science. First, stakeholder engagement is a key element of sustainability science. Second, many faculty likely have some experience in community engagement, which might reinforce their potential interest in working on sustainability issues in the community. Sustainability science might provide a faculty member the additional network and shared academic experiences for engagement in the community on particular issues such as climate change, youth development, energy savings, or affordable housing, for example.

Student interests.

Faculty members engage with students in a variety of ways. The sixth factor *student interests* could elicit a range of responses that relate to teaching undergraduate or graduate courses; serving as a student adviser, mentor, or adviser to student clubs or organizations; providing students with laboratory or field research experiences; supervising community-based or participatory action research with community members; or serving on master's thesis or doctoral program committees, for example. Student goals

and interests could motivate a range of actions among faculty members that have an overall influence on faculty behavior.

The influences of the student population at institutions of higher education can be significant. Sandmann, Saltmarsh, and O'Meara (2008) suggest that overall institutional engagement and changes in policy can result from graduate students acting as grassroots agents of change. Vincent and Focht (2011) find that student demand for interdisciplinary environmental education and subsequent growth in enrollment in environmental courses and programming has been dramatic. Technologies that can offer virtual service learning for students who are geographically dispersed or for intensive and collaborative information sharing and writing are addressing student interest in community engagement around sustainability (Pearce, 2009). Scientific organizations such as the American Association for the Advancement of Science respond to and engage students by emphasizing career opportunities in sustainability, noting that "creating a sustainable world will take lots of creativity and cooperation, with scientists in all fields working together and working with the community to help solve the complex problems our world is facing" (American Association for the Advancement of Science, 2017c, p. 1).

At the institution that provides the context for this study, the University of Minnesota (2017a), for example, each year about 20 academic departments and 50 undergraduate and graduate courses include service learning opportunities. In addition, data from the 2015 Student Experience in the Research University survey show that 86 percent of University of Minnesota students favor opportunities that connect students

with a community-based experience, and 268 undergraduate students were enrolled in the Community Engaged Scholars program in the 2015-2016 academic year (University of Minnesota 2017b, p. 40). Although, student involvement might include any aspect of community-identified priorities, some priorities will likely focus on aspects of sustainability. As stated previously, community and stakeholder engagement is a core element of sustainability science. Specific to sustainability, the University of Minnesota offers undergraduate students a minor in sustainability studies (Institute on the Environment, 2017a) and 17 related majors (2017b). For graduate students, the institution also offers three sustainability-focused degree programs, 11 sustainability-related programs, and five non-degree programs for graduate students (Institute on the Environment, 2017c). The community engagement and sustainability program options at the institution were established to address student demand for the interdisciplinary and transdisciplinary learning opportunities that offer real time and real world experiences for undergraduate and graduate students.

Faculty members maintain relationships with students in the classroom and through research projects, internships, service learning, community engagement, and mentoring. It is important, therefore, to analyze the relationship of students as potential drivers of change in faculty behavior related to issues in sustainability. In addition, as with other factors, student interests might be related to one or more of the seven factors in Figure 1. For example, a student's internship or project in a community – private sector company, non-profit organization, or local jurisdiction – might bring the faculty member,

as the student's mentor or adviser, into community settings where work on a sustainability problem leads to new avenues of research.

International arrangements.

The final factor *international arrangements* could elicit a range of responses by situation. The interviewees might routinely follow research contributions made by teams at institutions in other countries, or work with colleagues in countries other than the United States. He or she might have encountered colleagues through a sabbatical or by supporting a student who was pursuing an international experience. Although, in general, institutions of higher education are increasingly globalizing their research, teaching, and public engagement, some faculty members may report no influence from international arrangements on their work.

International meetings resulting in actions that included international declarations and public pledges for action by institutional leaders were early developments in the overall commitment of higher education institutions and others to address the wicked problems within the sustainability milieu. They include the previously noted *Talloires Declaration,* signed in 1990 (University Leaders for a Sustainable Future, 2017b) and the *Halifax Declaration* of 1991 (Lozano, Lukman, Lozano, Huisingh, and Lambrechts, 2013). These were followed by the *Kyoto Declaration of 1993*, which included a call to the International Association of Universities' (2017), and a number of others (Grindsted and Holm, 2012; Wright, 2002). Institutions in the European countries, in particular, have been at the forefront of actions to address sustainability and are regarded as more advanced in the theory and practice of sustainability than those in the United States

(Gardner, 2011). Kates et al. (2001) specifically emphasize that the scientific communities in the northern and southern hemispheres should discuss institutional capabilities to address sustainability, and that the scientific community overall needs to be connected to the international political agenda.

The interrelated sustainability issues of climate change, biodiversity, water resources, quality of life, and others are not defined by lines on a map, but require collaborative efforts across global geopolitical boundaries. The concept of international engagement is a core element of sustainability science, and therefore, might have an important relationship to faculty behavior. Faculty members in the United States are not bound by geography, and can readily engage with colleagues from other countries via electronic means, sabbaticals and fellowships, conferences, and professional scientific societies. Colleges and universities, too, might have memoranda of agreement or other formal relationships with institutions of higher education outside of the United States. As noted previously, other countries have been more advanced than the United States in pursuit of sustainability research and policy agendas. The desire to seek out colleagues or networks in other countries that have expertise in certain sustainability issues might motivate faculty to change their behavior or approaches to collaboration. The factor international arrangements consequently might have an important relationship to faculty behavior.

Methods

The study uses a qualitative approach following methods detailed by Miles, Huberman, and Saldaña (2014). An extensive literature supports approaches to qualitative data analysis. In *Fundamentals of Qualitative Research,* Saldaña (2011) discusses 14 commonly used genres of qualitative research that are variously distinguished by the approach and the way that the investigation is described. Genres includes ethnography, grounded theory, phenomenology, case study, content analysis, mixed methods research, narrative inquiry, action research, and critical inquiry, among others. In addition, other scholars have addressed the advantages and disadvantages of the pursuit of knowledge development through "generic" qualitative research, an approach that does not align directly with more commonly used genres (Caelli, Ray, and Mill, 2003; Kahlke, 2014).

Even with the range of genres, most scholars agree that qualitative research is a way to understand how people derive meaning from their interactions in the world – how they construct knowledge from their experiences. Merriam (2002) states, "The world, or reality, is not the fixed, single, agreed upon, or measurable phenomenon that it is assumed to be in positivist, quantitative research. Instead, there are multiple constructions and interpretations of reality that are in flux and that change over time" (p. 3).

From my constructivist stance, I refer to Miles, Huberman, and Saldaña (2014) as the guide to my analytical approach for this study. The authors are agnostic in identifying with a particular qualitative school of thought, but refer to their analytic processes as proximate to "ethnographic methods, with some borrowed techniques from

grounded theory" (p. 9-10). The authors' underlying emphasis on finding patterns that emerge from the richness of data – in this case, captured through personal interviews – seemed to be an especially good fit. Miles, Huberman, and Saldaña (2014) describe their stance as:

> "We believe that social phenomena exist not only in the mind but also in the world – and that some reasonably stable relationships can be found among the idiosyncratic messiness of life. There are regularities and sequences that link together phenomena. From these patterns, we can derive the constructs that underlie individual and social life (p. 7)."

To generate a rich and detailed data set, 20 University of Minnesota faculty members were interviewed using a semi-structured protocol. Given the parameters of the study, particularly the setting of a single institution of higher education, the conclusions of the study are likely not generalizable to a larger population. Based on the methodology described below, however, outcomes of the study contribute to a better understanding of the emerging field of sustainability science and its influences on faculty behavior. Outcomes are also the basis for recommendations for further research.

Interview Method

Detailed interviews with faculty members were the source of the study data. Interviews were structured with open-ended questions. I followed Miles, Huberman, and Saldaña (2014) in developing the interview protocol and conducting the interview sessions. I employed open-ended questions to solicit in-depth data collection and a deeper understanding, from each individual's experiences and perspectives, of the issues related to sustainability science and emerging themes (Bean, 2011; DiCicco-Bloom and Crabtree, 2006). The one-on-one personal interview method generates richer data from

each individual than use of a survey instrument or focus groups involving multiple faculty members. Semi-structured interviews are generally characterized by questions that have been determined prior to the conduct of interviews, but are open-ended and allow for follow up and clarification by the interviewer (DiCicco-Bloom and Crabtree, 2006). Bean underscores that:

> "Data gathered from face-to-face interviews for qualitative research have the potential to yield a gold mine of insights into the people's lives and situations. There is no substitute for prolonged and focused conversations between trusted parties to discover what is important to the interviewees and how respondents understand key elements in their own lives." (2011, p. 174).

As Cassell and Symon (2004) suggest, flexibility is a critical factor in conducting qualitative interviewing. The scholars note that interviewees might address topics that are not in the order of the interview protocol, or need prompts from the interviewer. The interviewer must be flexible and yet strive to move through the interview questions with some consistency across all interviews. Cassell and Symon emphasize key elements for successful interviews, including opening with questions that are easily addressed and that do not generate strong reactions or embarrassment. They recommend clear, simply phrased questions that do not reflect assumptions by the interviewer. Wording such as "What, if any, impact did…." (2004, p. 18) is likely to prompt a response from the interviewee that is a genuine reflection of a circumstance or understanding and free from a sense of the interviewer's bias or expectation. I intentionally framed questions related

to the seven factors of influence in a neutral way in order to be open to both positive and negative responses.

Interview Protocol

Faculty behavior is the focus of the study. Key questions posed to each professor are based on the study's conceptual framework (Figure 1). The conceptual framework describes seven factors related to sustainability science that may influence the behavior of faculty members in their work, in areas of research, teaching, and public engagement. The seven factors are new journals, associations, organizations, and networks, funders' priorities, colleagues from other disciplines, stakeholder and citizen interests, student interests, and international arrangements. The responses to questions posed to all 20 faculty members, based on the seven factors, inform answers to the research question: *How do key factors related to the evolving field of sustainability science affect the behavior of faculty members in addressing problems related to the interactions between human and environmental systems?*

I ordered the questions related to the seven factors intentionally, starting with those that focused most specifically on the individual's interactions and decision-making related to organizations. For example, I was seeking each professor's consideration of their publishing choices, their perspectives on their memberships in professional scientific societies and other membership organizations, and ways in which the proposal guidelines of funding agencies and philanthropic organizations might influence their work. In general, these three factors focus on the professors' relationships to existing organizational structures and processes – how they view the plethora of journals and their

respective publishing criteria, how they choose to engage with scientific organizations and with potential funders. The next three questions focused on the individual relationships that likely require a personal commitment and investment of time – the influences of colleagues from other disciplines, stakeholders, and students. Finally, the seventh question about international arrangements elevated relationships and influences to a broader realm of experiences. The progression of questions was intended to start from personal decisions related to the interactions with organizations to personal relationships to a broader global sphere of interactions. One interviewee made sense of the progression of questions when queried about the influence of colleagues from other disciplines, saying: "You know what you nicely did there in your questions? One was about the organizations. The other one was about people. When I went to the organizational question, immediately I said, '[the societies and associations] inform you, whatever.' But then when you asked about people…that's where [the influence] becomes huge!"

In addition to the seven questions that are grounded in the conceptual framework, I initiated the interviews with introductory questions that helped to establish a relaxed, conversational one-hour interview session. Introductory questions included:

- *"What does sustainability science mean to you?"*
- *"Please tell me a bit about your current research related to sustainability."*
- *"Are aspects of sustainability incorporated into your teaching? In what ways?"*
- *"Does your work in sustainability include public engagement? In what ways?"*

The first question was to ground the interview in the focus on sustainability science and allow each professor to proceed from his or her own definition. The questions related to each individual's research, teaching, and public engagement were not only to ground the interview in each professor's work but also to reinforce the sense that I wanted to hear about their work—and their views about the seven factors. Data derived from these three questions also had the potential to contribute to the data that was elicited from the seven factor questions.

Leading into the core questions, I asked:

- *"When did you first start focusing on sustainability?"* and
- *"How has the development of sustainability science as a field of study influenced your work?"*

The two questions related to sustainability refocused the interview on sustainability science prior to following with the seven factor questions.

The intent of these initial questions was to create a relaxed setting for conversation and to convey to the faculty members that I was assuming the role of listener, with keen interest in their responses. My role as research study interviewer was secondary to the shared thoughts of the interviewee, and thus "the possibility is increased that the views of the interviewee will emerge as their voices are freed from the impositional power of the research" (Barbour and Schostak, 2011).

In concluding the interviews, I asked each interviewee:

- *"What influence, if any, do institutional initiatives and/or constraints have on your work in sustainability?"* and,

- *"Is there anything else that you would like to add?"*

The final two questions were not included as part of the core analysis. The two questions again emphasized the importance of the interviewee in providing valued insights and perspectives in the context of the local institution, and offered a final opportunity to collect data that the interviewee regarded as primary from a personal point of view as it might relate to the seven factors. I understood that some faculty members might not choose to comment on institutional constraints on their work for personal reasons.

As stated above, the seven factors related to the emerging field of sustainability science have relationships to one another to some extent. Figure 1 and Table 1, together, demonstrate the connection between the factors that grounded the investigation and the questions that operationalized the factors. Exploring potential responses to questions related to the seven factors of influence and overall attentiveness to the development of the protocol helped to ensure a rich data set for the analysis.

Setting

In this investigation, data were collected from interviews with faculty members at the University of Minnesota. The University of Minnesota has made strides in sustainability research, education, and engagement, particularly through discrete projects and programs. For example, transdisciplinary and sustainability opportunities for faculty, students, and staff members are offered through grant competitions (University of Minnesota, Office of the Vice President for Research, 2017) and fellowships and

Table 1: Interview Protocol

Interviewer's introduction

Thanks so much for making time to talk with me today.

I am interested in your work that falls into the broad area of sustainability. As you know, sustainability science has emerged as a new field of study in more recent years. I'm particularly interested in how the development of the field influences your work.

Before we begin, may I have your permission to audio-record this interview?

OK, I'm going to turn the recorder on now.

To start, I'd like to confirm that I have your permission to audio-record this interview.

Thank you.

Interview questions

What does "sustainability science" mean to you?

Please tell me a bit about your current research related to sustainability.

Are aspects of sustainability incorporated into your teaching? In what ways?

Does your work in sustainability include public engagement? In what ways?

When did you first start focusing on sustainability? How has the development of sustainability science as a field of study influenced your work?

1. **New Journals**

   What influence, if any, do journals that focus specifically on sustainability and sustainability science have on your decisions regarding publication of your work in sustainability?

2. **Associations, Organization, and Networks**

   What influence, if any, do professional scientific societies, organizations, associations, or networks that have a focus on sustainability science have on your work?

Table 1: Interview Protocol (continued)

3. **Funders Priorities**

   What influence, if any, do the program priorities of funders – federal, state, or philanthropic – have on your work related to sustainability?

4. **Colleagues from Other Disciplines**

   What influence, if any, do colleagues from other disciplines have on your work in sustainability?

5. **Stakeholder and Citizen Interests**

   What influence, if any, do external stakeholders and citizens have on your work in sustainability?

6. **Student Interests**

   What influence, if any, do students have on your work in sustainability?

7. **International Arrangements**

   What influence, if any, do international arrangements with researchers, students, or organizations outside of the United States have on your work in sustainability?

Concluding questions

What influence, if any, do institutional initiatives or constraints have on your work in sustainability?

Is there anything else that you would like to add?

Thank you for your responses and for your investment of time today.

programming at six University-wide interdisciplinary centers (University of Minnesota, Office of the Provost, 2017). Sustainability activities include the establishment in 2011 of the Institute on the Environment, an interdisciplinary center under the Office of the Vice President for Research (Institute on the Environment, 2017d); undergraduate and graduate degree programs; the Resilient Communities Project that engages students and faculty in community-identified, sustainability projects (Resilient Communities Project, University of Minnesota, 2017); and ongoing campus-wide and community sustainability developments at the Morris campus in western Minnesota (Goodnough, Kildegaard, Kuchenreuther, Rasmussenand Wyckoff, 2009).

In addition, based on multi-sector collaborations and signature efforts at the University, the institution was a host of the annual meeting of the Association for the Advancement of Sustainability in Higher Education (2015) in October 2015 in Minneapolis. Also, the University was a co-sponsor of the annual meeting of the Citizen Science Association (2017) in the Twin Cities in May 2017. Although not specifically aimed at sustainability science, citizen science is founded on the engagement of the public, in collaboration with scientists, in scientific research—the transdisciplinary tenet of sustainability science.

Data Collection

The University of Minnesota employs approximately 4,000 faculty members across its campuses in the Twin Cities, Crookston, Duluth, Morris and Rochester (University of Minnesota, 2017c). The 20 professors who participated in the study were identified from a cohort of 64 scholars who had been selected as resident fellows by an

institution-wide interdisciplinary center that focuses on interdisciplinary collaboration and broadly on aspects of sustainability. Of the 64 individuals, I excluded those who were no longer affiliated with the institution and those who held appointments within the institution other than tenure or tenure-track faculty. The pool of potential interviewees was reduced to 50 individuals who appeared to have sustainability experience to varying degrees, and who represented various departments and colleges.

The pool of 50 faculty members, representing a range of disciplines, had been named fellows of the interdisciplinary center between 2010 and 2014. All who had been conferred with the title of fellow by the center received funding for projects in conjunction with their responsibilities as resident fellows and were encouraged to participate in center activities without term limits.

Human subjects protection process.

I submitted my research application to the University of Minnesota Institutional Review Board on September 30, 2015. The Institutional Review Board reviews human subjects research projects and assists investigators to ensure adequate protection and informed consent (University of Minnesota, Human Research Protection Program, 2017). The Institutional Review Board is a unit within the Human Research Protection Program of the Office for the Vice President for Research. The Human Research Protection Program strives to ensure the highest standards of research integrity in the work conducted at the University of Minnesota. The Office for Human Research Protections within the U.S. Department of Health and Human Services provides guidance for protection of the rights, welfare, and wellbeing of subjects involved in research.

The Institutional Review Board's Human Subjects Committee on October 30, 2015, determined that this study was exempt from review under federal guidelines 45 CFR Park 46. 101(b) category #2 (Appendix).

Pretesting.

Following approval by the University of Minnesota's Institutional Review Board, I conducted two pilot interviews with individuals within the pool of possible interviewees. I informed both individuals that I was conducting interviews using the Institutional Review Board-approved protocol, but that I would not be including data from the pilot interviews in my study. I specifically requested their feedback, as pilot interviewees, on the interview protocol so that I could ensure that it was an effective instrument to elicit detailed, data-rich responses from participating faculty members. I asked: Were the questions clearly stated? Did the order of the questions provide a logical progression of the overall topic? Could they offer general or specific comments on ways that the protocol could be improved to capture detailed responses from interviewees?

Based on points made by both pilot interviewees, I modified the interview questions slightly, specifically for clarity. I made no changes to the content of the questions. After notifying the Institutional Review Board of modifications and receiving confirmation that the information had been added to my study file on December 17, 2015, I began scheduling faculty interviews.

Interview process.

I sent email invitations to potential interviewees. To promote diversity in disciplinary perspectives among the interviewees, I initially extended interview

invitations to 36 individuals of the 50 potential interviewees in clusters rather than simultaneously. The clustered approach helped to ensure that I was able to confirm interviewees from a diversity of disciplines, as well as gender, before multiple people from similar disciplines all responded. I wanted to ensure that individuals from disciplines that might be regarded as having a stronger affinity to sustainability science were balanced by those from disciplines that might be regarded as further removed from a sustainability focus, such as the humanities.

Of the initial 36 invitations, 26 faculty members replied with their willingness to schedule an interview; 10 individuals did not respond. Of the 26 affirmative responses, I promptly scheduled 20 interviews; five people who indicated their interest in participating in the study encountered schedule conflicts that pushed their availability beyond the time parameters of the study, and one invited faculty member left the institution during the invitation period. Due to my process of clustered invitations, I had confirmed a relatively balanced group of 20 interviewees, and so I did not invite for interviews 14 of the total 50 possible faculty members. In addition, one individual who was confirmed for an interview chose not to proceed at the onset of the scheduled interview for reasons, and I returned to the list of respondents who gave affirmative responses. I confirmed a twentieth interview with an individual whose disciplinary background complemented the selected group and was able to participate within the timeframe of the study.

Following affirmative replies, I scheduled interviews of approximately one hour with individuals in their offices or other convenient locations of their choosing. I

confirmed the date, time, and location of the interview with each faculty member via email, and attached the consent form to the email so that interviewees could review the form prior to the interview. Although the interviewees had received a copy of the consent form by email before the day of the interview, I brought a printed copy of the form to the interview, asked if the individual had any questions or concerns about the content of the consent form, and asked the individual to sign and date the consent form before I conducted the interview.

I opened each interview session with a consistent and brief statement of my general research interests and data collection process, and assured the confidentiality of the discussion and my intent to protect the identities of the interviewees (Barbour and Schostak, 2011; DiCicco-Bloom and Crabtree, 2006). I used the interview protocol presented in Table 1 consistently for each interview. After each interview, I sent a note of appreciation to each interviewee, with a copy of the signed and dated consent form attached, which I had also signed as the researcher.

I recorded the interviews with a digital audio recorder, and uploaded files to my computer. I employed a professional service to transcribe all interviews from the recordings, and spot-checked the transcriptions against the audio recordings. I also conducted a review of the printed transcripts, and made corrections where discrepancies or misinterpretations had been introduced and where the transcriber had included queries in the transcription text. Data and information related to the study were stored securely, as required by the Institutional Review Board.

Analytical Approach

Following the interviews and the correction of any misinterpretations that had been introduced into the transcripts, I launched into the first and second cycles of the analysis. At this stage, Miles, Huberman, and Saldaña (2014) issue the reminder that words are the data. They state, "So we are focusing on words as the basic medium and are assuming that the words involved have been refined from raw notes or recordings into a text that is clear to the reader or analyst." The first cycle of coding categorized interviewee responses by their relevance to the seven factors of influence as well as to topical questions that provide context but are not part of the study.

With the understanding that coding, per Miles, Huberman, and Saldaña, is a process of "data condensation" (p. 73) that brings key points of information into a more meaningful focus, I proceeded to the second cycle, pattern coding. Pattern coding, according to Miles, Huberman, and Saldaña (2014), is the process of refining the categories from the first cycle of coding into another set of categories that lead to the emergence of themes. I categorized responses to the seven factors of influence as positive, negative, or qualified. I also further categorized responses that focused on why an individual's response was positive, negative, or qualified. For example, if professors said that the newer journals that focus specifically on sustainability science had no influence on their decisions on where to publish, I categorized the data (based on respondents' explanations) as a preference for disciplinary journals, their desire to reach a particular reading audience, or other categories. The refinements to the second cycle of coding resulted in the themes that led to the conclusions from the analysis.

In my final step, I employed what Miles, Huberman, and Saldaña (2014) refer to as "magnitude coding." Magnitude codes are applied to existing categories of data "to indicate their intensity, frequency, direction, presence, or evaluative content" (p. 80). The professors frequently did not respond with a direct yes or no answer to the seven core questions posed during the course of the interviews. Work focus, personal goals, circumstances, and personalities, for example, contributed to responses that were nuanced, thoughtful, and often couched in caveats. For the purposes of the analysis, however, I consistently describe the seven factors of influence presented in the conceptual framework by the following general descriptors: *very strong,* with close to all responding positively; *strong,* with about three quarters of positive responses; *moderate,* with about half responding positively; *weak,* with very few positive responses; and *no influence,* with no positive responses. I have used these terms judiciously in order to convey some noteworthy consistencies among the responses from the cohort of 20 professors, but to avoid implications that cannot be substantiated by the data.

The professors' responses were taken verbatim from the transcripts of the audio-recorded interviews. I have taken steps to protect the identity of the 20 faculty participants. I have restated references or phrases within the quotations that might identify the interviewee in a generic way that is intended not to detract from the content of the information being quoted. Generic restatements appear in brackets. When critical to the sense of an individual's key point, I provide a general indication of the information to ensure that respondents cannot be identified. Ellipses indicate where text in a lengthier response was omitted, for clarity and focus. Conversational idioms used by interviewees

such as *ummm, you know,* and *like,* for example, have been omitted with the intent of improving the readability of the quotations.

The next chapter presents the results of the analysis of factors influencing faculty behavior in the context of the evolving field of sustainability science.

CHAPTER 4

RESULTS

This study investigates the research question: *How do key factors related to the evolving field of sustainability science affect the behavior of faculty members in addressing problems related to the interactions between human and environmental systems?* The research question is premised on the assumption that faculty behavior is critical to the emergence of a field of science. Scholars suggest that faculty members, rather than academic institution leaders, are the change agents (Pittman, 2004; Miller, Muñoz-Erickson, and Redman, 2011) who can infuse sustainability science more broadly into research, teaching, and community engagement.

This chapter presents findings from interviews with 20 faculty members, representing a range of disciplines, who are affiliated with a university-wide interdisciplinary center. It includes a description of the study participants, the findings related to the seven factors of potential influence on faculty behavior, the respondents' perspectives on sustainability science, and discussion of the five themes that emerged from the analysis.

Study Participants

Faculty members at the University of Minnesota representing a spectrum of disciplines were interviewed for the study. I identified the participating 20 professors from a pool of 50 individuals, as described in Chapter 3. Of the 20 individuals I

interviewed, 12 present as male and eight as female, and range in age from their 30s through 60s. In addition, 14 are full professors, five are associate professors, and one is an assistant professor. General disciplinary categories of participants are: six in biosciences (broadly includes fields in agriculture, biology, and ecology); six in the social sciences, arts, and humanities (broadly includes communications, economics, education, design, geography, and literature); three in engineering fields; three in regulatory fields (including law and public affairs); one in health sciences; and one in physical sciences.

Perspectives on Sustainability Science

The interviewees frequently used *sustainability science* and *sustainability* interchangeably. In general, the interviewees' perspectives appeared to align with the definition of sustainability science as "a field that integrates study and practice, focuses on the interactions between environment and development, and performs use-inspired research to promote the goals of sustainability (Matson, Clark, and Andersson, 2016, p. 199). Many interviewees addressed the complexity of agreed-upon definitions for both terms, as discussed below. The discussion of results is predominantly couched in the research milieu. Research was most frequently cited in responses, but not to the exclusion of teaching and community engagement. In fact, responses clearly acknowledged the interrelated elements of teaching, research, and engagement in the academic setting.

I asked each faculty member at the beginning of each interview, "*What does sustainability science mean to you?*" The opening question was used not only to promote

a comfortable question-and-response session, but also to create context for the questions relating to the factors of influence. The responses from interviewees provided insights into the ways that these individuals think about the field of sustainability science and its relationship to their scholarly work.

Most of the professors initially commented on the challenge of defining sustainability science. Some chose to focus more broadly on the meaning of sustainability, viewing sustainability science as use-inspired research that addresses sustainability issues. One professor, for example, conveyed the need for a definition and yet was not troubled by a perceived lack of distinction between sustainability and sustainability science:

> "I spent a lot of time on this question [of the definition of sustainability science] because I teach classes in sustainability here. And I want to find accessible readings for my students to give them this definition. In fact, yesterday I saw that one of the editors for *Scientific American* tweeted out, 'What does sustainability mean to you?' It's something that I think a lot of people have an intuitive sense for what it means. It's making the world a better place, if you will, and that's inherent in the definition of the Brundtland Commission [the United Nations report of the World Commission on Environment and Development: *Our Common Future* (1987)] and many of the other groups that have worked at this – to maintain the same opportunities for future generations that we have today; to do so in an equitable way that looks at the economic, environmental, social aspects of problems that the world faces.
>
> I guess I personally haven't been so concerned with the distinction between sustainability and sustainability science, other than sustainability science is meant to provide some sort of quantitative or empirical measurement of what sustainability might be, and however one might define that. In some ways, it's very easy to define, and in other ways it's very complicated. One of the more memorable things that happened to me when it comes to thinking about the definition of sustainability: I was in Japan, and I asked somebody there what sustainability was in Japanese, and he wrote it down for me, and it literally translates to 'Maintain possibility.'"

Another professor commented, “I don’t think I have a good answer [as to the definition of sustainability science]. So, I would say that sustainability science would be science that’s devoted to understanding how humans can live on the planet for a longer period of time and with minimal impacts on the environment and on their own well-being.” Another noted the challenges of defining sustainability, even before moving to a definition of sustainability science: “Sustainability is actually a term that I always have a lot of trouble with. I think sustainability can mean anything. . . . Certainly [in] all the various definitions of sustainability, you need a mix of science and policy and law and markets as well as in developing technologies.”

Many professors emphasized the interdisciplinarity inherent in sustainability science and sustainability. One professor stated, “Sustainability science . . . should be thought of in an interdisciplinary sense: a science study that draws from different disciplines but with the focus on how to achieve a balance in the human-nature relationship as it evolves.” From a humanities perspective, one professor said, “I think one of the things about sustainability, even more so than many topics, [is] it requires that interdisciplinary team approach. . . . There’s no way that these issues can be studied purely from one specialized perspective and really be understood.” A researcher whose work has not been bound by definitions added:

> “I haven’t followed all of the history of the definitions that have come down the pike, so I’m pretty loose in my use of the word ‘sustainability.’ I think I have been influenced by some of the folks who are having that conversation . . . about the need to have co-generation of knowledge across the disciplines. As somebody who’s been involved in really interdisciplinary projects, I think that’s been something that I’ve found particularly challenging. . . . That’s the hardest thing, I think, to work across disciplines.”

The majority of interviewees are well-versed in sustainability science, but said that they would not refer to themselves as sustainability scientists if asked about their research focus. One respondent said,

> "I think sustainability science is a meta-concept that can help organize assumptions about interdisciplinary collaboration, and even transdisciplinary. I think it's well-known enough now where, in urban ecology, researchers will say how it relates to sustainability science. It's that big touchstone that a lot of different disciplines know. Whether everybody calls themselves a sustainability scientist is another thing. But in terms of a knowledge base and assumptions of problem solving that should be interdisciplinary and collaborative and address real world issues, I think there's a set of people that will always say how a specific discipline might relate to something broader, and sustainability science is that. A lot of disciplines fit under [sustainability science]. [Sustainability science] can be hard to nail down, but when it's specific towards interdisciplinary collaboration and the boundaries are specific, it can be powerful."

Many scholars were not concerned by the absence of a consistent definition of sustainability science, but spoke more specifically about the elements that it encompasses. Some noted the transdisciplinary aspects of sustainability science – the importance of voices on policy, culture, and economic viability. A professor said,

> "[Sustainability science] is going to involve all areas of science, depending on the problem being tackled. I guess the thing that always throws me is we call it *science;* it's so much bigger than science. It's got to involve social scientists, policy makers, so it's bigger than science."

One interviewee also emphasized the importance of expanding approaches to problem solving beyond science:

> "You know, science is always incomplete, but for some of these problems we're only learning to ask the questions. But if we do have to take action, you need to invoke the political process. Those twin ideas [of science and policy] have been around for a while, before sustainability science, and they got woven into it. So absolutely, for large, potentially high-risk, high-impact endeavors, in the absence of any good scientific understanding or limited scientific understanding, you need to invoke the political process."

Some professors specifically highlighted the importance of community engagement, a core element of sustainability science. One reflected on the problems identified by members of local communities:

> "When I look at sustainability science, I've seen it from so many different perspectives – from the remote communities that I have spent so much time with. What they are worried about is how they can sustain their life in the future based on the ever-changing environment, which is pretty dramatic in the areas where I have been."

Human-environment interactions are frequently linked to social justice issues in communities. A researcher described the value of sustainability science in integrating social and environmental issues:

> "I think there's a lot in sustainability science that owes itself to the [risk hazards] world without necessarily recognizing it as such. [Risk hazards] had to be understood as very often the collision between some kind of natural event and a social system, and once that door is opened . . . like [hurricane] Katrina, for instance – 'Oh, this is this terrible natural disaster.' Well, no. Absolutely, there was a natural component to it, but clearly race and class and all these other things entered into who was affected by it. I think a lot of risk hazard work underlay those ideas, and those works got imported into sustainability science. . . . I think that [engagement of stakeholders] was a key element to [the emergence of sustainability science]."

Interviewees also addressed the problem-solving or action element of sustainability science. As one scholar said, "One definition we use for [sustainability science] is use-inspired basic research. So, it's fundamental research that's inspired by problems and the need to address them and solve them." Another reflected, "[Certain recognized] programs are much more embracing of this idea of translating knowledge into action. I think that there's a group of people – sustainability scientists, I guess you would call them – that are much more comfortable just moving into that realm of translating knowledge into action, and not hesitating because they're worried that the

science that they do will be biased or lack impartiality." A respondent succinctly described three hallmarks of sustainability science, including the focus on action:

> "I see the main tenets [of sustainability science] being, one, a recognition of the value of a wide range of knowledge sources, certainly extending well beyond the academy. The other critical tenet, I think, is a commitment to a holistic or systemic framing of research agendas. And then the third . . . is a strong commitment to supporting action on complex sustainability issues. Sustainability science very directly aims to address wicked problems."

Some individuals commented on the longevity of sustainability science, from both an historical and future-oriented view. A professor said,

> "Sustainability science, I think, is a very old discipline even though it's probably hard to define sustainability as a discipline itself. As an engineer, I can tell you that this idea of sustainability has been around forever, since probably the time of Leonardo de Vinci. The definition of sustainability and how to do it, the methods for pursuing the idea, is much more recent. Right now we talk about sustainability science because we want to push that as a science itself. And it is very reasonable, and necessary because whenever we try to restore or to design a new system, any action that we make has environmental, social, and economic impact. I am very glad to see that people from different disciplines are actually really trying to push sustainability as a quantitative sustainability science in which there are methods, there are practices that are observed."

Some movement away from the focus on sustainability toward resiliency is occurring among a small percentage of scientists who have been working on sustainability issues. The transition is based on the view that the earth has surpassed the status of sustaining resources to a focus on strategies to support populations by managing remaining resources in a more effective and long-term way. A respondent reflected:

> "There are some scholars who have argued that sustainability is dead, and that we should really be thinking about resiliency. I don't think that's right. I think that one can have an adaptive notion of sustainability. I think that what they are debating about is what word we use to talk about an evolution that's happening, but I think the word sustainability could be used in that way."

A researcher speculated on the evolution of sustainability science as it becomes infused in existing disciplines:

> "I think the underlying ideas [of sustainability science] will continue. I think you're looking at trappings like sustainability minors on campuses, for instance. . . . I think you're still seeing a growth in [sustainability emphasis in] departments, and institutes. . . . In the business world, you're seeing growing numbers of vice presidents for sustainability and so on. I think you are going to see those continue. In some ideal world, [sustainability science] becomes so ubiquitous that it almost would be submerged in other disciplines. Sustainability would be a part of ecology, part of geography, what have you, but that probably wouldn't happen for a while, I would imagine."

The interviewees were largely consistent in their understandings of sustainability science as strongly interdisciplinary and with an action focus toward addressing complex challenges. Several noted the strength of sustainability science in its integration of cultural perspectives, local knowledge, and policy with the sciences. They viewed sustainability science as a useful framework for approaching interrelated issues, although noting that a specific definition is elusive. Even with the variety of interpretations, most interviewees saw a continuing evolution of sustainability science, noting that it will continue as a strategy for addressing the grand challenges of societies.

The 20 professors described the variety of ways that they incorporated sustainability science into their research, teaching, and public engagement. Examples were detailed and personal. I have not reported responses to those questions here to help ensure that the interviewees cannot be identified through descriptions of their work; however, key points made during the discussions of research, teaching, and public engagement that are related to the seven factors of influence are incorporated into the findings section below.

Findings Related to Seven Factors of Potential Influence

The seven core questions that are derived from the influencing factors in the conceptual framework were posed to the 20 participating professors in the order that they are presented in the conceptual framework (Figure 1). I describe the findings specific to each of the questions in the seven sections below.

1. New Journals

As noted in the preceding chapter, a *Web of Science* database search (Thompson Reuters, 2017) showed that there are about 947 journals that publish articles relating to aspects of sustainability, more specifically focusing on the integration of environmental, social, and economic sustainability. New journals and spin-offs of existing journals also target sustainability and sustainability science. With the range of options for publishing studies, it is informative to understand how the interviewees describe the influence that journals have on them, and, importantly, the influence that they wish to exert through their published work.

The first question related to the seven factors that was posed to the interviewees was: *"What influence, if any, do journals that focus specifically on sustainability and sustainability science have on your decisions regarding publication of your work in sustainability?"* A majority of the 20 interviewees responded that the newer journals that focus specifically on sustainability or sustainability science do not influence their decisions on where they publish their work. The professors commonly used audience and visibility as key criteria for their decisions on where to publish their work. Three individuals stated that the newer sustainability science-focused journals do influence

publishing decisions, and two provided alternative responses to the question. Notably, several professors articulated dual goals of publishing in their disciplinary journals and in elite journals that have an inherent interest in complex, interdisciplinary issues, a hallmark of sustainability.

The majority emphasized the importance of publishing in the elite journals for reasons of audience, impact, influences across broader reaches of science and media, and prestige. In some cases, professors held an underlying view that the elite journals are more receptive to papers relating to sustainability. Repeatedly referenced were the *Proceedings of the National Academy of Sciences* and its section *Sustainability Science, Science, Nature* and various *Nature* journals.

Publishing criteria.

Eight of the interviewees described criteria other than the availability of sustainability journals for making publication decisions. One professor said,

> "There are several factors that we consider. One is who the audience is that we want to reach, and we definitely pay attention to impact. I think those are the two main criteria. . . . The top journals [are] still *Science* and *PNAS* [*Proceedings of the National Academy of Sciences*]. *Nature* now has divided, so it's got *Nature Climate Change* and all these other *Nature* journals. Those are definitely a really important venue, I think, for sustainability-related articles. . . . I try to publish in both interdisciplinary journals like [*Science*], and in my disciplinary journals."

Another sought journals – but not necessarily newer sustainability journals – whose decision makers are attuned to sustainability and the wicked problems that challenge societies:

> "I obviously want to publish in as impactful a journal as I can. I definitely would say I've had more luck in journals where the editors and the reviewers have some understanding that the world's problems are going to have to be addressed. And

> that by integrating a number of difference perspectives – that's just what I believe and show through in my research – that's where I'll be the most successful."

One scholar described the goal of achieving high visibility through journals that are interdisciplinary venues for research articles: "I and my collaborators certainly do disciplinary work that we send to disciplinary journals, but more broadly, the challenge is to publish things in places where they will be seen, and where ideas will gain credibility. This is what pushes us towards the elite journals."

Another researcher expressed similar goals:

> "I choose what I want to do if I have important findings to get out to the public. The journals that make their way into the media are basically *Science, Nature, PNAS* [*Proceedings of the National Academy of Sciences*], and maybe [*Proceedings of the Royal Society*]. Those are the ones I want to publish papers in. If I publish them in any other journals, I'm only talking to the scientists I already know."

Listing priority publication criteria, a professor said, "I like to publish where I think I have an appropriate audience, and then I also consider the prestige of the journal, or the impact factor. Also, [I consider] the price and whether it's open access or not." Another said,

> "For me, it's the rigor of a society journal and the rigor of a scientific editor, a practicing scientist, and its editorial board that has scientists. That's number one. Number two is the impact of the journal, that is, the profile or the stature of the journal. Third is the topic, what the journal publishes . . . . I've published in maybe five journals consistently, only one of which has the word *sustainable* or *green* in the title."

One researcher simply stated, "Sustainability science is probably not a factor for me in deciding where to publish. There's a subject matter dimension and a prestige dimension." A professor working in areas of policy addressed publishing criteria for books and monographs, noting that the goal is to seek the leading presses in the field.

Several interviewees viewed what some might consider disciplinary journals to be inherently focused on sustainability and sustainability science, such as those relating to ecology, geography, landscape architecture, land use planning, and others. One professor underscored a point that appears to be a tacit thread running through almost all the responses: sustainability is so widespread that it is incorporated into numerous existing journals to varying degrees.

Disciplinary perspectives.

A portion of the interviewees who said that sustainability-related journals have no influence on their decisions for submitting articles to journals cited disciplinary orientation as their publishing priority. Many professors indicated that publishing in their disciplinary journals, either from habit or from personal and professional relationships in their disciplinary communities, continues to be important. Many respondents also referenced the structure of academia and its collegiate and departmental divisions that uphold disciplines and the disciplinary work of their faculty members. Having affirmed the importance of disciplinary journals, however, all noted their respective disciplines' relationships to sustainability, their desire to publish in journals beyond their discipline, or their interest in publishing in other types of journals with co-authors. One professor said, "I tend to publish in a lot of law journals . . . or write a book chapter for edited volumes. . . . Some of these law journals are environmental-specific journals." The professor added, "[I would publish in sustainability-related journals] particularly if I was co-authoring with someone who was more on the science side." Another described

journals that can be perceived as disciplinary but that are oriented toward sustainability science:

> ". . . when you're in the tenure track and going for full [professor] . . . you have to [publish in disciplinary journals] or in substantive things like the *Journal of Land Use Science* and so on, which, I'd argue, is actually very sustainability informed . . . *Global Environmental Change* . . . *Ecology and Society,* which is one of the first big online [journals], is essentially sustainability science now, or *resilience*. And there's that U.N. [United Nations journal], *Ecosystem Health and Sustainability*."

One researcher also described disciplinary journals that have an affinity for sustainability articles. The researcher noted the personal goal of reaching more diverse audiences:

> "Part of what drives my decision of where to publish, for good or for bad, is expectations to publish in journals in my discipline. The professor added, "…Urban planning journals have been a place that's been receptive to sustainability work. I think it's core to the field. The *Journal of Planning Education and Research* is one that has published a number of things related to sustainability….As I've done more of this cross-disciplinary work, I've spread out a bit more, and we've written in journals that relate to the range of disciplines that we have represented in our team. Some are more environmental. . . . Early on in my career, I wanted to target planning. I don't care so much now. I think it's easier to justify publishing in some of these other places and especially places that are more oriented to a broader disciplinary audience."

The strong pull of the disciplines does not necessarily change, even with the flexibility that comes with tenure. An interviewee reflected on the disciplinary structures of higher education institutions:

> "I think [where we publish] is telling of some things that we need to be changing. I publish in the top disciplinary journals in my field. I don't try to reach among people outside of environmental engineering with my scholarship, and I do that because of the rewards in academia. I'm in the position where I probably shouldn't be doing that anymore, but, you get into the system and that's what you do."

Students also can be affected by disciplinary constraints. A respondent expressed concern for students who choose to pursue sustainability science interests, perhaps forgoing career benefits that are derived from the traditions of the disciplines and disciplinary journals for their publications. The respondent said,

> "Students in [my discipline] get credit if they publish in [disciplinary] venues . . . If you have a paper in [the disciplinary high-impact journal], one or two papers there, the Facebooks and the Googles will be after you. It's super-prestigious . . . One of my students did a lot of work on [a sustainability project]. He went to interview at Google. Google said, 'We'll hire you. We don't care that you have not done anything of interest to us, but what you have done is a lot of good, interesting computation.' So, these things are happening, but I still get nervous for [the students] so that they stay competitive in the [disciplinary] market."

Expanding the audience.

A subset of the interviewees who stated that the new sustainability and sustainability science journals did not influence their decisions on where to publish their work, nonetheless, described their expansion, or interest in expanding, to interdisciplinary journals or those with a sustainability perspective. Their interest appears to be based on a desire to reach new and broader audiences rather than a singular goal of publishing in an elite journal. One scholar said,

> "[Our group is interested in journals] that are at the intersection of natural sciences and social sciences that are cognizant of the fact that people and environment actually do relate to each other, and that we should be doing research that tries to understand that coupling interaction. We've talked about journals like *PNAS* [*Proceedings of the National Academy of Sciences*] as a potential target but haven't had the right thing yet."

A professor focusing on big data analysis also expressed enthusiasm for opportunities to publish in journals that can be viewed as unrelated to the professor's discipline:

> "We published a paper together with [an ecologist] – and my students did most of the work. The next set of papers we are doing with [the ecologist's] post-docs,

> we are going to send to [a plant science journal] . . . because the editor is interested in getting these papers. [The journal] reached out to us."

Collaborations with colleagues from other disciplines can lead to opportunities to publish in multiple journals outside the researcher's core discipline. One researcher anticipated where the results of an engineering-social science collaboration might be published. The researcher said,

> "I have a colleague who's a biologist, and we've done some really nice work. I love working with other people that have other areas of expertise, and I think that those papers are more fun . . . they're blended. That work we published in a toxicology journal. That was, again, disciplinary, but a different group of people. I'm working now with an economist, and it will be interesting to see where that work [gets published]. I think that we could try to get that out a little bit more [to a broader audience]."

Sustainability influences.

The newer sustainability science journals have only a weak influence on the cohort of interviewees overall, but are regarded by a small number of researchers as an option, in certain circumstances. Three of the 20 interviewees described sustainability journals as a factor that influenced where they publish their papers. One respondent had published in a newer journal, and another had published multiple times in the sustainability science section of the *Proceedings of the National Academy of Sciences.* One professor said,

> "I think that's how my work is extremely different . . . . my areas were mainly technology journals and environment/geography-related journals. And that's probably some of my biggest [publication] influences, these areas of geography and sustainability education. I'm publishing in journals, not only here in the U.S., but in Australia and in Canada. In fact, [a newer sustainability journal] was one I was just published in, so I'm transcending a number of different audiences . . .

Another viewed sustainability-science journals as a venue for the respondent's work, depending on the research topic and the journal editor's criteria:

> "[I publish] in journals that are landscape related. Sustainability is important in all of those – *Landscape and Urban Planning, Landscape Ecology, Urban Ecosystems* . . . . It all kind of depends, if there are those who are really trying to address sustainability science as a knowledge area specifically, then *Sustainability Science* would be one [to consider for a publication]. But there are journals that are systems oriented, and some of it depends on the editors and what they want, and readers."

The third interviewee considered a long-standing, prestigious journal as a sustainability science option for publication, a journal that many of the interviewees had referenced:

> "The [journal] that I know most about . . . is the *Proceedings of the National Academy of Sciences*. They have a sustainability science section, and . . . most of the papers that I've produced that get published [in the *Proceedings of the National Academy of Sciences*] go into the sustainability science area."

Two of the 20 interviewees provided alternative responses to the question of the possible influence of journals that focus on sustainability and sustainability science. Both however, emphasized the increasing pervasiveness of sustainability, including across disciplinary journals. The pervasiveness of sustainability science is likely a key reason that the interviewees have not identified a need to publish in the newer sustainability journals. The professor said,

> "The section [*Sustainability Science*] in the *Proceedings of the National Academy of Sciences*] is a great section. In my opinion, even if you have a science that we call sustainability science, you don't necessarily need a journal in sustainability, because this idea of sustainability science is actually widespread, all over. Even the National Science Foundation and the National Institutes of Health are talking about sustainability. And the people that are editors and associate editors of journals are really trying to embrace that concept."

Aa a number of scholars noted, some journals appear to be publishing more interdisciplinary work related to sustainability science. The acceptance guidelines can be

unclear, however. One scholar described circumstances relating to the perception of sustainability held by some journal editors:

> "We're starting to run into some interesting spaces with [publishing]. The more interdisciplinary you get, the less sometimes something seems to fit. When I think about the big journals that I would traditionally publish in, they all use 'science.' They're the *Journal of Research in Science Teaching,* the *Journal of Science Teacher Education,* the *International Journal of Science Education.* If you deviate too far from the science, you'll be told, 'Oh, I don't know if that fits in our journal.' Climate change has not been a problem. Climate change seems to be very firmly anchored, and people don't have a problem with that. As you get more of science education embracing the notion of these socio-scientific issues . . . it really starts to look like social studies [to some journal editors]. . .

Conclusions related to *new journals.*

I conclude that the factor new journals has a weak influence on faculty behavior. Although the majority of interviewees, no matter their disciplines, were familiar with the newer sustainability and sustainability science journals that are seeking content, no one indicated that these publications had an influence on their publishing decisions. Many did, however, reference the prestige, visibility, and influence of *Proceedings of the National Academy of Sciences,* an elite journal that was established in 1914 but that added a sustainability science section recently.

The interviewees, in general, said that sustainability and sustainability science are increasingly permeating highly regarded journals, and viewed the change as a positive development. Subsequently, newer journals that focus on sustainability science and sustainability in title and content may not have significant impact and influence – except for researchers who are publishing studies that specifically address the evolution of sustainability science; its epistemologies; methods; and action-oriented, transdisciplinary strategies and objectives. The individuals that I interviewed publish research related to

specific sustainability issues at the intersections of environment, economics, and society rather than research related to the foundations and emergence of the field of sustainability science. As any emerging field develops, however, related journals are one characteristic of growth and momentum.

2. Associations, Organizations, and Networks

The second question posed to the interviewees was *"What influence, if any, do professional scientific societies, organizations, associations, or networks that have a focus on sustainability science have on your work?"* About half of the 20 individuals responded that scientific societies, organizations, or associations had no influence on them or the way they approached their work. Other respondents noted varying levels of influence by formal societies and associations, and five especially described strong influences of informal networks.

Lack of interest in organizations.

Of those who said that professional scientific societies, organizations, and associations have no influences on their work, a common response was that the individuals simply did not have an interest in participating in scientific organizations. One professor said, "I've never been one who's been big into societies. It would probably benefit me more, but it's just never interested me a whole lot to spend a lot of time in that area. I know they are tremendously important and serve a lot of people really well. I haven't really spent a lot of time with societies; in fact, I'm not even sure I'm a member of any society, to tell the truth. It's just who I am." Another noted, "I can't

think of an instance where a professional society had much to say about what I've decided to work on or had much influence on that."

A possible reason for the lack of interest in professional scientific organizations from many scholars might be the generally strong disciplinary focus of most scientific societies and subsequently the lack of appeal to scholars pursuing sustainability issues and other interdisciplinary work. One professor, for example, cited interests in interdisciplinary work as a mismatch with societies that are more discipline-oriented:

> "I think for most people, [professional scientific societies] have quite a lot [of influence on their work], and it has less than it should [on mine]. . . . I'm very interdisciplinary. . . and so because of that, [I] don't find myself at home in any given association. It's kind of like Joseph Campbell when [Bill] Moyers asked him, 'So, do you believe in God,?' and he said, 'I believe in all of them . . . .' It is, for most of the people that go [to professional scientific society meetings], the center of their world and where they get their enrichment and where they're in conversation, and that is how most academics should be done. But if you're doing the interdisciplinary approach, you probably are always going to be only one foot in that [society] . . . ."

Another researcher provided a similar sentiment, saying, "I have not invested very much in scientific societies; I've not been a good citizen of science in that sense in my career. And it's, I guess, partly just because I've been interested in exploring this kind of transdisciplinary space." A subset of those who said that professional scientific societies had no influence on their work said that they simply had no personal interest in societies or had not considered such a relationship with a scholarly organization.

Two interviewees found that highest value comes from engaging with an individual one-on-one rather than from larger group interactions. A publicly engaged scholar stated that societies had no influence on him because "they are not where I find my richest venue for thinking about working as much as talking to [members of a local

non-profit organization] or others in that critical praxis – critically engaged practitioners whose theory rises out of practice and practices, and has something to do with theoretical consideration." Another responded with a personal caveat: "I think people operate in different ways . . . . Thankfully, I have some very good collaborators in the areas that I'm working on. I think they have heavily influenced my thinking. My influences come from . . . a person. I'm not very good with big groups and gatherings."

For the other half of the interviewees, the influence of societies came from the opportunity to interact with colleagues across the field and learn about new research. Some noted the energy that comes from collaborating with colleagues on white papers and other scholarly partnerships. Others noted the influences of their professional scientific societies through the contributions that their societies have made by emphasizing various aspects of sustainability science and incorporating sustainability into their respective disciplines.

Of those individuals who described professional scientific societies as having a positive influence on their work, a professor with broadly intersecting interests, including public health, has extended a focus on interdisciplinary work to participation in multiple societies:

> "The role of the [professional scientific] societies was fundamental for me because I was able to come to the table with scientists that I was not used to collaborating with. I belong to [two very different disciplinary societies]. Both societies are trying to promote sections about sustainability science as a science itself and have discussions about the methods that we should use. I believe, to create a new science, you need to have methods which come from mathematics. The Ecological Society of America is also trying to promote mathematical methods that allow us to have the science attached to sustainability."

Others describe the benefits of scientific society participation through meetings, volunteer work on committees, and networking opportunities within a discipline. One scholar described the strong influence of professional societies, saying,

> "It's very energizing to work with other folks who are in the environmental and energy and natural resources . . . fields, and we write white papers and op eds and collaborate on scholarly work. [The annual meetings are] a great place to get ideas, new ideas for research and just have people to collaborate with and to get our work out to a broader audience."

Another described professional scientific societies as "a great place to network with my colleagues and also to get updated on the research that's going on – a pretty important thing." One respondent referenced the Ecological Society of America and its past leaders as "being more explicit about ecologists informing sustainability efforts and sustainability policy and doing research that was relevant to sustainability issues through the SBI [Sustainable Biosphere Initiative]," and added, "My roots are definitely very much in the Ecological Society of America and its tentacles and its networks."

Value of informal networks.

Informal networks emerge as a key element of sustainability science, based on this analysis. Several individuals especially emphasized the importance of informal networks, distinguishing them from scientific societies and associations. Some described, with enthusiasm, their preferences for informal networks rather than traditional scientific societies. The networks that professors described are interdisciplinary rather than disciplinary, and function at the local, national, and international levels. More than one interviewee commented that the work of sustainability science will be advanced through informal interdisciplinary networks, and emphasized the importance of

cultivating such networks now and for upcoming scholars. A professor with a similar perspective expanded the characterization of networks by their increasing breadth and the incorporation of sustainability science elements. Some suggested that it will be through these networks that projects based on sustainability science emerge.

A scholar with a strong interest in engaging community partners, said,

> "I would say that being in interdisciplinary networks, if not transdisciplinary networks, has been enormously influential to me . . . . I've been a faculty member for 30 years, and I've spent many of those years blindly, or very myopically, groping my way towards those kinds of networks. I have reached a point where I have one now, and it's very necessary as we think about sustainability science.
>
> [Sustainability science] will be done in networks. [It] is very much a team [effort]; it's an emerging property of networks. Having a network like that takes a long time to develop. I think we can help younger people understand how to take less time than older people have taken [to develop networks]. The cultivation of those kinds of networks is, I think, an important topic."

Another professor highlighted the multiple networks of scholars that have been spawned through the sustainability science section of the *Proceedings of the National Academy of Sciences,* and echoed the question raised at a related convening of whether a sustainability science society would be necessary to the maturation of this emerging field. The researcher stated:

> ". . . networks have been incredibly influential. . . . There was a meeting that was put on by the National Academy of Sciences, and it was trying to foster this community of people who think about sustainability issues. There was talk of 'Do we need to actually have a sustainability science society?'. . . . There are just lots of networks of people; it isn't a formal society right now, but certainly people who contribute a lot or are affiliated with the sustainability science section of *Proceedings of the National Academy of Sciences*. There are other groups, in Europe and elsewhere, that tend to be around this issue. And then, this bifurcation between high level general and then very specific – there are whole networks of people who do sustainable cities and sustainable agriculture and sustainable X, Y and Z."

The relationship between sustainability science and informal networks and future research was further underscored by another respondent:

> "We all work within various loose networks, and those networks have a lot to say about what we choose to work on. Because networks of scientists today tend to be much broader than they used to be, and incorporate more sustainability science elements, it's more likely that activities within those loose networks will include discussions about future projects that involve sustainability science."

A natural sciences professor described a local interdisciplinary network that had been nurtured within the University, saying that,

> "…It's more like a complete shift in approach, a complete shift in thinking about impact, thinking about who to work with and why, thinking about social scientists as really fun people to work with. I think that [the center] has been just amazing in producing this community of incredibly varied people who are really smart and engaged and fun, that have very widely differing expertise areas in the broad area of environment or sustainability."

The practice of sustainability science includes the public and private sectors as well as other communities, in addition to scientists. In addition to the earlier reference to collaborations with non-profits, one interviewee emphasized the positive effects of engagement with a network of corporate partners who are driven by both profitability and sustainability goals. A researcher whose work aligns with a large physical sciences-oriented society noted some influence from the society, particularly relating to subgroups focused on sustainability, but emphasized the influence of informal networks within the private sector:

> "Many companies have a sustainability link on their front page. People in those companies are passionate about sustainability issues in [my field] and have been motivational to me. They want to make money, but they realize that making money can be done if you eliminate waste. It's a win-win situation. I've been motivated and influenced by the passion and the drive that many companies have to meet their profitability goals and their sustainability goals."

Those interviewees who stated that professional scientific societies had no influence on their work indicated that participation in such organizations was not a priority, or that due to their interdisciplinary interests, such discipline-oriented organizations were not an ideal fit. Those who spoke to positive influences, however, described the benefits of participation and collaborations within societies and especially within informal networks.

Conclusions related to *associations, organizations, and networks.*

The split was about equal between professors who noted some influence of professional scientific societies and associations and those who said there is none. I conclude that the factor associations, organizations, and networks has a moderate influence on faculty behavior. The responses did not appear to align by disciplines. Rather, non-participation as a member of a society or non-affiliation with society activities appears to be based on personality or personal priorities. Some who reported no influence from societies or associations acknowledged that membership in scientific societies or participation in activities organized by scientific societies was common and likely beneficial to those who participated.

In general, these professors said that societies and associations were not a good fit for their interests, and that they drew their creativity from other sources, within and outside of academia. Some suggested that because of their interdisciplinary focus, they had no affinity with a more disciplinary organization or that, based on their wider ranging interests, they would likely need to participate in more than one society, which they did

not consider as a priority for their work. Others were more specific about the fact that they were not aware of societies that encompassed the intersection of the disciplines.

There was no consensus among interviewees regarding the need for a formalized sustainability science society. The professors frequently noted throughout the course of the interviews that a primary impact of sustainability science may well be its ability to permeate the range of disciplines, bringing transdisciplinary approaches to the fore over time.

3. Funders' Priorities

The third question posted to the interviewees *was "What influence, if any, do the program priorities of funders – federal, state, or philanthropic – have on your work related to sustainability?"* Of the 20 interviewees, the majority described the relatively strong influences of funders on their work. Three individuals noted circumstances whereby they conducted research and programs without the influence of funders, and three others reported minimal influence by funders.

The analysis shows that researchers track new sustainability-related funding opportunities and strive to be responsive to the program guidelines of agencies and philanthropic foundations while also accomplishing their own research objectives. A majority of those who reported the influence of funders on their work described the practical need to shape proposals to align with funders' criteria, while retaining the core intent of the proposed research. A professor with experience in Science, Technology, Engineering, and Math (STEM) education reflected,

> "Now, if you want to get funded by the National Science Foundation, you better do something with computer science. It's not that you can't get sustainability

> education funded, but in the education space right now, the National Science Foundation has gone broader. They have these huge programs that try and capture everything. So you have to say, 'Okay, do I want to play the funding game and reinvent myself in terms of integrating computer science?' or am I going to stick with what I am doing and be a little more creative with how I find my funding? Or, can I fit it all together and say, 'How does computer science play a role in thinking about climate change and sustainability?,' which you can definitely do. It's a constant game of sort . . . . I guess it's like changing your wardrobe every two or three years because skinny jeans are out of fashion."

The craft of proposal writing involves presenting a research idea within the guidelines of a particular funder. A respondent described an approach to developing a submission: "I can write a proposal in many, many ways around the same thing I want to do. It's more about how I frame the same idea. It's about how I write an idea [rather] than changing what I do." Another professor echoed the approach, saying, "I knew what the National Science Foundation [program] was looking for; I knew the elements that had to be included in [the proposal] to be successful. So, it did shape the way we wrote our proposal, which eventually got funded."

Review panels.

The analysis suggests that the review processes within agencies and foundations could be assessed or recast to best evaluate sustainability research, according to several interviewees. Professors specifically noted the challenges of the peer review of sustainability proposals, or more generically, interdisciplinary and transdisciplinary proposals. They saw an agency's focus on sustainability science in its programs as an important step, but said that the ability to critique proposals has not advanced sufficiently. They noted the need and the challenge of building capacity within review

panels of agencies and philanthropic organizations to evaluate proposals in sustainability effectively.

Some noted the challenges of the ways that funders navigate the review process for proposals anchored in sustainability science and other transdisciplinary areas. One professor said,

> "The difficulty is thinking up good sustainability science, describing it well. It makes sense to you because you have been thinking about it for years, but will it make sense to a review panel? There is a certain immaturity, I think, in our science about sustainability science – I'm using that to describe work that is transdisciplinary, that is trying to deal with complexity, that's trying to deal with the multiple dimensions that address the social and biophysical aspects, all in one. I don't think that we have a sophisticated capacity for critique of that kind of work in the academy just yet. Our peer review processes – just as they're an issue in publishing – are certainly an issue in funding."

Overarching concerns regarding review panels were described by a researcher who has also participated on federal agency review panels:

> "One worry that I have is that, while the agencies themselves may have these [cross-disciplinary] aspirations, do they have reviewers for these proposals who are familiar with the nature of this work? The National Science Foundation really wants to move this work forward, but do they have reviewers who are experienced doing transdisciplinary work and understand the nature of it, the challenges of it, the ways that the work actually happens and shows up in budgets and tasks – the way that those kinds of [transdisciplinary] proposals might need to be organized? How do you build capacity to do this kind of work? And, what kind of reviewers do you need to actually make it happen, and fund the right stuff, and be able to effectively evaluate it?"

A professor expressed concern related to inconsistent review comments from panel members, which suggests that individual reviewers might not have expertise in sustainability science-based research:

> "The National Science Foundation is making an attempt to try to do good interdisciplinary work. I have to say, though, sometimes you get very good reviews, very thoughtful; other times the reviews [of interdisciplinary proposals]

> are so variable. It's really strange. We get back some reviews, and you go, "Well, okay just chalk it up. Move on."

Advancing sustainability science.

Interviewees also credited funders for advancing research focused specifically on sustainability. Some interviewees noted that the National Science Foundation, in particular, has been influential in incorporating sustainability science into its funding programs, although not necessarily by including the term sustainability science in program titles. Some see the sustainability focus of the National Science Foundation and others as a driver that shapes their scholarship.

A professor commented, "I think the National Science Foundation has had a lot of influence over the development of sustainability science broadly defined through things like talking about broader impacts of your research, through developing funding programs in areas that may not have the word sustainability in them, but they certainly have the elements of sustainability science – and the National Science Foundation's Innovation at the Nexus of Food, Energy and Water Systems is one of those." Another described the approaches of the National Science Foundation as an innovator in creating programs to support sustainability science-based research:

> "Let's go back five, six years: The National Science Foundation did not have any mechanism to fund computer scientists, data scientists, hydrologists, and ecologists together. The National Science Foundation's Directorate for Computer and Information Science and Engineering is going out on a limb, I think, because they are saying, 'Our directorate has been doing well; there's a lot of good stuff in computing . . . Why don't we try to enable the next bioinformatics revolution?'
>
> So, the [Directorate for Computer and Information Science and Engineering] funded two projects: One called Computation Sustainability, at $10 million, and one Understanding Climate Change Using Data, at $20 million, so that's a big investment. [The Directorate for Computer and Information Science and

> Engineering leaders] are saying, 'We are committed to this . . . . You build a team in the community.' That is very impressive to me, for the National Science Foundation to do. It cannot be easy."

A subset of respondents specifically described experiences with philanthropic and corporate foundations. All noted the significant differences encountered in submissions to foundations, including the fact that some larger foundations choose to build a relationship with researchers and tap them for proposals rather than vice versa. One professor noted the investment of time that can be required in working with foundations, suggesting that many faculty members prefer to pursue the more predictable tact of submitting proposals to governmental agencies.

Approaching philanthropic foundations can be a challenge that is different from the familiarity of working with federal funding agencies, according to one researcher:

> "You don't just send something in out of the blue to one of these foundations and have it looked on favorably. You build up a rapport and you build up a reputation… In this case, we had a meeting [at a European location], and we'd invited a number of different groups including a fellow from [a major foundation with a global portfolio. The foundation] has a big interest in [our work], and so . . . they gave us some money to start up [the project]. Then they pulled together a number of different groups who are interested in this area to try to figure out how can they actually form a network of people who can address this issue most effectively."

Philanthropic foundations are increasingly focused on sustainability and resiliency issues worldwide (Charles Stewart Mott Foundation, 2017; Rockefeller Foundation, 2017; William and Flora Hewlett Foundation, 2017), and are a key source of funding for research on vexing societal problems. A respondent described both the rewards and challenges of working with foundations:

> "I think [funding from philanthropic foundations] is a topic of great interest. I've been personally doing more of that. . . . I think there is this sense that these

> foundations are fickle. [Some foundations] make these occasional forays into the environmental sustainability side of things, but, as someone characterized it, 'they date a lot, but they don't really commit.' I think it's hard for us, with our limited resources, to say we're really going to double down and this expectation [of funding from foundations] is going to pay off. . . . That said, I think academics need to be better about the foundation side of things."

Researchers also cited corporate foundations as a source of funding for sustainability-related projects. They described corporate foundations as more actively engaged in a funded project than were other types of funders, and noted that the range of investment, in some cases, is relatively small and insufficient to support a major research project. Funding through corporate foundations appears to be an important alternative that might supplement other awards. Two professors working in aspects of education described their work with corporations and corporate foundations. One said,

> "If you're looking more at the philanthropic route, there are definitely companies and individuals who are interested in funding [science education]. It's a smaller scale, but you start out at $5,000 here and there – it won't fund the level of research projects that I need to do at an R-1 institution [classification of a university characterized by extensive research], but it will certainly help fund schools."

The other professor compared two recent corporate funders,

> "[One corporation] was very hands-off. The [other corporation] is very hands-on, and the reason is that they also want to have their companies represented well. Although I've been very fortunate in getting money from [corporate] foundations, I always make sure I represent them in a way that they want to be represented. [The representation of the funder] hasn't impacted the way that I educate people."

Only a smaller number of interviewees said that the priorities of funders had no influence on their work. Two individuals reported that they have funds to pursue their research comfortably and so do not have the need to devote significant time to proposal writing. One researcher said, "I run a very large, well-funded research program. . . . The

other kind of work – the more sustainability science kind of work – I do is very inexpensive to do. It takes time, but that's it."

Other options for funding support.

Of the three interviewees who said that the priorities of funders did not influence their work, one individual highlighted the challenges to those who work in the humanities. The professor emphasized the point that participation in an interdisciplinary team often meant the availability of a minimal amount of project funds that could sustain a researcher in the arts and humanities and result in an outcome for the project. Researchers in the sciences, engineering, and medicine, for example, generally require larger funding amounts to execute research trials. Solutions to sustainability issues require the integration of disciplines within the social sciences and arts and humanities as well as the biophysical sciences, and so the level of funding support for the humanities is an important point. A professor emphasized differences in levels of funding that are required to execute projects in the sciences versus the humanities:

> "[The program priorities of funders] don't really have much effect on me at all. In the humanities and social sciences, you'd be waiting a long time if you had to wait for funding in order to get your work done. So, I pretty much just do what I think is important and then go from there. I know that's very different from colleagues in the sciences where their work is absolutely dependent on big grants. Having said that, the accidental shavings or table droppings from one of those grants can often fund a whole project in the humanities or social sciences, and to a certain extent [through my affiliation with interdisciplinary projects], that happens for me."

In addition, a minority of interviewees qualified their responses due to the orientation of their research and approaches to their work. One professor said,

> "I pretty much do what I do, and then I look for the funding agencies that would be interested in it. I definitely do get funding from the USDA [United States

> Department of Agriculture], and also from the National Science Foundation, but at a much lower funding rate. I also get funding from [agricultural] commodity groups.

A professor specializing in law and policy noted that other sources of funding are available to support the research, based on interdisciplinary research partners and their relationships. "When I collaborate with [a researcher from another discipline] – a lot of her work is grant driven – I'll be on a grant with her, and we'll put together various work products."

Conclusions related to *funders' priorities.*

The majority of interviewees said that the priorities of funders influence their work. I conclude that the factor funders' priorities is a strong influence on faculty behavior. Most respondents spoke specifically about funding from federal agencies, predominantly the National Science Foundation. References to the National Science Foundation came from professors representing a range of disciplines, including education, economics, engineering, public policy, and biological and physical sciences. The focus on the National Science Foundation suggests that these individuals are poised to respond to Notices of Funding Availability through interdisciplinary research teams, and are reasonably experienced in developing proposals that integrate disciplinary strengths to respond to complex problems. Most professors employed similar strategies to shape their proposals to align with the requirements of the funder's program. Many emphasized that they strive to fit their research idea into the funder's call. Their strategy is a reframing of the core idea, not a change of their core idea.

4. Colleagues from Other Disciplines

The fourth question posed to interviewees was *"What influence, if any, do colleagues from other disciplines have on your work in sustainability?"* Colleagues from other disciplines are essential to sustainability science-based work. All individuals described various aspects of the high value they derive from interdisciplinary collaborations with faculty members in disciplines other than their own. Respondents strongly emphasized the high value of these colleagues who collaborate with them to create and execute an interdisciplinary research idea. They are realistic about the difference between working as an interdisciplinary team versus as a sole investigator, and about the barriers to interdisciplinary work within academia. The investment of time required to develop an interdisciplinary team is a reality of the nature of sustainability science work.

Interdisciplinary teams.

In various ways, the interviewees spoke about the importance of the integration of expertise from disciplinary colleagues into a successful interdisciplinary research team. Some referenced the exhilaration and energy they experienced from colleagues who bring a new methodology or thought process to a sustainability issue. Others noted their excitement in learning about aspects of other disciplines and other world views from colleagues. Others, while emphasizing the need for close integration of an interdisciplinary team, also noted that collaborations among individuals need to be enjoyable. Some professors with a background in the sciences and engineering specifically noted the high value that social scientists bring to a sustainability problem.

An individual's proclivity to integrate across disciplines is well suited for sustainability science-based teams, but not for all researchers, according to a researcher:

> "In the sustainability field now, I feel like I've made that investment [in time with colleagues with expertise in other disciplines]. I've been exposed enough to many fields that I can at least feel like I know how to make an initial bridge. I find if you have a clearly stated issue that you're wanting to make progress on, and you can say that in a very clear and transparent way, then it's much easier because then it's not abstract. That brings people in. But, of course, that comes from your own experiences and your goals. I think there certainly are people who find that [interdisciplinary collaboration] is really an uncomfortable place to be. They're much more comfortable in a more discipline-oriented [situation]."

On the successful integration of team members with various areas of expertise, the researcher added,

> "I have a hard time thinking of what other disciplines are at this point. We just had our own retreat for a day, and several people said, 'I've gone to these meetings and people can't pin me down. They can't say, 'Oh, you are an ecologist, or you're an economist.' And [the team members] were saying that it's really kind of invigorating. They were very happy about this – that they weren't pigeonholed as this discipline or that discipline."

There is an inherent need for interdisciplinary teams in sustainability science. A scholar noted:

> "I don't suppose anyone can do sustainability science as we're describing it today on their own, and so the availability – I guess that's the right word – of colleagues is very important to working in these areas. Many of us are newly developing interactions in subjects that we often had no contact with before. That really means finding colleagues who you wish to work with and can work with in these different areas. Identifying colleagues, building working relationships with them – the existence of those relationships has a lot to do with the ability to put a good interdisciplinary project together and have it be successful in the end."

A number of interviewees also addressed the importance of their colleagues from other disciplines coming together to form an intentional team focused on the use-inspired research that is conducted with communities. One professor said,

> "[Our project] is an ongoing collaboration that is nested around that common set of ideas that we've developed as a group. . . . We really do need all of that multidisciplinary expertise in order to embed sustainability in this work effectively. I couldn't go to this community and say, 'I'm going to help you be more sustainable' because I don't know enough about the agro-ecological [status], and I don't know enough about the community economic development. I don't know enough about any of the pieces, really. But I have tools and decision frameworks and things that I can bring and others on the team bring those other pieces, and that allows us to really do research in a manner that is sustainable, that facilitates sustainability, and hopefully gets us to sustainable outcomes on the landscape and communities. To do [the community-based project] really well, you need a multidisciplinary approach."

Colleagues from other disciplines enhance an understanding of advancing solutions to complex sustainability problems. The value of an economist's contribution was described by an engineer:

> ". . . this idea of economic pressures on what ends up causing change . . . [my colleague] opened my eyes to this idea of behavior and choice, and why do people do what they do, and how do you get people to accept innovation? . . . . I think if you would have asked me 15 years so, 'How do we solve problems?,' I would have said technology. And now I would say technology, regulations, and behavior change. I think all three are really critical, and technology is way easier if you have the right regulations and the right behavior—all of those linked together."

Several interviewees referenced the differences in terminology across academic disciplines also as a challenge relating to the investment of time necessary to foster an integrated, interdisciplinary team. A scholar described the pitfalls of the team process:

> "[Interdisciplinary research] can be hard to do. . . . You get together and two months into it, everyone's like 'Oh, yeah, we're all on the same page. We're going to do research.' And then two months after that, it's, 'Oh, dear God. We actually had no idea, when you use this word, we had no idea what you were talking about.' [Terminology] is a bear. In the abstract, everyone believes that yes, interdisciplinary is the way to go in sustainability science; by definition it has to be an interdisciplinary endeavor. We do it very poorly within the university. And you could argue that as we're doing it, we're getting worse at it because the over-riding consideration is more production in narrower fields. Maybe I'm being little cynical, I don't know."

Another professor observed the challenges of integrating physical and biological science with the social sciences on interdisciplinary teams:

> "It's fascinating to people watch – just watch the scientists and economists sort of dance around the same issue. What counts as data is a fascinating conversation, to watch them tackle the same problem in a completely different way. The economists have got to deal with this fuzzy thing scientists don't like dealing with – people's behavior."

Investment of time.

Several individuals highlighted the significant investment of time required to nurture productive collaborations. A scholar with policy expertise said,

> "[Colleagues from other disciplines have] had a big impact on my work. [The value] is huge, because I'm not a scientist, and so for me to be able to understand and evaluate and potentially promote one or more policies, I need to make sure that the technology is there, that scientifically, it's valid, if it's going to bring us in the right direction. The investments of time for interdisciplinary work] is worth it."

The significant investment of time and effort over multiple years to nurture an interdisciplinary team – and the equally significant payoff – was described in detail by a researcher:

> "[Colleagues from other disciplines are] major influences. I could never do the work that we're doing right now by myself. I don't think any of us could. We wouldn't have the ideas. We wouldn't have the sense of scale. We wouldn't have a sense of how all the pieces fit together. We wouldn't have the sort of theoretical framework that we have now.
>
> We've been working together eight years. Writing proposals and being unsuccessful was actually quite helpful, because when you write, especially NSF [National Science Foundation] proposals, it forces you to really build that theoretical framework and think carefully about the key sources that we have to have represented from each of our disciplines – so that we can talk to reviewers, but also talk to each other. That forced us to start thinking about commonalities in our literature, the ways that they're in many cases complementary. We drew a lot of diagrams. In some cases, we each suggested a couple of articles, and we

> read stuff from each other's disciplines and talked about them. We had some sort of worksheet that we used at some point. That was helpful. It just took a lot of time.
>
> But now, I go to a lot of meetings, and I hear other people on the team explaining things in the exact same way that I would explain them. It's amazing that we are at this point where we can each explain these components, and we all buy into them, and we all see that this works when it comes together. Whether you have the right expertise or not, it has to be people who have similar working styles. . . . We ride in a lot of vans together now. You have to be able to like each other."

Stories of the time required to build an interdisciplinary team than could effectively address complex issues of sustainability were told by a number of respondents. A researcher described the goal of reaching productive, collaborative relationships:

> "[Three of us] had lunch together about every week for probably four or five years, at which time we talked with each other, affirmed what other people are doing, learned the terminology, became friends, and then started to collaborate. So, [the interdisciplinary interaction] was an investment. There's no way around it. You have to be willing to invest that kind of time to ever have a chance of a meaningful collaboration across disciplines."

A physical sciences researcher noted the personal commitment that is required to build interdisciplinary relationships:

> "It's been really tremendous for me to work with engineers, civil engineers in particular, on some water work that we've been doing, and to see their desire and their passion. Oftentimes the engineers are much more connected to technologies that are actually practiced, and so that's been very important for me to see what the real world is like. . . . sometimes the materials world gets a little separated. Being able to engage different people with different expertise – in psychology, sociology, ecology, economics, policy – will become more and more important, I think. There is an investment in time, and like any relationship, it's never a one-way street. Different disciplines have different approaches. I have to make the commitment . . . to learn about the way civil engineers [or others] think."

One professor noted not only the time commitment but also the importance of personalities and relationships: "I don't mind spending time learning about other perspectives if it's an enjoyable process, and I feel like I'm learning something. I guess I

do spend a lot of time collaborating with people I like. I tend to avoid the collaborations where it's not fun."

Structure of academic institutions.

The structure of institutions of higher education that reinforces the maintenance of discrete disciplines and barriers to interdisciplinary work was addressed by many interviewees. Some saw sustainability science as a way to dismantle barriers and support interdisciplinary research. A professor looked internally to the structure of academic institutions:

> "I think [disciplinary colleagues] see [sustainability science] as an area that helps organize interdisciplinary collaboration and thinking across disciplines in universities. It's a way to better connect with people and problems. Sustainability science is a little bit of a funny animal in a sense because there's no one discipline that it's identified with, but it's identified with a lot."

A scholar additionally noted the challenges within academia related to the interdisciplinary nature of sustainability:

> "Academia is a very traditional environment, very conservative. I always believed it was probably the most open environment, but I changed that idea because I started to collaborate with industry. People outside in the real world are much more open to change and new methods, particularly around the sustainability concept.
>
> My interaction with colleagues is good and bad in the sense that there are many places [within academia] where you have a refusal of the idea of a new science like sustainability science. I think that it's driven by the fact that it's much harder to promote a science that is not a pure science. It's not biology. It's about discussing how we can actually implement the theory of sustainability into practice. Even though people may be excited around the concept of sustainability, it's very hard to work with some people because they don't share the same mental model that we have."

The academic traditions of the tenure process can extend the time line for scholars who are interested in launching into interdisciplinary research. A view held by many respondents was articulated by one researcher:

> "I think that, number one, [working across disciplines is] what needs to be done. I try to do as much as I can . . . but I truly think it has to do with time and space, meaning that people don't have enough time. When you think about the whole academic process of getting tenure, you need to get your publications out there. You need to get them out there quick. And you need to make an impact. Collaborations take a while to see if you can get going, and people are more interested in sitting in their office and writing their research to get published in order to get tenure."

Despite barriers, there are benefits to the breadth of disciplines that are housed within a large research university. A professor provided a different view of the academic institution, based on perspectives shared by a colleague in the humanities:

> ". . . part of the point of the university – emphasizing the *universe* part – is that it's full of people who will be really interested in, as a scholarly and intellectual challenge, what for you is a barrier. And so I have gained an appreciation for the role of humanistic ways of knowing in transdisciplinarity; I have learned how to go beyond the limited pathways towards social learning . . . . The institution is so full of amazing people and resources. Being able to move freely about in that space until you can find people with whom you can engage in effective interdisciplinarity is really important and, of course, hard to do."

Sustainability science can be viewed as the grounding for interdisciplinary and transdisciplinary work. A researcher addressed the long-term nature of work in sustainability and a personal sense of responsibility:

> "It is a lot of work developing really genuinely productive interactions across topics that can bring the right people together to do sustainability. I would say I probably could have written more papers and even gotten more grants in my life if I hadn't attempted any of this [interdisciplinary collaboration]. There is a certain inefficiency measured that way. But on the other hand, it's allowed me to do things that I think are very meaningful in the long-term. We owe it to the world around us; we owe it to future students to lay groundwork for what has to come next. And so, it's been worth it even though it's been inefficient."

Conclusions related to *colleagues from other disciplines.*

All 20 professors place high value on their collaborations with colleagues from other disciplines. I conclude that the factor colleagues from other disciplines has a very strong influence on faculty behavior. Many described the discussions, partnerships, and collaborative research with colleagues from other fields as essential to the ability to solve the problems they are trying to address around aspects of sustainability. They described human behavior, economics, and social circumstances – essential components of sustainability science – as necessary elements in the steps toward solutions to complex problems. A majority of interviewees spoke to the investment of time required to nurture and solidify interdisciplinary partnerships. All interviewees referenced the benefits of the investment of time, but also noted the deliberate pace of interactions that matured, in some cases, over five to eight years.

Interviewees described the integration of disciplines as core to sustainability science. Some, however, referenced barriers to interdisciplinary work that are inherent in the structure of academic institutions. The majority stated that the increasingly complex problems confronting societies will be tackled through the tenets of sustainability science, including interdisciplinary and transdisciplinary approaches. Sustainability science may be a strategy to enhance interdisciplinary work within institutions of higher education.

5. Stakeholder and Citizen Interests

The majority of interviewees described multiple ways that stakeholders and citizens influence their work, in response to the fifth question: *"What influence, if any, do external stakeholders and citizens have on your work in sustainability?"* Only one

professor said that external stakeholders had no influence, and three had qualified responses.

The scholars described the variety of ways that external groups and individuals influence the ways they approach their work. A strong undercurrent of a key tenet of sustainability science – the engagement of citizens, organizations, and policy makers – was evident in the responses.

Local knowledge.

Some professors specifically noted the essential engagement of citizens, interest groups, the private sector, policy makers, and other entities beyond the sciences in approaches to addressing sustainability issues. They noted the importance of local knowledge that stakeholders bring to a problem. A deeper understanding of other ways of knowing can help move local communities and scientists collectively toward solutions.

Researchers who work with indigenous populations both in the United States and internationally, noted the importance of ways of knowing other than Western science. They specifically referenced the ways that the stories and traditions of local populations – and the relationships to goals for sustainability – can be told. One scholar said,

> "People want to tell their story because their world is changing, and people who are in the depths of Africa would hope that an American professor would be able to have some influence within this region. Another whole aspect of my work is 'How do you give back to these people who have given to me?' . . . . Even in the Amazon, people really wanted us to tell their story because they're afraid. They're afraid that people aren't doing enough research around sustainability in order to help them sustain their lives in the way that they want."

Attentiveness to indigenous and other local knowledge can help develop trusting relationships, learning opportunities, and better designed strategies to solve problems. An interviewee addressed different stakeholder group experiences:

> "Stakeholders have influenced [my] approach in a place-based sense. If I'm in a farming community, they have opinions about tile drains that are not maybe the same as the scientists' opinions about tile drains. So, that becomes interesting. I did a lot of work on [a tribal] reservation with a program. If I'm on the reservation, [I] have to be sensitive to where people are coming from, so I have to think about indigenous views of science. [If an issue] becomes a point of tension, then the question becomes, 'How can you use that as something teachable, and does it cause a rift that becomes difficult?' With stakeholders, it's really more thinking about where I am when we're having these conversations."

A focus on stakeholders and citizen expertise can lead to researcher encouragement for local people to co-develop and co-lead projects, developing an iterative process of providing data to users and getting feedback to improve a process or policy, and learning and assessing a problem differently by being engaged with community members. A professor emphasized the importance of external stakeholders as co-creators in sustainability work:

> "This entrepreneurial spirit and energy . . . the things that the [local people] know how to do and have done, and the projects that they want to pursue are completely fundamental to [transdisciplinary work]. We're trying to bring together a group of people who wish to co-lead and co-develop and co-govern the development of agriculture in [a region of the state] . . . . We're trying to attract people who have great ideas . . . That's what sustainability science, I think, has to tap into—those kinds of people."

Local knowledge at the heart of an issue can frequently enrich scientific information, according to some respondents. A scholar described an engagement among scientists and non-scientists:

> "All of the work that we're doing with stakeholders acknowledges that we bring information, but they're the ones who need to process it, vet it, integrate it into

> decision making. They have information that, in many cases, can correct what we have and add to it – that common base of knowledge. So, in all the work we've done, the stakeholder piece – which reveals all of that expertise and all of that local knowledge and shares it with all of the other folks locally – is at the core. We're providing, I think, a platform for decision-making or providing some facilitation, but at the core of this is the knowledge that exists locally.

In addition, a researcher noted the importance, too, of integrating different ways of knowing, both scientific and local knowledge, and understanding a situation or boundary object from different world views:

> "The idea [of types of knowledge] comes under expert knowledge; if you work with practitioners, how do you blend these different types of expert knowledge, but also [blend] expertise together in interdisciplinary and transdisciplinary collaborations… That gets into the whole idea of boundary objects, and for me, it's like landscapes. It could be cities, but everybody looks at the city or landscape differently, and they have different values added to beliefs, and those [values] influence what people think about that boundary object."

Boundary objects, whether concrete – such as a city or a landscape, noted by the professor – or abstract, have different meanings to different segments of society. They are "plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (Star and Griesemer, 1989).

Special interest groups.

In addition to place-based populations and communities that influence the sustainability science-related work of the interviewees, non-profit organizations, agricultural groups, and the private sector exert an influence on scholars through research partnerships and other types of engagement. One scholar addressed the influences of a volunteer leader of an environment-oriented non-profit:

> "Part of [the influence] is mutual interest . . . . She has been incredibly influential, and she's one of those soft-spoken people that you suddenly realize you've learned tons from without even knowing you were learning it. People like that are really important. It's been more from the non-profit, volunteer sector that [my partnerships in research and public engagement] happened."

Through the work with non-profit organizations, a professor noted the importance of the two-way flow of information between researchers and stakeholders, even when joint projects are not the anticipated outcome:

> "Sometimes groups are interested in getting advice or recommendations from me. I'm often just trying to get more information about topics that I'm writing on, seeing what their experience is with it or their views on the topic. So it goes both ways. I write a lot on various laws and policies that are relevant to issues that [environmental and energy non-profit organizations] are interested in – they might be interested in my perspective on ways to reform a particular regulatory system. They may think it's great; they may think it's not. . . . But it's a good exchange of information to see other people's ideas."

Stakeholders are also sources of information, and with a differing world view from that of scientists. A researcher emphasized the basics of sustainability science – engaging with non-scientist citizens:

> "Stakeholders influence my work in a variety of ways. I like to work with stakeholders because they are a great source of information. Many times, as people in academia, we arrive with something that we call the perfect solution. But that's not something that we can implement because it's not in their set of values. We deal with very poor communities, and they are attached to some cultural values that have nothing to do with what we consider optimum solutions. Sustainability science is actually starting from cooperation, from a dialog, which can take time. Sitting around a table, that's sustainability. Very simple stuff, but very practical."

A professor also addressed the knowledge that non-scientists can bring to sustainability research:

> "A lot of times I'm kind of removed from some of the on-the-ground stuff that's going on [with farmers]. So, when I go talk to them, I can find out [number of acres planted and the location], and I can learn about their attitude towards what I

> want to do [in my research] . . . . There are some things that the [farmers] observed because they are there [in the field] every day. So, it's very important to talk to them. They know what's going on in the field to some extent better than we do."

The development of joint projects involving a transdisciplinary team is an investment of time, perhaps even beyond that of the time required to develop an interdisciplinary team of scientists. Integrating goals, research design, and the priorities of a funder are essential to success. A professor described some of the questions to be considered when joint projects are being developed:

> "When you're putting together a collaborative proposal, it's a combination of what [stakeholders] are wanting and what the funders are wanting. What are the [stakeholders] doing? What are their successes and failures, and how are the current structures constraining what they do and helping what they do?"

Stakeholders can exert influences on researchers through opposing positions or negative responses to scientific outcomes. Such circumstances also provide researchers with opportunities for increasing their understanding of strongly held beliefs and avenues for communication and engagement. A respondent addressed the reality of differing points of view among stakeholders and aspects of academic scholarship:

> "I guess [external stakeholders influence me] all the time. A lot of influences have been positive, and some of them are negative. A lot of times groups have said, 'We need this,' or 'We want this,' or 'We want to preserve biodiversity and prevent further loss of habitat,' for instance. And that resonates well with me. Or, 'We want to make people's lives better in this way.' And sometimes, though, [what] often gets me really riled up and really motivated is when I hear lies . . . groups that are blatantly stretching the truth or telling falsehoods. I want to contradict those and say, 'No. That's not the case.' Sometimes it's the positive influence, and sometimes [engagement with stakeholders is] calling people out when they're not being truthful."

Among those referencing only the indirect influences of stakeholders, one professor distinguished organizations as stakeholders from citizens as stakeholders: "[The

influence comes] mainly through working with some of the cities and watershed districts . . . most driven by needs not just of the general public, but of this public works department. Otherwise, [the external stakeholder influences on my work] are more indirect."

Scientific solutions to a problem may be available, but those solutions delivered by science alone might not be accepted by citizens or policy makers. Many interviewees noted that engaging non-scientists in problem-solving and understanding the traditions and behaviors of those groups that are affected by a problem are key elements of identifying sustainable solutions. A professor reflected on the larger context of stakeholders in understanding social behaviors and adoption of new technologies:

> "[External stakeholders have influenced me] only in a very broad sense. I tend to be independent, self-motivated, self-guided. But I cannot help but ask questions such as: Why do people behave in certain ways that might be environmentally beneficial or environmentally harmful? What leads farmers to do what they do? Farmers aren't trying to hurt the environment with what they are doing. They're just trying to earn a living. So, I try to understand all the different people involved in these processes, understand what they are doing, what is motivating them . . . .
>
> When you're trying to solve a problem, it's one thing to find somebody who solves it on paper, but it's a very different question to find a solution that people would readily adopt and use on their own on a day-by-day basis. To me, that is the point where we're at in terms of solving the environmental problems. We have many, many scientific papers that show there are solutions, very few of which have been adopted by people or by governments. And so, I try to understand what it is that motivates people involved in creating problems to find out ways they might be involved in solving the problems, and what might be needed to guide, encourage, those kinds of behaviors. To me those are the stakeholders."

Stakeholders also influence sustainability research through their involvement in the funding decisions of some grant-making organizations. The relationship

demonstrates another example of the interrelationships among the seven factors of influence. An example of a type of indirect influence was described by a scholar, based on experiences with a funding organization:

> "The [organization] has funded me several times in the past, and the projects were very successful, but one thing which distinguishes their review process from NSF [the National Science Foundation] or other places is . . . what they get to fund is strongly influenced by a group of stakeholders. The [funder] has people interested in water resources inside and outside of universities at the table to make final rankings of projects, and so stakeholders basically have go/no-go power over some of my work. I am not interacting with them directly when that happens, but they're there at the table."

Companies and other private sector organizations are stakeholders that can influence sustainability research through partnerships and funding support. An interviewee noted the relationship between consumers and corporations as well. The interviewee anticipated that consumer preferences will emerge through corporations, which may or may not influence scientific research directions:

> "More and more, sustainability issues come to the forefront: global warming, trash in the oceans, population increase. People are going to demand [sustainable options]. That demand comes through industry. If Walmart says that all of our packaging has to be sustainable starting in 2020, you will see a wave of activity rush through the industry. The policy side is also going to be important. China has huge bans on polyethylene plastic bags. These [choices] will ultimately influence what kind of materials are acceptable."

Students are important contributors to community engagement and the incorporation of local knowledge into collaborative research projects. Implicit in the responses of many interviewees was an emphasis on community engagement opportunities for students and experiences in transdisciplinary research. The sole professor who said that stakeholders have no influence, explained,

> "The [stakeholders] should have more [influence], but there's a particular logic to the academic enterprise that really rewards a certain kind of work. And there is not enough [influence from stakeholders] . . . . 'Clamber out of your ivory tower, academics, and engage!' I realize the importance of it; what I'm personally doing is a whole other question. But I can push my students towards [community engagement], though, because I think it's important."

Conclusions related to *stakeholder and citizen interests.*

The professors described multiple ways that stakeholders can be a powerful influence on their work. I conclude that the factor stakeholder and citizen interests has a very strong influence on faculty behavior. All but one of the professors who were interviewed spoke to the importance of external stakeholders and citizens on their work. A few respondents addressed ways that external stakeholders affect their work more indirectly. One pathway of influence was described as the demands of consumers that cause corporations to change products and processes and how such changes influence scientific research. Another indirect mechanism was through citizen boards that guide a funder's decisions on priority areas of research and grant making.

Only one professor experienced no engagement or influence from external stakeholders. The professor pointed to a concern that academic researchers can be viewed as being far removed from the day-to-day realities that are problematic for communities, and that academic institutions traditionally have not placed a higher value on community engagement. The professor emphasized the value of community engagement as a way of enhancing research and saw encouraging students to incorporate engagement with stakeholders into their work as a strategy for spurring change and approaches that are consistent with sustainability science.

6. Student Interests

The sixth question corresponding to the seven factors of influence posed to interviewees was, *"What influence, if any, do students have on your work in sustainability?"* All respondents described the significant influence of students on their work. Only one scientist noted that students have a minimal influence, but with a caveat. A majority of professors emphasized student interests in the context of sustainability science. They cited the positive influences of students as sources of new ideas, as research collaborators, and as being more independent from the disciplines and attuned to interdisciplinary work than some faculty members.

Sustainability science savvy.

Students today exhibit a level of global awareness, including both scientific and social awareness, of complex issues beyond that of students of a decade ago. The savviness that students have for employing sustainability science methods to address societal grand challenges affects professors in their research and in their incorporation of sustainability issues into the curriculum. Scholars described the strong influences of their students with enthusiasm and pride. A professor compared the growing interest of students in the interaction of humans and nature with the emergence of sustainability science:

> "[The influence of students] is constant in the sense that they'll come in and ask really good questions. They oftentimes bring in new and fresh perspectives. I get exposed to students who are really interested in issues about where we are headed – what's happening in the environment, and what's happening to environment and society. I think the particular topics change. There's a lot more now about global changes than there was 20 years ago, and there may be some greater concern. I think this is the rise of sustainability science . . . . I don't know which came first, the fact that we realize we're getting to be a pretty full planet, and that we do have

> global consequences. Did that realization come first and spark sustainability science? Or has sustainability science helped promote that awareness? I think it's some of both."

Students appear to be pushing a culture change that is recognized by faculty members. Some professors are meeting the interests of students through research opportunities and in the classroom. A scientist described the change in student interests over time, consistent with sustainability science, and the concomitant influences of sustainability science on research projects:

> "Students have changed tremendously in my career. When I was a graduate student and then shortly after that became a faculty member, we paid almost no attention to whether our work was relevant to sustainability of the planet. In fact, quite the contrary, there was an attitude when I started my career – quite a pervasive attitude – that basically looked down on any projects that had social relevance. The thinking was, if you're doing something socially relevant, it's because you aren't good enough to come up with an idea that's saleable otherwise.
>
> And today, the pendulum has swung so far that almost every project, almost every student who comes to me, starts with an idea of, even in general terms, 'We're increasing carbon dioxide, and the climate's changing, and therefore we have to know X, Y or Z.' I would have to think very long to remember the last student who expressed an interest to me that was disassociated with social forces and sustainability science broadly defined. Every student says they want to work on biology or ecology or limnology today because they care about people of the planet. There has been a tremendous cultural shift. . . . It's hard to do anything anymore just because it's interesting or cool or can help us understand nature. Almost everything has to be couched in terms of how the science will affect people or our ability to manage the planet."

Students influence their professors by introducing them to related areas of research, through their relationship to the professors as mentors, advisers, or teachers. A scientist described a new area of investigation and the learning that the scientist experienced through advising a student:

> "I've had a few [students] come in from the get-go with a really strong idea of what they wanted to work on, and that's been really fun because over time you can see how it connects to your other work, too. And I had one [student] who was really interested in storm water treatment and rain gardens, which is not something that I've thought of myself as doing. I co-advised this [student]; and he was so smart, and it was a really nice three-way partnership. I learned just a ton from him, and I think about storm water now, where I never would have bothered to think about it before. . . . When I first started [teaching], the students seemed not very engaged in the political world and social enterprises. They seemed pretty focused on themselves and their other activities. Now, I see a change; the students are really engaged and want to save the world. They're much more politically aware – and not just necessarily Washington politics – but in general, the movements going on, Black Lives Matter, and various equity and social justice things going on. I think they're much more aware of developing world issues."

The genuine receptivity to student ideas and research findings that many respondents described was articulated by a researcher:

> "Students bring new ideas that are not my area of expertise, but are around my area of interest or my area of application. I have an excellent Ph.D. student who actually proposed to me a new method. I was very skeptical at the beginning, but we evaluated that method with other previous methods that we used, and her method is much more efficient. So, I love when these things happen because they open my mind."

Students may be a factor in deepening interdisciplinary interactions through their work with scientists and other students in multiple disciplines. A big-data researcher reflected on the influences of students from various disciplines, using an example that included post-doctoral researchers:

> "I have seen that a few of my students, while they were working with a post-doc coming from the science domain of ecology and climate science, get locked into the problem, and then they start teaching me. One of my students is studying how plants adjust their various properties in different biomes, and she knows more about this than I do. And she educates me. She understands what I know and understand, and she'll bring it down to my level and explain to me what we are trying to do. I learn more from the [students] than I would get from [reading] a *Nature* or *Proceedings of the National Academy of Sciences* science paper. . . .

> And the post-docs in other disciplines teach me a lot, a lot. I do serve on the committees of various students, somebody working on leaf venation structures – how leaf veins work. Somebody working on plant species that are going extinct . . . they often need a sounding board on the mathematical and computing ideas. I think this is a fantastic use of my time. . . . This stimulates your brain; this person unfolds this whole new world. I find that fascinating. And, in some ways, I believe I can help them."

Students are strong motivators of the professors who were interviewed. The give and take between a student's interests and the expertise of a scientist can result in changes in the way a scientist approaches a research question and encourages a student to pursue a research direction. A respondent addressed the passion of students for working on the wicked problems facing society and the challenges of addressing their curiosity and creativity:

> "Graduate students who come into our program are very keen on, to be a little bit flip, saving the world. They want to work on sustainability initiatives whether or not it's in energy or water or food or green chemistry. That transition is evident since the last decade or 20 years since I've been here.
>
> The student population is changing so much. They really are passionate about solving these practical problems, so they push me in that direction. It's really kind of synergistic. I pitch it, but they're already committed to it, and so they give me more motivation to continue along those lines. If the students are coming in with a particular interest in a framework of sustainability, how can I work my science and research projects to connect to the students? Can I emphasize and grow the sustainability aspect on the basis that this is what the students want to work on? I like the latitude of letting the students take the projects in the directions they think are most important."

The ongoing challenges of defining sustainability and sustainability science reach beyond the literature to student interests and their academic endeavors. A professor commented on the students' evolving understanding of sustainability and use of the term:

> "Students are interested in cutting-edge issues, and sometimes they're the ones who present new twists and turns on things. That leads to a broader question about sustainability and design, and sometimes I think what's ironic is that

> sustainability science is growing bigger and deeper as interest in sustainability is waning in the design fields. It's kind of a funny thing, because [the design fields] have been doing it longer, and so they've moved on to *resilience* now.
>
> In terms of sustainability, I can remember a time 10 years ago where it was a new concept, and people were struggling to define it. [Sustainability was] one of the *it* words for [students] to use in their design work or projects. I think that's waned now. I think now it's 'resilience,' but do they know what it means versus sustainability? I guess that's debatable. [Students are] smart enough to question it, but whether you can pin them down to a definition, that's challenging. I think [students will] still be involved with a lot of practices that are sustainable, but maybe the word gets put into the background some."

The academic organization.

Student interests are a very strong motivator of faculty behavior. The combination of student and faculty desires to apply sustainability science methods – interdisciplinary and transdisciplinary approaches, among others – will likely drive change within the structure of academic institutions. Institutions, in general, strive to meet student needs in the classroom and through graduate education experiences. Interviewees addressed their goals for addressing student interests and also described the opportunities and challenges for graduate education.

A professor described the pervasiveness of sustainability and student interest as the impetus to incorporate sustainability approaches in the classroom:

> "I think that students are definitely interested in sustainability. Most students who come to the field of urban planning know what it is, know how to use the term, and refer to things that they're doing as sustainable or not, and have some basic understanding. They're often motivated in saying, 'You know, I really want to do sustainability planning. What opportunities for me are there in sustainability?' What I try to do in the class that focuses on it most totally is to think about tools and ways that sustainability is implemented – take a set of ideas and a set of aspirations and some sort of ideal concept that we can get to, which is sustainability, to think about, for planners or for people in public policy, what are the tools that they have to get to [do sustainability]? Early on there wasn't a tremendous amount of interest [in sustainability]. I think I've seen it tick up a bit.

> I don't [know] if it peaked or not. I feel like we're getting to the point where it's so engrained in everything that we don't have to really say it anymore. It's just sort of taken for granted."

New approaches to graduate student training and interdisciplinary work could be developed using a sustainability science lens. A scientist commented on the benefits of education from a disciplinary and interdisciplinary frame:

> "I've had a few students, and I could see having a growing proportion of students, who are doing work that is essentially informed by sustainability science. I had one student who did a mix of applied economics and ecological modelling to create the scenarios of land use, and that work is increasingly being subsumed under sustainability science. . . . If you could get the graduate students inured to an interdisciplinary sustainability focus, then they will carry that forward. The [graduate students] would be trained in that way – have a home discipline in which they are experts, but get used to playing with other folk."

Within the current configuration of higher education institutions, students pursuing sustainability science or other aspects of interdisciplinary work will likely find barriers. An interviewee expressed concern for students who seek interdisciplinary expertise in educational systems constrained by the disciplines. The interviewee posited that a strong disciplinary focus might better position students for the future, given the current structure and reward system of academia.

> "When you have a graduate program like conservation biology or sustainability studies, I worry that [the students are] going to be undercut when they go on the job market. Say you want to get hired into a sociology department; most sociology departments would rather hire a straight up sociologist than someone who did a sustainability science degree with a sociology focus, which kind of speaks to the tyranny of the discipline."

The majority of faculty members in academia conduct disciplinary research, following the traditional structures of higher education institutions. That mix of disciplinary and interdisciplinary focus might change over time as young academics with

sustainability science or interdisciplinary expertise move through the tenure process. A scientist described enthusiasm for working with students compared to working with peers: "The students haven't been beaten down by disciplinary pressures for decades, so it's much easier to do interdisciplinary work with them than it is to do it with senior faculty. And [the students] also bring lots of energy."

Student interest in sustainability can better inform the public as graduates with sustainability science and interdisciplinary expertise move into the workforce. This expertise can benefit young learners in kindergarten through 12th grade classrooms, as well as the general public. A professor with interest in science education said:

> "[University students] tend to come in [now] having had a few more, I would say very loosely, interdisciplinary experiences or different experiences in learning. They're more likely to have seen examples of how to use sustainability as a way to teach their disciplines. Sustainability has been a way for me to bridge that [interest in science by students who do not intend to become scientists]. For me, it's really: how do you get the public in any way, sense, or form, to care about scientific issues? Sustainability just becomes one of those drivers [of interest in scientific issues]."

Only one respondent considered the influence of students to be minor. I view the response as qualified, however, because the respondent also described an instance where a student researcher had a major impact on an aspect of the respondent's ongoing research:

> "The undergraduate students don't have that much of an influence on me. Some of [my graduate students] don't have that much of an influence because they're basically brought in here to work on grants that I've gotten. They'll have an influence, but it's kind of minor because they're just doing the research that I planned.
>
> But sometimes they find out things that I never would have thought. I have an example of that with a student doing what he was supposed to be doing, but then he found something really different that really changed everything. So that can

> happen. [The student's finding] made us think differently about the [work]. That was a case of a student just doing a regular experiment and finding out something that really sort of blew our minds."

Conclusions related to *student interests.*

Respondents were attentive to the interests and capabilities of their students and value the contributions that students bring to research and discussions founded in sustainability science. In addition to colleagues from other disciplines and external stakeholders, students have a noteworthy influence on the work of the 20 professors. I conclude that the factor student interests has a very strong influence on faculty behavior.

Many professors described the changes in the interests of students that they observed over time. Specifically, some suggested that students today are more attentive to science and policies that have social components and global ramifications. The interviewees said that students now seem to be more outward looking than solely focused on their personal objectives, with concerns about climate change and environmental issues and, in turn, their effects on human populations. While acknowledging the strong interests of students in sustainability and transdisciplinary approaches, one researcher also voiced some concern about the academic traditions of the disciplines that can constrain students in their future work.

Several respondents described how they strive to incorporate students' interests in sustainability issues into their teaching and creation of research opportunities. Others spoke to the ways that the questions posed by students and the research directions of students had strongly influenced their own research. The professors described students as

motivating, passionate, and able to inject fresh perspectives and cutting-edge ideas into the work.

7. International Arrangements

The seventh and final question relating to influencing factors was, *"What influence, if any, do international arrangements with researchers, students, or organizations outside of the United States have on your work in sustainability?"* About three quarters of the professors said that various types of international arrangements influence their research or teaching. Some reported on the significance of international relationships based on time spent in other countries at some point in their respective careers. Others noted the benefits and influences from participating in or tracking international networks related to their interests, or long-term relationships with colleagues in other countries. Three professors said that they had not experienced any influences from international arrangements, and two individuals provided notable perspectives, but without influences.

Early international experiences.

Early experiences in countries outside the United States appear to have provided insights for several scientists that are valuable in considering research focused on grand challenges in sustainability. Some respondents reported that international experiences while they were in college or during early stages of their careers were the basis of research interests and collegial relationships that matured and have been maintained over time. Some also indicated that any exposure to different approaches to tackling sustainability problems – by leading students on study-abroad experiences or spending

more time in a country or region of the world – provided new dimensions for analyzing issues in sustainability and exploring strategies that could be used in the United States to address similar problems within a different governance framework.

Very early influences anchored in international work placed one scholar on a sustainability track, even before launching into an academic career:

> "I've always been pretty internationally-oriented – my more local, domestic work has really flowed out of international environmental rights, bringing me into climate change. What convinced me to go into academia was a year I spent in China. . . . I also spent one of my summers at school in [a European capitol city] and I worked with [an international environmental organization]."

In-country experiences, even if not related to sustainability at the time, can shape research that comes later in a career. A scholar conveyed early research that became relevant to current investigations:

> "Most of my international influences were from another life of research that was not as directly environmental . . . . Having said that, there are some people [who] have been interlopers for me . . . . One does work in the [arts in South America]. She had me come down to give a talk . . . . Basically, what I was able to find in some Latin American [countries], are some people doing things around the environment and [the arts]. . . . I would say that's been one of my major influences there. . . ."

Other early international influences can come through faculty research awards or sabbaticals, for example. A scientist noted that a well-funded award for junior faculty was an entrée to international research opportunities and research relationships that have continued over time:

> "I used that funding to go to Europe. I spent five months in the Netherlands and England . . . and made a number of really good connections over that time. In fact, I'm putting a grant proposal in tomorrow with one of the people I met in the Netherlands. Quite frequently I communicate with people that are there, [and in] Asia and South America."

Another professor had a similar experience:

> "I spent a sabbatical in the UK [United Kingdom] at [an institution that] had an internationally well-known group there. I learned a lot about how to do science and how to communicate science effectively from the collaborators I had in that group. That was a very important interaction for me, and long after that sabbatical was done, I went back and interacted with those people, and I still see them; they're still friends, and we still collaborate and talk . . . .
>
> Also, in China I've interacted with a group that's doing agricultural research, and scholars in that group have come and visited me, and I have gone there to see them and interact. I've done work in a few other countries, also. [There is] the limitation on interacting with someone who's far away; it's just harder to have consistent interactions of the kind that lead to the best collaborations, but I've had some wonderful collaborations and learned a lot from people in other countries."

International projects and activities.

International experiences bring into sharp focus the importance of sustainability science approaches that incorporate a global view to solve the vexing issues that confront populations and the resources they need to achieve a higher quality of life. A scientist's in-country experiences demonstrate complexities that become more immediate, viewed from on-site analyses, and underscore the balance of policies that could be shaped to address human needs and environmental conservation:

> "In the last five years, I've spent a fair amount of time in China. . . . China is fascinating because it's changing so quickly, and it's also such a microcosm of all of the important issues. You've got the focus on development, which is essential for a country which has lots of people in very abject poverty. [China] really is a tale of two countries right now because you've got the urban, eastern part which is very developed and is suffering from woes of development, incredible air pollution, and water pollution. But then you still have the rural areas, and some of the rural areas haven't changed very much. They're still incredibly poor.
>
> To me, there's a challenge for sustainability science. How do you get people out of poverty and in a way that doesn't destroy the environment, which is necessary for future prosperity and well-being? In going to countries in the developing world and seeing how people who don't have access to electricity, for example, you realize what that means. It's very easy to say, 'Oh, we should conserve

> more.' Well yes, we should. But also, there are people who need more [resources].
>
> Teaching our course with people from [other countries], for example, just constantly reminds me of the kind of different needs and different problems that arise in places."

Even brief international experiences can have strong influences, perhaps especially when the travel is structured as a learning experience. An interviewee who created a sustainability-oriented study-abroad opportunity for students described how observations during travel can prompt new research questions:

> "The international connections that I have are fairly limited and just *ad hoc,* actually. I did lead a study abroad for students focused on urban sustainability, and so we looked at sustainability applications in [one country] – applications that related to waste and energy and transportation and land use and water and ag and things like that. . . . I think [international experiences] help to further flesh out my thinking about how to implement sustainability and attention to the context.
>
> What's always helpful when you go somewhere else outside of the U.S. is it helps you reflect on your own context. How do we then get to some of the things that we aspire to? We're never going to have the European system, so how do we work within the system that we have? It helps me analyze and break down our context and figure out where the points of intervention are. I hope the students picked up a little bit of that when we were there. It takes some experience and observing in a variety of places. But that's helpful to me. Obviously, the European context is a place where a lot of this is happening. There are national- and [European Union]-level resources that are advancing sustainability, both the research and practice. You have a lot more promotion and visibility, communication around great models of sustainability at the community scale, at the national scale. That would be lovely to have, but we don't, so we find other ways to get it done."

Tracking international developments.

Advancements in sustainability issues are being made in other countries, notably European countries. The interviewees described this distinction in various ways, from a competitive motivator to learning opportunities to a more action-oriented approach to

sustainability by government agencies and other organizations. Many, even those who have not been involved in international collaborations, see sustainability research and teaching that is occurring in other countries as inspiring, motivating, and the source of new ideas. A professor described the strong influences of informal international networks, even without specific involvement in international work:

> "I've never done any international project in my life. . . . I've been very influenced in my thinking about education in relation to sustainability challenges in agriculture by a group of Western European agroecologists who all participate in this interesting distributed graduate program across about five countries in Western Europe around agroecology. Just seeing what those people are doing and learning from their experiences, . . . learning from their growing pains and their successes has been good."

Progressive approaches in other countries can influence faculty who do not necessarily engage in international research. One scientist described the power of observing research and application in other countries:

> "I haven't been as engaged in international activities. I've done sabbaticals overseas, but that's been more personal scholarship. I would say that there's a lot of activity in Northern Europe that has informed my field in general in the sustainability area, and the work that I've done has been, in part, responding to that. [The Northern Europeans focus more on] innovative wastewater treatment activity and innovative water treatment approaches. They don't chlorinate in some places in Europe at all; we chlorinate our water here. They're more first adopters of some of these low-energy treatment technologies, and we've tended to be, in the U.S., a little more status quo. [There are] more water re-use opportunities over there.
>
> A lot of that work [in Northern European countries] has informed what we've talked about in the think tank [involving faculty across departments]. [The Europeans] have different regulatory structures over there. I think they tend to be less command and control than we do. I would say all of that has informed what I do; that's an influence for sure."

European countries have a strong lead over the United States in areas of sustainability, as stated previously and reflected in the literature (Gardner, 2011). The

level of understanding and support for sustainability research by the citizenry in other countries and national policies play key roles in progress on sustainability research. The sense that the United States is lagging in aspects of sustainability research is a factor in the way that some respondents think about their research and teaching. A researcher said:

> "More of the international influence for me is that, from a sustainability standpoint, Europeans are way ahead of us. That's motivation for us. We are in catch-up mode. They've implemented policies that are much more restrictive than we have in the United States with respect to emissions or landfilling or energy, and plenty of them are doing just fine. The policies that people want and are willing to implement are driving that [research]."

Another professor also compared the support for sustainability science in European and other countries with that in the United States:

> "One [international influence] is a little glib in a way, but in the field, the Europeans are ahead of the game on being very conscious about institutional structures that can support [sustainability science] work. So, whether it's setting quotas for conference participants or even just the focus of conferences, they seem to have more money and more interest in bringing people together around sustainability. . . .I get the sense that places like China, India, a growing number of African nations, Brazil, a lot of these emerging economies – without falling into caricatures – see that they can keep their economy moving, but they're also seeing that if they don't do it right, it's all going to go to Hell."

Some international work is necessary due to the nature of the research that a scientist is conducting, whether related to human populations, comparisons of the world's biomes, species interactions, and a host of topics. Time spent in other countries provides insights into science, science organizations and policy, and ways to fund international research. Two interviewees said that the majority of their work is internationally focused. A professor said,

> "[International influences] are huge. Both of [my major] projects have an international component. [For one research project], I had to go to China and South Korea and Japan to do research there. You have to have a scientific connection there, and so in all cases, I was either working with a university, in the case of Japan, and in China it was more like the government and also the university. You always need to have some kind of hosting institution when you are trying to do that kind of work. In order to do this work, the international collaborations are super-key."

A researcher described the cycle of travel and then fundraising that is essential to support expanded international work:

> "I've been very fortunate to be able to travel to all of these different locations around the world and to hear people's stories, which has enabled [our ability] to educate millions of learners around the world. Now – those connections that I made – I'm trying to build upon them in order to get additional dollars to do more research around sustainability. We put in a grant that had to have three different countries involved. And there is no way that I would have been able to do that if I hadn't done the work [in other countries] that I had done earlier. I love the ability to collaborate [on international projects]."

Behaviors in other countries and the attentiveness of their general publics is related to national policies and practice, as noted in the comments of other interviewees. A professor who came to the United States from another country but who did not indicate any direct international influence, provided observations on international aspects of sustainability:

> "I'd say that [international influences are] less the case for me, which is kind of ironic having not grown up [in the United States]. For as long as I've lived [in the United States] . . . I'm still blown away by how hard it is to get people to change their behavior in this country because it's so huge. People [in the United States] just don't think about resources differently [yet]. If you're in Europe, everyone recycles and thinks about how they use electricity. Everyone is very conscious of their gas use, but then when you think about policies, gas is $6, $8 a gallon, so you have all these different ways policy plays out in people. It's hard to tell: Are people just inherently more environmentally conscious in Europe?, or is that just a factor of living in too crowded a space?"

Conclusions related to *international arrangements.*

International arrangements influenced the majority of interviewees either directly, through in-country research or collaborations, or indirectly, through their attentiveness to tracking sustainability developments in other countries. I conclude that the factor international arrangements has a strong influence on faculty behavior. More than half of the professors interviewed described some type of influence on their work through international arrangements or relationships. International experiences and observations appear to have established a platform for the interviewees' ongoing pursuits to address sustainability research questions in a broadly collaborative if not necessarily international context.

Strength of Influence of Sustainability Science Factors

The seven factors that I analyzed are interrelated; however, the questions posed to interviewees were developed to collect data that would best characterize each factor. Through the coding process, I identified the relative strength of influence for each of the seven factors, as described in Chapter 3. The descriptors are: *very* strong, with close to all responding positively; *strong,* with about three quarters of positive responses; *moderate,* with about half responding positively; *weak,* with very few positive responses; and *no influence,* with no positive responses. The frequency and intensity of responses was captured through magnitude coding. Intensity of responses was based on the passion and emphases with which interviewees responded to the questions. The factors that are described as a very strong influence on faculty behavior reflect responses by the majority

of interviewees, and with a notable level of intensity. The results are presented in Table 2.

Three of the factors have a very strong influence on faculty behavior: colleagues from other disciplines, stakeholder and citizen interests, and student interests. Two factors, funders' priorities and international arrangements, have strong influence. The factor associations, organizations, and networks has a moderate influence; and new journals has a weak influence.

The strength analysis leads to the answer to my research question: *How do key factors related to the evolving field of sustainability science affect the behavior of faculty members in addressing problems related to the interactions between human and environmental systems?*

Of the three factors that have very strong influence on faculty behavior, two involve campus-based groups, in general, colleagues from other disciplines and students. With the priority career focus that the interviewees have on the interdisciplinary requirements of sustainability issues and sustainability science as a field of work, it is not surprising that colleagues from other disciplines are a very strong influence. All professors stated that sustainability science is based on interdisciplinary team efforts. The 20 professors most often indicated that their collaborators and interdisciplinary team members were located on the University campus. Some, however, have collaborators who are located at other academic institutions in the United States and abroad. Similarly, their campus-based students also have a very strong influence on the professors. The professors indicated that the fresh perspectives, ideas, and energy of the

Table 2: Strength of Influence of Factors Related to Sustainability Science that Affect Faculty Behavior

Factors	Strength of Influence
Colleagues from other disciplines	Very strong
Stakeholder and citizen interests	Very strong
Student interests	Very strong
Funders' priorities	Strong
International arrangements	Strong
Associations, organizations, and networks	Moderate
New journals	Weak

students are compelling motivators for their teaching, research, and community engagement. Perhaps most important, the professors emphasized the ready understanding that students have of the wicked problems of sustainability and the application of sustainability science. Many professors especially noted the broader perspective of their students that includes social and economic aspects of environmental issues. The student influence on the professors is very strong. The dedication to students, reciprocally, is obvious from the professors' responses to questions. The professors addressed the need to educate future scientists to be able to work collaboratively on interdisciplinary teams and to explore new approaches to solving complex societal problems. Proximity to both students and colleagues from other disciplines might contribute to the very strong influences of both factors.

The very strong influence of the factor *stakeholder and citizen interests* could be viewed as unexpected. Academic scholars are frequently pegged by the public as aloof and disengaged from day-to-day realities from their ivory tower perch. The interviewees, with their involvement in the transdisciplinary work of sustainability science do not match the profile of a typical, discipline-oriented academic. The professors described the engagement of citizens, non-profit organizations, other public and private sector entities, and elected officials as essential to their work. The engagement of external partners in working toward solutions to sustainability issues is core to sustainability science. Although working with communities and groups of non-scientists to build trusting relationships as the basis for research projects can be challenging, all professors saw stakeholders as essential to advancing sustainability solutions.

The factors *funders' priorities* and *international arrangements* had strong influence on almost all professors. Professors said that they strive to address the criteria established by funders while also maintaining the integrity of their research idea. They acknowledged the shifting priorities that can characterize federal and state funding agencies and philanthropic organizations. They also noted the increasing trend toward a sustainability focus in Notices of Funding Availability and calls for proposals. The strong influence of international arrangements likely reflects the global perspective of sustainability science – the oceans, climate change, and biodiversity are not discrete or isolated issues. Even when some professors did not mention international research projects, they referenced their attentiveness to the results of international collaborations and networks and the advances of sustainability research in other countries.

There might be linkages between the factors *new journals* and *associations, organizations, and networks,* specifically related to the fact that professional scientific societies frequently are the publishers of disciplinary journals. The influence of *new journals* was weak, and the influence of *associations, organizations, and networks* was moderate. The new journals that focus specifically on sustainability and sustainability science likely do not yet have the readership or visibility of long-standing publications. Many of the articles in the new journals focus on the epistemology and methodology of sustainability science rather than the issue-oriented research that is a priority for the professors I interviewed. In addition, the professors tended to pursue publication of their research in the established, high visibility, elite journals that are receptive to interdisciplinary and sustainability science research. About half of the professors said

that associations, organizations, and networks have an influence on their work. Informal networks that focus on sustainability were cited by many professors as an important influence on their work. Others stated that such scientific organizations have no influence because their generally disciplinary focus is not a best fit for professors who conduct interdisciplinary research.

Concluding Questions

In addition to analysis of the seven factors related to the field of sustainability science, I inquired about institutional constraints that might influence the interviewees work. Those responses are incorporated into the discussion of factors as appropriate and contributed to the themes that emerged from the data analysis. I also inquired about the professors' insights on the field and their visions for the future.

As noted in Chapter 3, I was aware that some interviewees might not choose to comment on the institutional constraints that they may encounter in their research, teaching, or community engagement. In response to the question, "What influence, if any do institution initiatives or constraints have on your work in sustainability?," two thirds of the faculty members noted the positive influences of the interdisciplinary center with which they were affiliated. Although this question was not part of the analysis of factors of influence, it is useful to describe responses.

Several scholars noted the funding for innovative and entrepreneurial interdisciplinary research that they accessed through the center as seed funding or a way to leverage opportunities to compete successfully for external funds. The majority, however, emphasized the importance of the center as an informal forum for sharing ideas.

A researcher summarized, "[The center has] provided a real forum for people to do this hard work, to get to know each other across these fields, and talk about these [sustainability science] issues." Another scholar noted that the interdisciplinary center helped to overcome the challenges of bringing people together across multiple campuses. Others described the value of the interdisciplinary center in terms of comprehensive research support – support beyond funding – and its physical space, signature events, and the internal and external information provided by the center's communications team.

Institutional constraints were more frequently articulated through responses to the influence-factor questions, as well as in the section that follows on sustainability science, rather than directly to the question regarding potential constraints. Five individuals, however, specifically addressed barriers that can disadvantage students. An interviewee noted,

> "The biggest barrier we have to effective interdisciplinary work at the University of Minnesota is the way in which money is structured around teaching and research. Because schools lose money when students take courses outside of their units, schools are highly disincentivized to want students to have interdisciplinary education. . . . A lot of students, especially graduate students, aren't getting an interdisciplinary education, because their schools are going to limit how many courses they can count from outside, because [the schools] lose money."

Two scholars commented on the length of time required to advance an interdisciplinary course or degree program through the administrative system. One interviewee described a time-consuming effort among multiple internal partners to update and refresh a long-time environmental education program and transform it into an interdisciplinary sustainability education program. The respondent said, "The issue of the course designator became such a problem…'Who has ownership? Who decides?' It

was just not worth the argument of rules about tuition split." The other faculty member stated that "it took us about four or five years to get approval to team teach because we had three colleges [involved]…to orchestrate that was a nightmare."

Institutional constraints that were identified through responses to questions related to the factors of influence are characterized in the subsequent section on themes resulting from the analysis.

Sustainability Science: A World View

To conclude each session, I asked the interviewee, *"Is there anything else that you would like to add?"* All 20 professors reflected on the role of sustainability science in their current and future work. The comments underscore the creativity, commitment, and passion of these individuals for contributing to solutions for complex and interwoven environmental, social, and economic issues. Responses also suggest the collective view that a focus on sustainability – through the transdisciplinary lens of sustainability science – will continue and likely be integrated or subsumed into the range of disciplines.

The respondents addressed sustainability and sustainability science from their academic work, to engagement of citizens and policy makers, to long-term global concerns. They repeatedly referenced the challenges of conducting sustainability work within the structures of institutions of higher education.

Institutional Barriers

Academic institutions like other large and complex organizations are relatively slow to make change to their internal structures. With the efforts of faculty and students as change makers, disciplinary constraints may ease more quickly than some envision. A

researcher noted the need for institutions to pursue the culture change that fosters transdisciplinary experiences of sustainability science for the benefit of younger faculty:

> "I think we're broadly talking about growing sustainability science, it seems to me, and I think that there's a really big deficit [regarding] young faculty. Their intentions around addressing complexity and complex challenges and transdisciplinarity parallel the graduate students. [Young faculty] want to do their work in an engaged way, and meanwhile, they have all these things that they have to do that makes that long lag time . . . to form interdisciplinary communities. That long lag time is a problem.
>
> How do we let those folks continue to develop and achieve their heartfelt aspirations around everything we've been talking about – to do sustainability science? How do we help them develop while they're pre-tenure? And, how do we develop a culture that says, "Okay, this complex, professional practice that sustainability science consists of has certain skills associated with it, and certain habits of mind and certain perceptions that add up to the skill set of the transdisciplinary scientist.
>
> We don't all have to do [sustainability science] obviously, but, in this sustainability science space, in this transdisciplinary space, how do we grow that capacity not just among the faculty, but [as] an emergent property of the institution?"

The disciplinary and other institutional barriers that can slow advances in sustainability science work were described by several interviewees. One noted:

> "I would sum up both my approach and the issues that I have to deal with as being breaking down silos. So, whether it's thinking about how you fit climate change into a K-12 [kindergarten through 12th grade] curriculum or how you think about doing interdisciplinary work at the University, it's taking those traditional silos that exist, whether they're departments or disciplines, and breaking the walls down…allowing content to move across, or people to move across, science and education."

The Role of Faculty Members

Faculty members can serve as role models for students through their research, teaching, and community engagement. A scholar addressed the interdisciplinary and

transdisciplinary enhancements that need to involve students and practitioners – and a role for faculty members as connectors:

> "For sustainability science, in the end, it's really looking at: how do we develop better interdisciplinary collaborations and transdisciplinary collaborations too? How do you make better connections between the academic research and application, whether it's my students or working with scientists who are trying to figure out how to do that? One term that's out in the literature now is 'knowledge broker,' and I would say that's one of my roles. . ."

A professor who works on a range of big-data projects also emphasized the need for faculty members who work at the intersection of various fields to serve as connectors across disciplines:

> "[Sustainability science] is a growing area, and I think you need a certain mindset. . . .You have to be able to go out of your comfort zone – understand that you will not be able to publish in your own favorite venue and so on. But going forward, what I think will help is two things: give people tools so that they don't have to look at the raw data. We don't want to get between the scientists and the data. We want to make a nicer bridge, so that they'll look at the data in a right way . . . This has been a success in our ecology work. The second goal I have is that [sustainability science] becomes a part of the discussion in the computer science community, in the data sciences community. . . This is just something we're doing for our future generations on our planet. . . . This is something I'll continue to do: go out to our community and keep talking about [sustainability science]."

Research and public understanding can be maximized through intentional efforts of scientists working on sustainability issues, through training and inviting others to participate. A researcher voiced a commitment to ongoing research and education:

> "[My hope is] that knowledge will build on itself, that by trying to integrate fields that have traditionally been separated, we'll get somewhere better. I look at my piece as trying to train people to think that way and to work in that [sustainability science] area to put out high-quality research that others can build on, and to communicate as best I can with the public to encourage them to also feel that same passion to make things better. I get really disheartened when I hear of . . . habitat loss, and the irreversibility in the world that happens as we become more affluent. There are more of us, and I want to do whatever I can in trying to make it so that we don't lose some of what took nature billions of years to develop."

Sustainability science success is based on engagement well beyond the campus. A professor emphasized: "Part of [sustainability science] is making connections and being collaborative. I think that naturally broadens your perspective and makes it clear why you might want to reach beyond academia which in the end, I think, is where we need to go." A scholar who uses a range of engagement processes noted the need to convey information to a broader audience through a variety of formats:

> "My contribution is tied to methods that can serve sustainability science. I am trying to promote art visualization…to promote this idea of sustainability. An artistic presentation of mathematical models can be pictorial or it can be a dance. Papers are good and necessary, but they rarely influence decision makers; they rarely impact local people."

Another professor also expressed the need to work beyond academia and find ways to engage with a broader international public:

> "Everything I'm doing is integrated around the core notion of understanding and maintaining biodiversity. That's what my research is focused on, and I'm reaching out to the political arena through [an intergovernmental group under the auspices of the United Nations]. That's a primary vehicle for connecting to a larger audience and a larger world, and trying to have an impact outside of the ivory tower."

Many respondents addressed the overall contributions of sustainability science approaches as sustainability challenges increasingly affect regions of the globe. They described sustainability science as a way of looking at the world and working toward long-term solutions. Transformational change related to sustainability science is in process. Several interviewees described the significant changes among students and the public regarding the desire to address environmental, societal, and economic issues in a comprehensive way. A professor stated:

> "I think the growth of interdisciplinary thinking and the grounding of natural science in social forces are maybe the most important things that have happened in my professional lifetime to change how people think and what they work on. So, in that regard, the development of sustainability science is maybe the most important thing that's happened, even though I still consider myself very much in the natural science, biology camp. If people asked me what I do, I would list ten or 12 things before I said sustainability science . . . but it's been a gigantic factor in my professional lifetime."

Others underscored the dual priorities of the health of the environment and the well-being of human populations. A scholar described the personal significance of sustainability science work:

> "What are those central purposes of why we do [sustainability]? For me, it is biodiversity, the exigency, and the Anthropocene, to make sure that we kill as few species as possible and increase biodiversity when possible; environmental health, that people have a certain health and welfare no matter who they are; and then, environmental justice, that it's not certain people bearing the costs of our rhetoric and actions… Questions of environmental justice—that's been a big one."

Another researcher described a personal commitment to continued sustainability research:

> "I think, of all the major environmental questions that the world faces, the two biggest ones have to do with human need for food and human need for energy. I'm more interested in the food aspect of that, not because I don't think the energy and greenhouse gases are not important, but I think that food has been systematically overlooked by scientists much more than the greenhouse gas issues have been. . . . All the various impacts of how food is produced, water pollution, air pollution, greenhouse gas release, land clearing, extinction of species, and so on are all things which interest me.
>
> I think it'll be those kinds of issues that I'm going to keep pursuing: extinction, habitat loss, loss of biodiversity, groundwater pollution, greenhouse gas emissions from land clearing. Those are all the things that I am dedicating my time to. I think they're incredibly important, and I'm excited to work on them. I can't imagine not doing that work."

Contributions to sustainability solutions will result from the work of scholars and citizens, and holds true for the many who see their roles as both. One interviewee said:

> "I decided in my early 20s I really had two career goals. I wanted to make the world a little better than I found it, and I wanted to do work that feels meaningful. So sustainability is one piece of that for me. There are a lot of pieces to it, and similarly, academia is one path that I could be taking and not the only path. . . . I do feel like I want to do a better job at trying to be a constructive participant in public dialogs on [sustainability] issues."

A professor encapsulated the perspectives of many of the interviewees as they reflected on the pathway through their academic careers, contributions to new knowledge, and the responsibility of preparing the next generation of scholars who wish to address societal grand challenges through sustainability science:

> "The older I get, the more I think about long-term implications of the work we do. When I was young, I was trying to get tenure and thought about, well, how do I get tenure? And just after that, how to sustain a research group and get grants. For me, I'm all in now because I have a track record, and a group of publications and maybe discoveries that have been the springboard for what I want to do. I want to continue in this area because, not only is it hard, it's challenging. The students want it. It has the potential for long-term impact. That's what drives me in the sustainability front."

Sustainability science is the scientific approach to addressing local and global issues of sustainability. Sustainability science can help to make the work that encompasses the environmental, social, and economic less overwhelming. A researcher reiterated the increasingly ubiquitous nature of sustainability and the ways that it might become infused into the way that scholars and others view the world:

> "For me, sustainability is something that is a way of thinking about the world. It's [so] engrained that I almost am not even conscious of it, which maybe means I gloss over it and assume that other people are thinking about it. Maybe I don't communicate about [sustainability] as well as I could or explicitly call out the way I am framing it. I think there are more and more people who are at that point where it's not just a 'Well, I'm going to do sustainability,' like it's just a thing that I do or learn about. I think it's a way of life. It's just in the way that you think about the world, and the way that you want to work in the world. . . I see students with that orientation more and more often. I see people capable of doing

> [sustainability] and knowing that there are skills and tools to be able to do that. So, I hope we get more to that point where it's just what we do."

The comments of the professors at the close of the interviews in addition to their opening comments on the meaning of sustainability science are important bookends to the analysis of the seven factors. The results of the data analysis showed common themes across the influence factors. Themes that emerged are described below.

Themes Resulting from Analysis

In addition to the interviewees' responses to the questions corresponding to the seven factors that could affect faculty behavior, themes that cut across the factors emerged from the interviews. I identified themes through the coding process, and discuss the five predominant and overarching themes below.

The five themes that I identified in my analysis are: the nature of sustainability science, disciplinary research traditions, interdisciplinary research, reaching broader audiences, and saving-the-world motivation. The themes arose as individuals reflected on each of the seven factor questions and on context questions that are not technically part of my analysis. Given the weight that interviewees gave to these issues directly and indirectly, I include descriptions of the themes as an outcome of my analysis.

The Nature of Sustainability Science

The 20 professors interviewed for the study were all well-versed in sustainability science and spoke in strong, positive terms about its contributions. They see their students as highly motivated to contribute to problems that require the interdisciplinary approaches that embrace the integration of environmental, social, and economic

elements. They also view the contributions of local knowledge by citizens and interest groups as high value. Although complex in its interdisciplinary nature, sustainability science is an ongoing area of contribution that will continue to advance knowledge and problem-solving, either as a field of science itself or through its integration into the range of disciplines.

The majority of interviewees discussed the complexities of lack of consensus on the definition of sustainability and sustainability science in the literature, given the number of definitions of sustainability and sustainability science that have been posed over the years. Many literally recited the definition of sustainable development provided in the 1987 report *Our Common Future* (World Commission on Environment and Development), as the gold standard. Others referred to the "use-inspired research" that is included in the definition by Matson, Clark, and Andersson (2016). In general, interviewees described sustainability science as the work of addressing problems of sustainability.

Students and stakeholders are key elements of sustainability science, according to the interviewees. One scholar noted the time spent investigating various definitions, particularly to benefit students who were taking the professor's class entitled Sustainability Science. Others discussed the savviness of their students, who describe their projects and educational and career interests in terms of sustainability science – and their students' comprehension of the term. They emphasized interdisciplinarity and transdisciplinarity, specifically the engagement of citizens, policy makers, and other external stakeholders as critical components. One researcher described sustainability

science as "so much bigger than science. It's got to involve social scientists, policy makers."

Interviewees described sustainability science in two distinct ways: as inherent in certain disciplines and as being incorporated to further expand disciplines. Some see the germination of sustainability science in their respective disciplines of ecology, geography, and landscape design, for example. Alternatively, others see sustainability science as being infused into the discrete disciplines over time. One professor described sustainability science as "a meta-concept that can help organize assumptions about interdisciplinary collaboration, and even transdisciplinary."

Others view sustainability science as a comprehensive problem-solving approach to address the intractable, wicked problems that challenge our societies. The emergence of sustainability science was couched as a "which came first" question: did sustainability science help to direct interdisciplinary approaches to the large, intractable problems, such as climate change? or did these complex problems prompt the origin of sustainability science?

Almost all the respondents, having noted the challenges of defining sustainability science, said that an agreed upon definition is not of major consequence. They are clearly focused on the grand challenges to be addressed, and the interdisciplinary creativity involved in finding solutions to those challenges. They all appear to have an inherent compass for addressing issues of sustainability, and any disagreements about the definition in the literature or elsewhere do not hamper what they see as the pressing issues at hand. It is noteworthy that, when asked about their work, none would describe

themselves as sustainability scientists, although all said that their work is squarely in the realm of sustainability science.

Disciplinary Research Traditions

The 20 professors are clearly accomplished in their respective disciplines, and in some cases, nationally or internationally known for their scientific contributions. "The tyranny of the discipline," as one professor put it, was emphasized repeatedly by professors during their responses to the interview questions. While appreciating the need for strong academic disciplines, they also emphasized disciplinary expertise as a springboard for fostering quality interdisciplinary research.

Several researchers addressed the structure of academic institutions, describing the strength of departments in maintaining discrete disciplines; the silos that are reinforced by departments, colleges, and other units; and the tenure process that keeps individuals focused on a narrower pathway of scholarship. They described the early-career need to focus on their discipline. One professor addressed the frustration and weight of the very narrow focus of scholarship leading up to tenure, at the same time that the professor was eager to dig into sustainability challenges that were of broad scope. Another respondent ruefully described the ingrained disciplinary traditions and rewards of academia, saying "I'm in the position where I probably shouldn't be doing that anymore, but, you get into the system and that's what you do." Another described "disciplines in the draconian sense," sharing the conclusions of a colleague who summarized years of work: "I didn't realize how much that I had done, until I got tenure, was done to get tenure."

Many noted the liberation that tenure provides, enabling faculty members to overstep the bounds of their disciplines. They seemed to appreciate – or perhaps were relieved by – the post-tenure opportunities to address broader, complex issues with colleagues from other disciplines and to expand the options for their published work through venues other than disciplinary journals.

Interdisciplinary Research

Interdisciplinary research was, in general, described across all seven factors as the essence of sustainability science. Most of the 20 professors concurrently emphasized the incorporation of stakeholder engagement in interdisciplinary work, or otherwise referred to sustainability science work as transdisciplinary. It is important to note that interdisciplinary research was not couched as an alternative to disciplinary research. The respondents addressed the relationship between disciplinary and interdisciplinary research, highlighting the need to merge expertise from multiple disciplines to solve sustainability problems.

The interviewees all have conducted interdisciplinary research with colleagues and all emphasized the high value that interdisciplinary solutions bring to a complex problem. Many described the drive and energy generated through shaping a research project collaboratively, and the excitement of learning more about a facet of an issue through the expertise of a colleague from a different discipline. The professors spoke strongly about their students' inherent interest in approaching questions from an interdisciplinary perspective. One described the need for academic institutions to offer students the experiences and training that will prepare them, from their own disciplinary

expertise, to facilely move into interdisciplinary team work. Another noted the joy of working with students on interdisciplinary sustainability projects compared with collaborating with faculty colleagues who were set in their disciplinary ways. Some also noted that their interdisciplinary work included the collaboration of colleagues in the private sector and in institutions outside of the United States.

The enthusiasm for interdisciplinary work was balanced by descriptions of the reality of forming interdisciplinary teams and conducting interdisciplinary research. Respondents emphasized the years of effort necessary to establish a cohesive, effective research team. They noted the team challenges of terminology, differing approaches based on disciplines, and personality. Some noted the challenges for researchers in the natural sciences to recognize the often difficult-to-quantify aspects of human behavior and other elements of the social sciences. Others described the personal decisions to forgo time invested in individually authored journal articles to work on grand challenges in sustainability that can be addressed only through interdisciplinary approaches. The result was fewer publications, but publications that were perceived as making greater contributions and having broader impact through elite rather than disciplinary journals. Some professors also noted that interdisciplinary work is not for everyone. They emphasized that success comes from a commitment to solving complex problems through a sustainability science approach and patience in formulating a tight-knit team. They underscored the personal rewards of learning and contributing to solutions with colleagues.

Reaching Broader Audiences

The professors addressed the outcomes of their work and its effects in a variety of ways that I have clustered under the theme *Reaching Broader Audiences.* Key elements relate to the readership of the journals where they publish; their community engagement work, locally and internationally; the cascading influences of their students; and communication and advocacy.

Many of the professors identified reaching a broader audience as a key factor in their decisions on where to publish their research results. In general, the reading-audience goal focused on the elite journals that often accept more sustainability-focused work than do the disciplinary journals, and attract a diversity of disciplinary readers. One scholar particularly noted the personal desire to reach beyond the disciplinary journals and "the scientists I already know." In addition, the point was made that the media are more likely to report science stories that appear in the elite journals, and so the potential to reach a general reading audience is increased.

The relationships fostered through involving citizens, non-profit organizations, public agencies, and the private sector in sustainability research was cited by a number of professors. Some noted that through community engagement, local people who participated often developed a strong interest to be leaders on sustainability issues in their communities. Others gave examples of working with underrepresented communities locally and internationally. They addressed the importance of ways of knowing that represent a world view other than that of Western science, and the trusting relationships that must be nurtured over time. Such relationships can lead to new opportunities for

research partnerships and engage new philanthropic partners, extending new knowledge through a variety of conduits.

One scholar described the reach of University students who are using sustainability science to teach science courses in primary and secondary class rooms. The individual noted that similar sustainability science-based teaching techniques can be used to expand the general public's understanding of science. Such techniques focus on the problem rather than the science *per se,* for example, developing public information on water pollution, changes in weather patterns or biodiversity due to climate change, or other issues of concern to a community.

A few respondents noted the importance of serving as a spokesperson, whether to the media or to various organizations and other audiences. They felt strongly that communication is an important role for scientists, as individuals and through institutions such as professional scientific societies and universities. They noted the importance of media training and a deeper understanding of the need to make science relevant to the public. A researcher emphasized a commitment to reaching out to "a larger audience and a larger world" through the political arena. Sustainability science provides a core approach to issues of science and society.

Saving-the-World Motivation

A number of professors spoke eloquently about the urgent need to solve the complex societal problems that will help to ensure the sustainability of humans and the environment over the long term. A catch phrase that was used in some instances to convey the sustainability goals – and not in a glib or superficial way – was "save the

world." The passion for sustainability science work included the long-term status of the planet, issues of environmental justice, and legacy.

Several researchers cited "the potential for long-term impact" or the capacity to stave off habitat loss and other irreversible changes in the environment as the driver for their continuing work on sustainability issues. Some described the importance of sustainability science as the need to manage the planet under the pressures of population increases.

The needs of populations worldwide, and the differences across regions that are resource poor and economically challenged from those that have a higher quality of life were raised by several respondents. Some scholars expressed the insights gained through international experiences and witnessing the need, in different parts of the world, to bring people out of poverty while maintaining natural resources. One professor specifically emphasized the issue of environmental justice and the need to address environmental health but also human health and welfare for people everywhere.

A sense of personal responsibility as scientists and the legacy that sustainability science can provide was noted repeatedly by respondents. Several professors articulated the responsibility to educate students and train others to apply sustainability science to solve problems. Some hoped to pave the way for new faculty members to pursue sustainability science and its transdisciplinary approaches, noting also the need to influence changes in the structure of academic institutions. Others said that their contribution is to conduct research that others can build upon or that enhances methods that will serve sustainability science. One scholar said, "I want to do whatever I can . . .

so that we don't lose some of what took nature billions of years to develop." Another professor simply described the desire to "make the world a little better than I found it."

The five themes represent the threads of ideas, values, responsibilities, and contributions that the 20 faculty members interviewed for the study articulated with some consistency as they responded to questions about the seven factors of potential influence. The themes contribute to the foundation that supports the conclusions of the study.

CHAPTER 5
DISCUSSION

This study analyzes the influences on faculty behavior of seven factors related to the evolving field of sustainability science. It explores the extent to which the factors *new journals; associations, organizations, and networks; funders' priorities; colleagues from other disciplines; stakeholder and citizen interests; student interests;* and *international arrangements* affect the ways in which faculty members approach their research, teaching, and community engagement. The factors were derived from the literature on characteristic elements that are associated with the emergence of new fields of science (Crane, 1969; Griffith and Mullins, 1972).

Factors of Influence on Faculty Behavior

The results of the analysis provided the conclusions and insights to answer the research question: *How do key factors related to the emerging field of sustainability science affect the work of faculty members in addressing problems related to the interactions between human and environmental systems?* Three of the seven factors of influence – colleagues from other disciplines, stakeholder and citizen interests, and student interests – exert a very strong influence on faculty behavior. The factors funders' priorities and international arrangements have a strong influence. The factor associations, organizations, and networks has a moderate influence, and new journals exerts only a weak influence.

The factors that reflect not only an engagement with individuals, but also a deep and oftentimes lasting relationship, bear the strongest influence on the work of the professors I interviewed. All interviewees addressed, in different ways, the invaluable relationships they developed over several years with colleagues from other disciplines – as interdisciplinary team members and as co-learners. Similarly, all spoke with conviction about the innovative capabilities that their students bring to the classroom and to a research project as master's and doctoral students (and some undergraduate students as well). It is common to acknowledge the influences that faculty members have on their students. This analysis documented the major influence that students and their creative view of global sustainability problems have on their professors, including on collaborating professors with a different disciplinary expertise.

The 20 professors were also notably experienced in conducting sustainability science research, not simply *in* a community but *with* a community. They described, in an altruistic manner, the need to incorporate community members into research as the sources of local knowledge. They worked with farmers and rural communities, Native Americans, public schools, non-profit organizations, corporations, and small pockets of populations in resource-poor and economically challenged regions across the world, for example. The 20 professors appear to be driven by the excitement of finding faculty colleagues, students, and partners outside of academia who also have concern for the confounding problems that are roiling in regions of the world. They are driven by others who hold a comprehensive concern and curiosity about the world around them and demand a multi-pronged approach to problem-solving.

I found that the priorities of funders and international arrangements are factors with strong influence. The ability of savvy researchers to capture external funding awards is essential to their ongoing investigations. It is subsequently not surprising that funders' priorities are strongly influential. The increasing focus on sustainability issues – the integration of environmental, social and economic concerns – by funders, appears to reinforce, validate, and motivate the professors in their sustainability science-based investigations. International activity in sustainability science is also a motivator. The professors viewed the national policies, funding levels, and public support for sustainability issues as circumstances that place other countries, particularly European countries, in a league above the United States. For some, a sense of competition in the international arena is a motivator for intensifying their work. For others, collaborative relationships and witnessing advancements in sustainability science in other countries is a strong influence.

Associations, organizations, and networks is a factor bearing a moderate influence, with about half of the professors describing a benefit to their work. The option of publishing in new journals that target sustainability and sustainability science had weak influence on the professors. The associations and publications might be viewed as less interactive, institutional entities, especially compared with colleagues, students, and external partners. The importance of individual relationships appears to outweigh organizational relationships for the 20 professors. In theory and practice, these professors may be on the leading edge of sustainability work and in front of the positions of disciplinary societies, rendering the benefits of the societies less meaningful to them.

The establishment of new journals specifically focused on sustainability and sustainability science has not deterred them from pursuing placement of their research findings in the handful of elite journals that attract broader reading audiences.

In response to the research question, five of the seven factors related to the evolving field of sustainability science have strong or very strong influences on the way that the 20 professors interviewed for the study conduct their research, teaching, and community engagement activities. In addition, the five themes that cut across the responses to the questions expand the conclusions of the study. The themes, described as the nature of sustainability science, disciplinary research traditions, interdisciplinary research, reaching broader audiences, and saving the world motivation, are incorporated into the discussion that follows.

Discussion

The study of factors related to the influences on faculty research, teaching, and community engagement provides important validations and insights. I highlight four areas in which the study builds on existing literatures: emerging fields of science, community engagement and transdisciplinarity, faculty and the academic culture, and sustainability science. The study findings are consistent with the literature on characteristics of emerging fields of science. The influence of students was strongly articulated by the interviewees and with an insistence beyond that captured in the literature. The influence of stakeholders came from the sustainability-science stance, rather than from the Land Grant tradition of outreach or the growing focus across

institutions of higher education on community engagement, also referred to more generally as public engagement.

The study demonstrates the role of these faculty as leaders, not only through their sustainability research but also through their accomplished approaches to interdisciplinary and transdisciplinary work. The study also demonstrates the deep understanding and passion that these 20 professors – representing 16 disciplines, if not more – have for sustainability work. I especially underscore the range of disciplines represented and the consistency of respondents' views on the factors related to sustainability science. The consistency across disciplines of education to engineering to biology to public policy suggests, from this relatively small group, that sustainability science is accepted and practiced by an unusually broad spectrum of scientists, collaborating in very interdisciplinary and transdisciplinary ways.

Emerging Fields of Science

I based the seven factors of analysis on the literature of emerging fields of science and the emergence of sustainability science to date. The analysis of responses to the seven factors together provides a view of sustainability science over time, which is relatively consistent with the literature on the emergence of new fields of science. The study points to varying degrees of importance of some of the literature-based characteristics of an emerging field. I describe contributions from this study that might provide additional understanding or insights about the evolution of sustainability science, especially related to the factors student interests, colleagues from other disciplines and stakeholder and citizen interests.

Students are important drivers of an emerging field. Griffith and Mullins (1972) describe the importance of engaging graduate students, in particular, to participate in research and training opportunities and to teach younger students. They emphasize the essence of engaging students in learning experiences, stating, "The importance of these activities is clear: groups without students die" (Griffith and Mullins, 1972, p. 962). Specific to sustainability science, student interest in interdisciplinary environmental education continues to grow (Vincent and Focht, 2011; Brower, 2011).

My study demonstrates the very strong influence that students have on the professors who were interviewed. The professors' responses went beyond an interest in training young scientists who will be well prepared to work on sustainability problems and perpetuate the field of sustainability science. They emphasized the fresh perspectives that students bring to the classroom and to research projects, generally with a strong integration of the environmental, social, and economic issues. Student demand for sustainability science experiences is resulting in what one professor referred to as the "trappings" of sustainability science – sustainability minors, sustainability courses, and community experiences, for example.

Professors described students as a benefit to their own thinking and work, rather than only considering their responsibilities as teachers and mentors to students. Several interviewees also spoke of their students as collaborators. The results from assessing student interests as an influencing factor contributes to the literature, specifically as professors and students engage in interdisciplinary projects with students and professors

from other disciplines – and in transdisciplinary projects that include community partners.

The very strong influences of the factors stakeholder and citizen interests and colleagues from other disciplines are described in detail in the following sections, based on their importance to the findings of the study.

The factors funders' priorities and international arrangements were a strong influence. Developments in funders' priorities are likely occurring more quickly than is reflected in the literature. Funders are increasingly visible drivers of sustainability science through programs focused on sustainability or comprehensive interdisciplinary emphases that are not necessarily titled as sustainability programs. They include prestige federal agencies such as the National Science Foundation (2017a, 2017b) and philanthropic foundations (Rockefeller Foundation, 2017; Charles Stewart Mott Foundation, 2017). The majority of interviewees especially noted the strides that some funders were making in creating new sustainability-based programs, and anticipated that the sustainability science focus would continue.

The factor international arrangements can be viewed, consistent with the literature, as an element of the communication structures that develop as a new field of science emerges (Fagerberg and Verspagen, 2009). The influence of international arrangements in this study was strong, perhaps due to the global nature of sustainability science itself and the wicked problems that challenge all regions of the world (Foley et al., 2005; Foley et al., 2011; Ostrom, 2009; Rockström et al., 2009). The literature is replete with publications from scholars from non-U.S. institutions, and European and

other countries are viewed as more advanced in their sustainability goals and practices than the United States (Gardner, 2011) – a point confirmed by the study interviewees. Interviewees were attentive to international developments through active research collaborations, contributions to the literature, student experiences, and networks. The literature does not, however, provide clarity on ways that international networks can lead to local outcomes (Keeler et al., 2016). Keeler et al. offer suggestions for types of academic institution-based partnerships across multiple countries that could potentially accelerate research, teaching, and related outcomes.

The establishment of professional scientific societies and new journals was not as critical to sustainability science as it might be to other fields, based on results from this study. Pfeffer (1993) underscores the achievement of consensus, including on theoretical and methodological groundings, as essential to advances in knowledge and scientific progress in a field. Consensus might be achieved through multiple pathways; however, the establishment of interpersonal networks is critical to the development of a new field of science (Fagerberg and Verspagen, 2009). Informal networks of scientists working an area of research have been called the "invisible college" (Crane, 1969; Griffith and Mullins, 1972), and are critically important to the development of a new field of science. The organized communications vehicles, journals, professional scientific societies, and related structures, follow as a new field develops (Fagerberg and Verspagen, 2009).

The lesser influences of new journals and professional scientific societies found in this study might relate to the nature of sustainability science as inclusive of multiple disciplines rather than based in a sole discipline. Several of the professors interviewed

noted examples of professional societies and their respective journals that were moving to incorporate sustainability into their activities and publications. The importance of "loose" networks (Griffith and Mullins, 1972) was strongly emphasized, however, by many interviewees. The lesser influences of journals and formal scientific societies may be a relatively unique characteristic of the emergence of sustainability science. The dominance of loose networks over formal structures is notably different from what is described in the literature on the emergence of new fields of science, which traditionally have been more discipline-oriented.

Disagreements over definitions, terminology, and constructs are a common characteristic of emerging fields (Griffith and Mullins, 1972; Proctor, Landsverk, Aarons, Chamber, Glisson, and Mittman, 2009). Consistent with the literature, the professors noted the variety and inconsistency of definitions for sustainability and sustainability science since the inception of both. The professors appear to hold a relatively consistent, general definition of sustainability science, and so the lack of clarity in definition has not hampered the professors' work. Miller (2015) describes sustainability science work that is undertaken without deep concern for a definition as universalist, or "thin," sustainability. Universalist sustainability is a more general definition that includes the compelling status of complex global issues and a moral underpinning that is accepted by most people.

Community Engagement and Transdisciplinarity

The interviewees overwhelmingly said that they are influenced by external stakeholders and citizens. They place high value on the local knowledge and expertise

that non-scientists in the community can bring to sustainability research. All interviewees appear to adhere to the importance of transdisciplinarity as a key component of sustainability science – the engagement of a variety of individuals, organizations, and policy makers that have interest in or are affected by a circumstance that can be addressed through aspects of science and technology in a local context (Kajikawa, 2008; Kates, 2001; Matson, Clark, and Andersson, 2016).

The interviewees are faculty members at a Land Grant university that was founded on the tripartite mission of research, teaching, and outreach. The expert model for outreach, or extension, has changed over time to a two-way interactive engagement between faculty members and citizens and community organizations (Byrne, 1998; Ray, 1999; Simpson, 2000; Spanier, 1997). Community engagement has become increasingly incorporated into academic institutions, including with the establishment of a voluntary classification of engaged institutions by the Carnegie Foundation for the Advancement of Teaching (Driscoll, 2008). Academic institutions, however, are slow to overcome structural barriers to community engagement, and its value continues to be overshadowed by priorities for research and teaching in many colleges and universities (Bridger and Alter, 2006).

The value that the 20 professors appear to place on their work directly with external stakeholders and citizens is noteworthy. Their individual disciplinary backgrounds do not appear to have an influence on their commitment to external engagement and inclusion of communities of various kinds in their work. Their focus on external engagement appears to emanate, not from an institutional emphasis on the Land

Grant tradition of outreach or on the literature and practice of community engagement, but rather from their research experiences, transdisciplinary approaches, and grounding in the components of sustainability science. The professors are highly knowledgeable about the transdisciplinary approaches that are embedded in sustainability science. They appear to engage stakeholders in their work because it strengthens their research outcomes and better ensures that new knowledge will be incorporated into actions that solve sustainability problems. In their day-to-day work, they pursue use-inspired research with non-academic partners because it bears results, not necessarily because it is sustainability science, by definition.

The professors' community-engaged work also achieves the goal to reach broader audiences that some described. The stories of the academic-local partnerships focused on a sustainability issue frequently are told in venues other than professional scientific society journals. Project outcomes might include: development of an agricultural crop in a region that results in a new product and subsequently jobs and an improved local economy; improvement of water quality in lakes to benefit aquatic species and meet the needs of local residents; or the design of walkable urban centers that feature green space, a mix of housing, and public transportation options that conveniently link people to jobs, schools, and recreation. These stories are conveyed through city councils, local newspapers, and across citizens' organizations and can establish a familiarity with the positive outcomes that result from collaborative work with academic researchers. The literature on emerging fields of science specific to communication networks generally does not include avenues that reach the public. Scholars are urging that measures of

success for interdisciplinary research should include the mechanisms that researchers can use to extend scientific information to the public (Goring et al., 2014). The community-engaged, transdisciplinary element of sustainability science is perhaps a newer reflection of developments in the nature and conduct of science than the traditions that are reflected in the literature of more disciplinary-oriented fields.

Faculty and the Academic Culture

The 20 professors who were interviewed for the study are notable examples of faculty as change agents. Sustainability has not been visibly elevated by University of Minnesota leaders as a priority at their home institution, as is the case at many institutions of higher education. The professors, however, emphasized the importance of their affiliation with an interdisciplinary center to their ability to engage with other faculty, share sustainability science-related interests, and cross fertilize to expand research ideas. Pittman (2004) states that transformational change within academic institutions is generally ineffective when using a top-down approach. The interviewees' descriptions of their work and goals are consistent with Pittman's view that it is the individuals within an institution who will make change. These faculty members chose to participate in the interdisciplinary center, it appears, from personal interest in the interdisciplinary and transdisciplinary approaches to complex societal problems, but also as a way to support students. (The interdisciplinary center was established through the vision and urging of faculty members and is led by faculty. The institution supports the center, in part, with internal funds.) Their dedication to students translates to the development of new

courses, community-based experiential learning opportunities, and options for delving into interdisciplinary research through seminars and symposia.

The study supports the literature on the structure of academic organizations and the challenges that institutional leaders face in making transformational change. The disciplinary silos within higher education institutions are barriers to fostering the interrelated and integrated approaches of sustainability science (Cortese, 2003). Decentralized management, bureaucracy, student and faculty turnover, and non-standardized processes are also barriers to the enhancement and elevation of sustainability science-based research, teaching, and community engagement within academic institutions (Velazquez. Munguia, and Sanchez, 2005). The interviewees addressed, in a variety of ways, the burden of the disciplines in the promotion and tenure policy, departmental expectations, and the standard advice to young, non-tenured faculty members and students not to stray from the narrow, disciplinary focus. They expressed concern for their students who are passionate about working on interdisciplinary grand challenges, noting the expectation of academic employers, in particular, for an intellectual base in a discipline. Some also noted the need to shorten the time line for tenure, or otherwise develop options so that younger faculty who wish to do so could move into interdisciplinary and transdisciplinary research more quickly.

The study emphasizes the importance of faculty members as change agents within an institution of higher education for the expansion of sustainability science-based approaches to research, teaching, and community engagement. The dedication of the faculty pursuing solutions to the complex problems of sustainability, coupled with the

demands of the students for transdisciplinary experiences through sustainability science, might be increasingly strong drivers for institutional change. The extent to which stakeholders and the range of external partners benefit from sustainability-science-based solutions to problems might also become a driver for institutional change. The interrelationships of faculty and students described by this study contribute to existing literature on drivers for change that can impact institutions of higher education.

Sustainability Science

This study suggests that sustainability science will continue to expand. Sustainability issues will be addressed at the University of Minnesota and through academic institutions, agencies, and funders nationally and internationally, according to the responses of the interviewees. The nature of the expansion is unclear. The professors described two possibilities whereby sustainability science could further unfold in a more powerful way: by bringing disciplines together in an integrated way to address challenging problems, or by infusing sustainability science into disciplines, thereby solidifying the transdisciplinary approaches within the disciplines that help to address environmental, social, and economic issues in an integrated way.

The literature confirms, too, the expansion of sustainability science. Sustainability is "an ever-broader 'tent' under which the multiple constituencies of scholarship, advocacy, and action are now working…" (Matson, Clark, and Andersson, 2016, p. 3). The number of journals that are publishing sustainability-related articles demonstrates the broader tent for scholarship. My own *Web of Science* (2017) search of journals that have published articles that focus on the integration of environmental,

social, and economic sustainability rose from 568 journals in April 2015 to 947, based on a March 2017 search. The additional 379 journals might represent new journals that have been added to the *Web of Science* during the two-year period, and include existing journals that have published one or more sustainability articles since April 2015.

Other scholars propose the "umbrella" of sustainability science to bridge disciplinary approaches and facilitate communication among researchers, taking into account the concepts of resilience, social-ecological systems, vulnerability, and climate change, among others (Shahadu, 2016). Miller (2015) proposes a repositioning of sustainability science as a "science of design" (p. 80) that focuses on the future that ought to be rather than the present that is now – a focus on solutions rather than problems.

The concerns that interviewees expressed regarding sustainability science learning and research opportunities for students and young faculty members are also reflected in the literature. Scholz and Steiner (2015) suggest that sustainability science provides the grounding for institutions to establish transdisciplinary colleges or other academic units. Such new organizational structures would serve higher-level students and offer the continuing education programs in transdisciplinarity that would provide ongoing learning opportunities for external partners in the public and private sectors and the general public.

The results of this study suggest that the 20 professors interviewed are among the highly knowledgeable, experienced, and accomplished academics who practice sustainability science. They engage colleagues from other disciplines, students, and external stakeholders in the process of their work. They are solutions-oriented and strive to contribute to a better future. They are part of a growing cadre of people who are

addressing the complex issues of an increasing global population and a fragile natural resource base.

My study extended the literature with consistent points of emphases that emerged from professors representing a range of disciplines. Especially noteworthy is the strength with which professors described the importance of students, colleagues from other disciplines, and stakeholders. Professors also noted the importance of informal networks as a source of research collaborations, curriculum development and teaching, and other shared information.

The study has implications for both theory and policy that I describe in the following sections.

Implications for Theory

Implications for theory relate to the importance of loose networks and the role of stakeholders in the field of sustainability science. I have established that sustainability science is evolving consistently with the literature on emerging fields of science, but with some exceptions. The significance of loose networks that may or may not advance to established formal entities is an important characteristic to monitor. Similarly, the involvement of non-scientists – the transdisciplinarity of sustainability science – is an exception to the characterizations of emerging fields of science in the literature.

Sustainability Science Networks

Some scholars have called for the establishment of sustainability science as a discipline. There will likely continue to be proposals for one or more formal organizations and ongoing discussions of epistemological frameworks and definitions in the literature. The emphasis that many of the professors interviewed for this study placed on informal networks is an insight that should not be dismissed. The informal networks they described are local, national, and international. They include faculty, students, public institutions, and private corporations. This underlying grid of sustainability science networks can be thought of as infrastructure, in a sense. Like the unseen communications cables and pipelines that carry water or natural gas throughout the country, sustainability science networks are not prominently visible but deliver high-value products that meet societal needs. The pre-eminent American Association for the Advancement of Science (2017a) and the National Academies (2017) have supported centers, roundtables, and networks of researchers, but have not staked out the establishment of a scientific society for sustainability science. One professor noted the bifurcation between higher-level, general networks for sustainability science relationships and discussions, and then "whole networks of people who do sustainable cities and sustainable agriculture and sustainable X, Y, and Z." The diversity of sustainability issues suggests that the creation of a professional scientific society may be as complex an endeavor as addressing sustainability itself.

The breadth of sustainability challenges – climate change, biodiversity, food and energy production, poverty, human health, design of urban areas, water quality and

availability, environmental justice, and more – might be too expansive to bring into one organization. About half of the professors interviewed did not describe professional scientific societies as an influence or benefit to their work. The evolution of an emerging field of science generally leads to the establishment of a formally structured organization. In the case of sustainability science, the strengths of multiple, interrelated networks that span the globe may be more effective. Informal networks might be a critical element that contributes to the theory of emerging fields of science, or to the evolution of sustainability science specifically.

The Role of Stakeholders in an Emerging Field

The nature of sustainability science differs from characterizations of the emergence of new fields of science in the literature specifically because of its transdisciplinary element – the engagement of citizens, public and private sector entities, and policy makers. My study did not focus on the types of external partners that were included in the professors' work, or how external partners were selected, at what point in the research they were included, if engagement persisted following the conclusion of the study, or how all or some of the interdisciplinary team members interacted with external partners. The professors' very strong emphasis on the importance of stakeholders to sustainability work suggests that stakeholders and other external partners should become a key characteristic in describing the emergence of new fields of science.

The literature addresses public engagement in the emergence of technoscientific fields such as genomics and nanotechnology, for example. The public's role in technoscientific fields has been viewed, however, from the lens of ethical and social

issues related to the application of technologies, and to what extent the public should be involved in the early stage development of a technology (Felt, Fochler, Müller, and Strassnig, 2009). In sustainability science, the use-inspired focus on solutions to sustainability problems engages stakeholders as problem-solving experts with local knowledge. An understanding of differing values and the need for trusting relationships are key in sustainability science, and ideally occur early in the design of a project. Stakeholders' knowledge and adoption of research results are linked to their participation in the initial design stage of a project and identification of objective (Garnett et al., 2009).

The continuing emphasis on public engagement across academic institutions might also be employed to support a stronger focus on the role of stakeholders and external partners in the theory of emerging fields of science.

Implications for Policy

Implications for policy primarily focus on institutions of higher education, but also address the processes of funding agencies and other grant-making organizations. The study has focused on faculty members as change agents within an institution rather than on the academic institution itself. The professors interviewed for the study frequently pointed to the need for major transformations in the structure and emphases in institutions of higher education. Policy changes could enhance research, teaching, and community engagement within institutions. The professors also noted the importance of policies within funding agencies and philanthropic organizations that ensure a deep

understanding by their review panel members of sustainability-oriented work and its interdisciplinary and transdisciplinary practices.

Institutions of Higher Education

The study results are especially relevant to the organization and policies of institutions of higher education. The interviewees repeatedly expressed concern for students and young faculty members who were striving to expand their learning and research experiences and their careers, while under the academic traditions of disciplinary boundaries. Institutions could better support research that addresses broad societal issues by focusing on, ideally, institutionally-valued interdisciplinary approaches to research. Support could initially be offered in the form of campus-wide forums that welcome individuals from all colleges and departments, seminars, and programming through interdisciplinary centers. Sustainability science could provide a context for describing ways that interdisciplinary work can address the wicked problems that require the combined strengths of many disciplines.

In addition, deans and department chairs, in conjunction with institutional leaders, could identify ways to remove disciplinary barriers by considering research issues of common interest across units and providing incentives – funding, recognitions, and flexible time, for example – for interdisciplinary collaborations. Accomplishments in interdisciplinary and transdisciplinary collaborations could be included in promotion and tenure reviews. Performance measures could include qualitative measures of impact on policies and professional practice (Brown, Deletic, and Wong, 2015). In tandem with the focus on faculty members, interdisciplinary experiences could meet student interests

through courses, seminars, and internships and other experiential community-based learning opportunities. Such steps would not diminish the essential contributions of and need for disciplinary work, but rather build upon the disciplinary strengths that can enhance interdisciplinary work.

Similar steps could be taken to focus on expanding from interdisciplinary efforts to the transdisciplinary approaches that include citizens, interest groups, policy makers, and others. Researchers who practice community-engaged transdisciplinary work are in the minority at most institutions of higher education. The strategies to honor values, incorporate local knowledge and address power imbalances among citizens, researchers, and policy makers, for example, are complex (Reid et al., 2016) and could be demystified through routine and consistent opportunities in learning and practice for students and faculty members.

Funding Agencies and Philanthropic Organizations

Based on the experiences of interviewees, results of the study suggest that funding organizations could advance new knowledge, especially related to sustainability, by assessing their policies for the review and award of grants for sustainability-related interdisciplinary research. Review panels should include individuals who are well-versed in the conduct of interdisciplinary research and consider including the users of the new knowledge such as policy makers and practitioners (Brown, Deletic, and Wong, 2015).

The implications for theory and policy are anchored in the results of the study. I acknowledge, however, caveats to the implications and conclusions based on limitations that are described in the following section.

Limitations

With the focus on sustainability science and the importance of integrating the social with environmental and economic elements, the detailed responses that are elicited through interviews can convey a lived experience in a broad social context. The strength of a qualitative approach is appropriate for this study, because of the richness, complexities, and underlying views that are revealed by inviting individuals to share their experiences and interpretations (Miles, Huberman, and Saldaña, 2014).

The sample size of 20 professors was determined by the pool of interview candidates affiliated with an institution-wide, interdisciplinary center, and the objectives of including a relatively broad range of disciplines and gender balance, as well as the availability to schedule interviews within a reasonable time frame. Although about 16 disciplines were represented in the 20-person group, numerous other disciplines were not included. Also, only 40 percent of the interviewees were women. Data are not available to confirm whether this percentage accurately represents the number of women engaged in sustainability science research at the University of Minnesota or across all research universities in the United States. The size of the participant group, however, is relatively small and based at a single institution. Faculty at other public research institutions might have responded differently based on geographic location, personal and professional goals, and structure and policies of their institutions, among other factors. The study did not investigate the relationships of various disciplines in sustainability science-based projects or the nature or comparisons among disciplinary, interdisciplinary, and transdisciplinary research strategies and success rates. The study also did not differentiate student

influences by discipline or type of student, undergraduate, master's or Ph.D. student, nor the types of stakeholder and citizen groups that the professors have collaborated with in their projects. Also, there might be other factors that influence faculty behavior beyond those explored here. The study results are instructive, but are not likely generalizable.

An interview of one hour was a reasonable request of time from the professors, although each of the seven factors alone could have been the topic of a one-hour discussion. In that sense, the issues raised by the professors provided a higher-level overview of factors relating to sustainability science as a new field – and the concomitant issues of interdisciplinary and transdisciplinary research that emerged as priority cross-cutting themes. Although limited to an overview, the study not only contributes to the literature but also suggests opportunities for further research.

Directions for Further Research

My study provides a strong foundation for pursuing additional research in the academic setting. Studies could focus in more detail on faculty members, students, or institutions of higher education related to sustainability and sustainability science approaches.

Personal interests, educational experiences, mentors, colleagues, and institutional settings shaped the focus on sustainability of the 20 professors interviewed for this study. Further research could identify characteristics of individuals who are drawn to work in issues that are grounded in sustainability science. Does disciplinary background play a role? What personality traits are a best fit for interdisciplinary and transdisciplinary team

work? A determination of whether researchers who focus on sustainability science-based work have certain consistent characteristics could be important to the development of programs that support young faculty and students as they pursuing sustainability-related research.

Further research could also identify the influences that motivate students to pursue sustainability science-based work. The professors who participated in my study clearly stated the influence that students have on their work. Is the influence of faculty working toward sustainability solutions a strong influence on students as well? What is the nature of the reciprocal relationship between faculty and students within the parameters of work that is grounded in sustainability science? Are interdisciplinary programs and fellowships especially designed for students an influence? To what extent are broader societal issues an influence on students' interests in sustainability science-based work?

The study also has implications for the ways in which academic institutions might address sustainability issues through research, teaching, and public engagement. Further research could assess institutions of higher education. How can institutions best foster sustainability science work or interdisciplinary and transdisciplinary work in general? Are there institutional barriers to sustainability science efforts? If so, how can they be removed? How might graduate students and undergraduate students systematically be introduced to working toward solutions to the complex, wicked problems of sustainability through interdisciplinary and transdisciplinary means? What are the costs and benefits for an institution to focus prominently on sustainability as a priority?

Multiple avenues of subsequent research can provide additional insights into the nature of sustainability science and the importance that it brings to solutions for the complex problems that are affecting populations across the globe.

Conclusion

A generation has passed since the concept of sustainability debuted in the report *Our Common Future* (World Commission on Environment and Development, 1987). The sense of urgency to address grand and vexing challenges where environmental, social, and economic issues are intertwined continues.

Sustainability science is yet in the early stages of evolution as a new field of science, having been first described as a concept in the 1999 report of the National Research Council and solidified in a subsequent article in *Science* (Kates et al., 2001). In a relatively short time, many researchers have embraced sustainability science as a scientific approach to address the global problems of sustainability – food production and world hunger, biodiversity, the availability of clean water, melting polar ice caps and rising sea waters, shifting locations of plant and animal pathogens based on temperature, poverty, and disease and human health, among others. The concerns for our small planet and its growing population have motivated faculty and students in institutions of higher education (and other organizations) to employ best strategies to find solutions. Complex problems require interdisciplinary and transdisciplinary approaches.

This study highlights the need, described by the professors who were interviewed, for strong integration of the disciplines and the engagement of students and citizens – and

their passion to make the world a better place – to move toward solutions. The sobering intricacies of environmental, social, and economic relationships on a world-wide scale are summarized by the United Nations Secretary-General António Guterres,

> "Once again, the past year was the hottest ever. Sixteen of the 17 warmest years on record have occurred during this young century. This trend not only threatens the world's ecosystems and biodiversity but poses a serious risk for peace, security, and sustainable development. Many conflicts are triggered, exacerbated or prolonged by competition over scarce natural resources; climate change will only make the situation worse. That is why protecting our environment is critical to the founding goals of the United Nations to prevent war and sustain peace" (United Nations Environment Programme, 2017, foreword).

The daily news headlines will continue to keep sustainability issues, by many names, at the fore. International organizations, countries, regional coalitions, corporations, non-profits, local communities, and citizens' groups will continue to address aspects of sustainability issues, locally and globally. Through sustainability science approaches, the faculty and students within institutions of higher education can reach beyond the campus to work with stakeholders and citizens' organizations to confront sustainability challenges together.

REFERENCES

Allen, E., Kruger, C., Leung, F., & Stephens, J. C. (2013). Diverse perceptions of stakeholder engagement within an environmental modeling research team. *Journal of Environmental Studies and Sciences,* 3, 343-356.

American Association for the Advancement of Science. (2017a). About the Center for Science, Technology and Sustainability website. Retrieved on February 17, 2017, from https://www.aaas.org/page/about-center-science-technology-and-sustainability

American Association for the Advancement of Science. (2017b). Website for affiliations with other membership organizations and professional societies. Retrieved on February 16, 2017, from https://www.aaas.org/aaas-affiliates

American Association for the Advancement of Science. (2017c). Science careers in sustainability website. Retrieved on February 17, 2017, from https://www.aaas.org/page/science-careers-sustainability

American Association of Community Colleges. (2017). About website. Retrieved on March 22, 2017, from www.aacc.nche.edu/About/Pages/default.aspx.

American Association of State Colleges and Universities. (2017). Members website. Retrieved on March 22, 2017, from www.aascu.org/members/by-state-and-territory/

American College and University Presidents' Climate Commitment. (2017). Climate

guidance and leadership network website. Retrieved on March 20, 2017, from secondnature.org

American Meteorological Society. (2017a). *Journal of the Atmospheric Sciences.* Retrieved on March 20, 2017, from https://www.ametsoc.org/ams/index.cfm.publications/Journals/journal-of-the-atmospheric-sciences/

American Meteorological Society. (2017b). *Journal of Climate.* Retrieved on March 20, 2017, from https://ametsoc.org/ams/index.cfm/publications/Journals/journal-of-climate/

American Planning Association. (2017). *Journal of the American Planning Association*: aims and scope. Retrieved on March 20, 2017, from http://www.planning.org/japa/

Arizona State University. (2014a). About the Julie Ann Wrigley Global Institute of Sustainability website. Retrieved on March 24, 2017, from https://sustainability.asu.edu/about/

Arizona State University. (2014b). A new American university. About Michael M. Crow website. Retrieved on March 24, 2017, from https://president.asu.edu/about/michaelcrow

Association for the Advancement of Sustainability in Higher Education. (2015). *Salaries and Status of Sustainability Staff in Higher Education – 2015.* Retrieved on March 23, 2017, from http://www.aashe.org/files/documents/programs/2015_staffing_survey_report.pdf

Association for the Advancement of Sustainability in Higher Education. (2017a). Campus sustainability hub, academic programs website. Retrieved on March 24, 2017, from https://hub.aashe.org/browse/types/academicprogram/

Association for the Advancement of Sustainability in Higher Education. (2017b). About AASHE mission, vision and goals website. Retrieved on March 20, 2017, from http://www.aashe.org/about/aashe-mission-vision-goals

Association for the Advancement of Sustainability in Higher Education. (2017c). Membership directory website. Retrieved on March 22, 2017, from http://www.aashe.org/membership/member-directory

Association for the Advancement of Sustainability in Higher Education. (2017d). Campus sustainability hub, resource collections website. Retrieved on March 23, 2017, from https://hub.aashe.org/

Association for the Advancement of Sustainability in Higher Education. (2015). Website for 2015 conference and expo: transforming sustainability education. Retrieved on February 11, 2017, from http://www.aashe.org/conference/2015/Summary-of-Changes

Association of American Universities. (2017). About AAU website. Retrieved on Mach 24, 2017, from http://www.aau.edu/about/default.aspx?id=58

Association of Public and Land-Grant Universities. (2017a). Members website. Retrieved on March 20, 2017, from http://www.aplu.org/members

Association of Public and Land-Grant Universities. (2017b). *Science, education, and outreach roadmap for natural resources.* A report of the Board on Natural Resources and the Board on Oceans, Atmosphere, and Climate. Washington, D.C.: Association of Public and Land-Grant Universities. Retrieved on March 22, 2017, from http://www.aplu.org/library/natural-resources-roadmap/File

Barbour, R. S., & Schostak, J. (2011). Interviewing and focus groups. In B. Somekh &C. Lewin (Eds.), *Theory and Methods in Social Research* (2nd ed.). London: SAGE Publications Ltd.

Basulto, D. (2015, February 18). The weird way that climate change could lead to new disease outbreaks around the world. *The Washington Post.* Retrieved on April 18, from, http://www.washingtonpost.com/blogs/innovations/wp/2015/02/18/the-weird-way-that-climate-change-could-lead-to-new-disease-outbreaks-around-the-world/

Bean, J. (2011). Intellect, light, and shadow in research design. In C. F. Conrad & R. C. Serlin (Eds.), *The SAGE Handbook for Research in Education* (pp. 165–182). Thousand Oaks, California: SAGE Publications, Inc.

Bekessy, S. A., Samson, K., & Clarkson, R. E. (2007). The failure of non-binding declarations to achieve university sustainability: a need for accountability. *International Journal of Sustainability in Higher Education,* 8(3), 301-316.

Bettencourt, L. M. A., & Kaur, J. (2011, December 6). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences of the United States of America,* 108(49), 19540-19545.

Bioregional. (2017). One Planet Living website. Retrieved on March 20, 2017, from http://www.bioregional.com/oneplanetliving/

Birnbaum, R. (1988). *How colleges work: the cybernetics of academic organization and leadership.* San Francisco: Jossey-Bass.

Borden, R. J., Cline, K. S., Hussey, T., Longsworth, G., & Mancinelli, I. (2007). A river runs through it: a college-community collaboration for watershed-based regional planning and education. *Human Ecology Review,* 14(1), 90-100.

Boyer, E. (1990). *Scholarship reconsidered: Priorities of the professoriate.* Princeton, NJ: Carnegie Foundation for the Advancement of Teaching.

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D., Newig, J., … & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics,* 92, 1-15.

Bridger, J. C., & Alter, T. R. (2006). The engaged university, community development, and public scholarship. *Journal of Higher Education Outreach and Engagement,* 11(1), 163-178.

Brinkhurst, M., Rose, P., Maurice, G., & Ackerman, J. D. (2011). Achieving campus sustainability: Top-down, bottom-up, or neither? *International Journal of Sustainability in Higher Education,* 12(4), 338-354.

Brower, H. H. (2011). Sustainable development through service learning: a pedagogical framework and case example in a third world context. *Academy of Management Learning & Education,* 10(1), 58-76.

Brown, R. R., Deletic, A., & Wong, T. H. F. (2015, September 17). How to catalyse collaboration. *Nature,* 525, 315-317.

Brown University, Swearer Center for Public Service. (2017). *Swearer Center launches initiative to advance community engagement field.* Retrieved on March 22, 2017, from https://news.brown.edu/articles/2017/02/swearer

Burnham, M. (2010, August 23). In Oregon, students seek key to a sustainable city. *The New York Times*, energy and environment section website. Retrieved on August 20, 2014, from http://www.nytimes.com/gwire/2010/08/23/23greenwire-in-oregon-students-seek-key-to-a-sustainable-c-87835.html?pagewanted=all

Byrne, J. V. (1998). Outreach, engagement, and the changing culture of the university. *Journal of Public Service and Outreach*, 3(2), 3-8.

Caelli, K., Ray, L., & Mill, J. (2003). 'Clear as mud:' toward greater clarity in generic qualitative research. *International Journal of Qualitative Methods,* 2(2), 1-13.

Calder, W., & Clugston, R. (2004). Lighting many fires: South Carolina's Sustainable Universities Initiative. In P. B. Corcoran & A. E. J. Wals (Eds.), *Higher Education and the Challenge of Sustainability: Problematics, Promise and Practice* (pp.249-262). The Netherlands: Kluwer Academic Publishers.

Carlson, S. (2013, May 20). 10-week think tanks: students at the U. of Oregon, acting as consultants, test ways to help nearby cities. The idea is spreading. *The Chronicle of Higher Education.* Retrieved on August 20, 2014, from http://chronicle.com/article/Students-Go-Into-the/139349/

Carlson School of Management, University of Minnesota. (2011). Carlson School and Wells Fargo launch sustainability initiative, news. Retrieved on March 25, 2017, from https://carlsonschool.umn.edu/news/carlson-school-and-wells-fargo-launch-sustainability-initiative

Cassell, C., & Symon, G. (2004). *Essential guide to qualitative methods in organizational research.* London: Sage Publications Ltd.

Chalker-Scott, L., & Tinnemore, R. (2009). Is community-based sustainability education sustainable? A general overview of organizational sustainability in outreach education. *Journal of Cleaner Production,* 17, 1132-1137.

Charles Stewart Mott Foundation. (2017). What we do: Environment website. Retrieved on February 17, 2017, from https://www.mott.org/work/environment/

Citizen Science Association. (2017). Citizen Science Association conference, Twin Cities, Minnesota, website. Retrieved on February 11, 2017, from http://citizenscience.org/association/conferences/citsci2017/

Clark, W. C.. (2007). Sustainability science: a room of its own. *Proceedings of the National Academy of Sciences of the United States of America,* 104(6), 1737-1738.

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: the emerging research program. *Proceedings of the National Academy of Sciences of the United States of America,* 100(14), 8059-8061.

Clugston, R. M., & Calder, W. (1999). Critical dimensions of sustainability in higher education. In W. L. Filho (Ed.), *Sustainability and universitylLife* (pp. 1-15). Bern, Switzerland: Peter Lang.

Cohen, M. D., & March, J. G. (1974). *Leadership and Ambiguity: The American College President*. New York: McGraw-Hill.

Cohen, M.D., March, J. G., & Olsen, J. P. (1972). Garbage can model of organizational choice. *Administrative Science Quarterly,* 17, 1-15.

Corcoran, P. B., Walker, K. E., & Wals, A. E. J. (2004). Case studies, make-your-case studies, and case stories: a critique of case-study methodology in sustainability in higher education. *Environmental Education Research,* 10(1), 7-21.

Cortese, A. D. (2003, March-May). The critical role of higher education in creating a sustainable future, *Planning for Higher Education,* 15-22.

Cox, R. W. (1981). Social forces, states and world orders: beyond international relations theory. *Millennium – Journal of International Studies,* 10(2), 126-155.

Crane. D. (1969). Social structure in a group of scientists: a test of the "invisible college" hypothesis. *American Sociological Review,* 34(3), 335-352.

Crow, M. M. (2007, Winter). None dare call it hubris: the limits of knowledge. *Issues in Science and Technology,* 1-4.

Crow, M. M. (2010). Organizing teaching and research to address the grand challenges of sustainable development. *BioScience,* 60(7), 488-489.

Crow, M. M., & Dabars, W. B. (2015). *Designing the new American university.* Baltimore, Maryland: Johns Hopkins University Press.

Dedeurwaerdere, T. (2013). Transdisciplinary sustainability science at higher education institutions: science policy tools for incremental institutional change. *Sustainability,* 5, 3783-3801.

DiCicco-Bloom, B., & Crabtree, B.F. (2006). Making sense of qualitative research: the qualitative research interview. *Medical Education,* 40, 314-321.

Dietz, T., Ostrom, E., & Stern, P. C. (2003, December 12). The struggle to govern the commons. *Science,* 302, 1907-1912.

DiMaggio, P. J., & Powell, W. W. (1983, April). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review,* 48, 147-160.

Driscoll, A. (2008, January/February). Carnegie's community-engagement classification: intentions and insights. *Change,* 2008; 39-41.

Elsevier. (2017a). *Journal of Environmental Sciences,* about website. Retrieved on March 20, 2017, from https://www.journals.elsevier.com/journal-of-environmental-sciences

Elsevier. (2017b). *Journal of Environmental Economics and Management.* Retrieved on March 20, 2017, from https://www.journals.elsevier.com/journal-of-environmental-economics-and-management

Elsevier. (2017c). *Journal of Cleaner Production,* about the journal website. Retrieved on March 23, 2017, from https://www.journals.elsevier.com/journal-of-cleaner-production/

Emerald Group Publishing. (2017). *International Journal of Sustainability in Higher Education,* About the journal website. Retrieved on March 21, 2017, from http://www.emeraldgrouppublishing.com/products/journals/journals.htm?id=IJSHE

Etzkowitz, H., Ranga, M., Benner, M., Guaranys, L., Maculan, A. M., & Kneller, R. (2008). Pathways to the entrepreneurial university: towards a global convergence. *Science and Public Policy,* 35(9), 681-695.

European Commission, Directorate-General for Environment. (2011). Importance of industry's R&D contribution to sustainability, Eco-Innovation Action Plan website. Retrieved on March 25, 2017, from http://ec.europa.eu/environment/ecoap/about-eco-innovation/research-developments/eu/427_en

Fagerberg, J., & Verspagen, B. (2009). Innovation studies – the emerging structure of a new scientific field. *Research Policy,* 38, 218-233.

Felt, U., Fochler, M., Müller, A., & Strassnig, M. (2009). Unruly ethics: on the difficulties of a bottom-up approach to ethics in the field of genomics. *Public Understanding of Science,* 18(3), 354-371.

Ferrer-Balas, D., Lozano, R., Huisingh, D., Buckland, H. Ysern, P., & Zilahy, G. (2010). Going beyond the rhetoric: system-wide changes in universities for sustainable societies. *Journal of Cleaner Production,* 18, 607-610.

Fien, J. (2002). Advancing sustainability in higher education: issues and opportunities for research. *International Journal of Sustainability in Higher Education,* 3(3), 243-253.

Filho, W. L. (2000). Dealing with misconceptions on the concept of sustainability. *International Journal of Sustainability in Higher Education,* 1(1), 9-19.

Fitzgerald, H. E., Bruns, K., Sonka, S. T., Furco, A., & Swanson, L. (2012). The centrality of engagement in higher education. *Journal of Higher Education Outreach and Engagement,* 16(3), 7-27.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., … Snyder, P. K. (2005, July 22). Global consequences of land use. *Science,* 309, 570-574.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., … Zaks, D. P. M. (2011, October 20). Solutions for a cultivated planet, *Nature,* 478, 337-342.

Franz, N. K., & Cox, R. A. (2012, April). Extension's future: time for disruptive innovation. *Journal of Extension,* April, 50(2). Retrieved on August 20, 2014, from http://www.joe.org/joe/2012april/comm1.php

Furco, A. (2010). The engaged campus: toward a comprehensive approach to public engagement. *British Journal of Educational Studies,* 58(4), 375-390,

Gardner, G. (2011). *Creating sustainable prosperity in the United States: the need for innovation and leadership*. Washington, D.C.: Worldwatch Institute.

Garnett, S. T., Crowley, G. M., Hunter-Xenie, H., Kozanayi, W., Sithole, B., Palmer, C., . . . Zander, K. K. (2009). Transformative knowledge transfer through empowering and paying community researchers. *Biotropica,* 41(5), 571-577.

Gettleman, J. (2017, March 27). Drought and war heighten threat of not just 1 famine, but 4. *The New York Times.* Retrieved on March 30, 2017, from https://www.nytimes.com/2017/03/27/world/africa/famine-somalia-nigeria-south-sudan-yemen-water.html

Gibbons, M. (1999, December 2). Science's new social contract with society. *Nature* 402, Supp., C81.

Goodnough, T., Kildegaard, A., Kuchenreuther, M. Rasmussen, L., & Wyckoff, P. (2009). Leveraging assets: a case study of the sustainability initiative at the University of Minnesota, Morris. *Journal of Cleaner Production,* 17, 1138-1142.

Goring, S. J., Weathers, K. C., Dodds, W. K., Soranno, P. A. Sweet, L. C., Cheruvelil, K. S., . . . Utz, R. M. (2014). Improving the culture of interdisicpinary collaboration in ecology by expanding measures of success. *Frontiers in Ecology and the Environment,* 12 (1), 39-47.

Gouldner, A. W. (1957). Cosmopolitans and locals: toward an analysis of latent social rules. *Administrative Science Quarterly,* 2(3), 281-306.

Griffith, B. C., & Mullins, N. C. (1972, September 15). Coherent social groups in scientific change. *Science,* 177(4053), 959-964.

Grindsted, T. S., & Holm, T. (2012). Thematic development of declarations on sustainability in higher education. *Environmental Economics,* 3(1), 32-40.

Harvey, C. (2017, January 23). One of the last Obama-era climate reports had a troubling update about the rising seas. *The Washington Post.* Retrieved on April 2, 2017 from https://www.washingtonpost.com/news/energy-environment/wp/2017/01/23/one-of-the-last-obama-era-climate-reports-had-a-troubling-punchline-about-the-rising-seas/?utm_term=.25070f4dbc60

Head, B. W. (2007). Community engagement: participation on whose terms? *Australian Journal of Political Science,* 42(3), 441-454.

Innes, J. E., & Booher, D. E. (2004). Reframing public participation: strategies for the 21st century. *Planning Theory & Practice,* 5(4) 419-436.

Institute for Sustainable Social Change and The Prescott College PhD Program in Sustainability Education. (2017). *Journal of Sustainability Education.* About us website. Retrieved on March 22, 2017, from www.journalofsustainabilityeducation.org

Institute on the Environment, University of Minnesota. (2017a). Sustainability studies minor website. Retrieved on February 17, 2017, from http://environment.umn.edu/leadership/susted/sustainability-studies-minor/

Institute on the Environment, University of Minnesota. (2017b). Undergraduate degree programs website. Retrieved on February 17, 2017, from http://environment.umn.edu/leadership/susted/degree-programs/undergraduate/

Institute on the Environment, University of Minnesota. (2017c). Graduate degree programs website. Retrieved on February 17, 2017, from http://environment.umn.edu/leadership/susted/degree-programs/graduate/

Institute on the Environment, University of Minnesota. (2017d). About us website. Retrieved on February 17, 2017, from http://environment.umn.edu/about-us/

Intergovernmental Panel on Climate Change, Pachauri, R. K., & Meyer, L. A. (eds.). (2014). *Climate change 2014: synthesis report.* Contribution of working groups I, II, and III to the Fifth Assessment Report to the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change. Retrieved on March 25, 2017, from http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf

International Association of Universities. (2017). Policy statements website, *Kyoto Declaration on Sustainable Development of 1993*. Retrieved on March 22, 2017, from http://www.iau-hesd.net/sites/default/files/documents/sustainable_development_policy_statement.pdf

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., … Persson, J. (2011). Structuring sustainability science. *Sustainability Science,* 6, 69-82.

Jessie Smith Noyes Foundation. (2017). Funding priorities website. Retrieved on March 23, 2017, from http://www.noyes.org/grantmaking/funding-priorities

Jiusto, S., McCauley, S., & Stephens, J. C. (2013, Spring). Integrating shared action learning into higher education for sustainability. *Journal of Sustainability Education,* experiential education, part two. Retrieved on August 14, 2014, from http://www.jsedimensions.org/wordpress/content/integrating-shared-action-learning-into-higher-education-for-sustainability_2013_06/

Johnston, P., Everard, M., Santillo, D., & Robért, K. H. (2007). Reclaiming the definition of sustainability. *Environmental Science Pollution Research International,* 14(1), 60-66.

Joyce Foundation. (2017). Environment programming website. Retrieved on March 22, 2017, from http://www.joycefdn.org/programs/environment/

Kahlke, R. M. (2014). Generic qualitative approaches: pitfalls and benefits of methodological mixology. *International Journal of Qualitative Methods,* 13, 37-52.

Kajikawa, Y. (2008). Research core and framework of sustainability science. *Sustainability Science,* 3, 215-239.

Karnowski, S. (2017, March 8). General Mills teams with UMN to boost eco-friendly grain kernza, *Associated Press.* Retrieved on March 25, 2017, from http://www.twincities.com/2017/03/08/general-mills-teams-with-umn-to-boost-eco-friendly-grain-kernza/

Kates, R. W. (2002). Humboldt's dream, beyond disciplines, and sustainability science: contested identities in a restructuring academy. [Peer commentary included in "Commentary/response: Turner's 'contested identities'"]. *Annals of the Association of American Geographers,* 92(1): 79-81.

Kates, R. W. (2011, December 6). What kind of a science is sustainability science?. *Proceedings of the National Academy of Sciences of the United States of America,* 108(49), 19449-19450.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., … Svedin, U. (2001, April 27). Sustainability science. *Science,* 292(5517), 641-642.

Kauffman, J., & Arico, S. (2014). New directions in sustainability science: promoting integration and cooperation. *Sustainability Science,* 9, 413-418.

Keeler, L. W., Wiek, A., Lang, D. J., Yokohari, M., van Breda, J., Olsson, L., . . . Evans, J. (2016). Utilizing international networks for accelerating research and learning in transformational sustainability science. *Sustainability Science,* 11,749-762.

Kellogg Commission on the Future of State and Land-Grant Universities. (1999). *Returning to Our Roots: The Engaged Institution.* Washington, D.C.: National Association of State Universities and Land-Grant Colleges. Retrieved on March 20, 2017, from http://www.aplu.org/library/returning-to-our-roots-the-engaged-instituion/file

Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology,* 14, 78-91.

Kemp, R., & Martens, P. (2007). Sustainable development: How to manage something that is subjective and never can be achieved? *Sustainability: Science, Practice & Policy,* an open access e-journal, 3(2). Retrieved on August 20, from http://sspp.proquest.com/static_content/vol3iss2/0703-007.kemp-print.html

Kitchenham, A. (2008). The evolution of John Mezirow's transformative learning theory. *Journal of Transformative Education,* 6(2), 104-123.

Lehmann, M., Christensen, P., Thrane, M., & Jørgensen, T. H. (2009). University engagement and regional sustainability initiatives: some Danish experiences. *Journal of Cleaner Production.* 17, 1067-1074.

Leimbach, M. (2003). Equity and carbon emissions trading: a model analysis. *Energy Policy*, 31, 1033-1044.

Leveille, D. E. (2006). Accountability in higher education: a public agenda for trust and culture change. University of California, Berkeley: Center for Studies in Higher Education. Retrieved on April 21, 2015, from http://www.cshe.berkeley.edu/sites/default/files/shared/publications/docs/Leveille_Accountability.20.06.pdf

Levy, B. L. M., & Marans, R. W. (2012). Towards a campus culture of environmental sustainability: Recommendations for a large university. *International Journal of Sustainability in Higher Education,* 13(4), 365-377.

Loorbach, D. (2010). Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance: An International Journal of Policy, Administration, and Institutions,* 23(1),161-183.

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner Production,* 16(17), 1838-1846.

Lozano, R., Lukman, R., Lozano, F. J., Huisingh, D., & Lambrechts, W. (2013). Declarations for sustainability in higher education: becoming better leaders through addressing the university system. *Journal of Cleaner Production,* 48, 10-19.

Martens, P. (2006, Spring). Sustainability: science or fiction? *Sustainability: Science, Practice, & Policy,* 2(1), 1-8.

Mary Ann Liebert, Inc., Publishers. (2017). *Sustainability: The Journal of Record.* Overview website. Retrieved on March 21, 2017, from http://www.liebertpub.com.overview/sustainability-the-journal-of-record/252

Mathur, V. N., Price, A. D. F., & Austin, S. (2008). Conceptualizing stakeholder engagement in the context of sustainability and its assessment. *Construction Management and Economics,* 26, 601-609.

Matson, P., Clark, W. C., & Andersson, K. (2016). *Pursuing sustainability: a guide to the science and practice.* Princeton, NJ: Princeton University Press.

McMichael, A. J., Butler, C. D., & Folke, C. (2003, December 12). New visions for addressing sustainability. *Science,* 302(5652), 1919-1920.

McNall, M., Reed, C. S., Brown, R., & Allen, A. (2009). Brokering community-university engagement. *Innovation in Higher Education,* 33, 317-331.

MDPI AG. (2017). *Sustainability* – open access journal website. Retrieved on March 21, 2017, from http://www.mdpi.com/journal/sustainability/about

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental Impact Assessment Review,* 18, 493-520.

Merriam, S. B. (2002). *Qualitative research in practice: examples for discussion and analysis.* San Francisco, CA: Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: a methods sourcebook,* ed. 3. Thousand Oaks, CA: Sage Publications, Inc.

Miller, T. R. (2013). Constructing sustainability science: emerging perspectives and research trajectories. *Sustainability Science,* 8, 279-293.

Miller, T. R. (2015). *Reconstructing sustainability science: knowledge and action for a sustainable future.* Oxon, England: Routledge.

Miller, T. R., Munoz-Erickson, T., & Redman, C. L. (2011). Transforming knowledge for sustainability: towards adaptive academic institutions. *International Journal of Sustainability in Higher Education,* 12(2), 177-192.

Moore, J. (2005). Policy, priorities and action: a case study of the University of British Columbia's engagement with sustainability. *Higher Education Policy,* 18, 179-197.

Moore, T. L., & Ward, K. (2008). Documenting engagement: faculty perspectives on self-representation for promotion and tenure. *Journal of Higher Education Outreach and Engagement,* 12(4), 5-27.

Morrill Act of 1862, 7 U.S.C. §301 et seq. (1862).

Myers, R. A., & Worm, B. (2005). Extinction, survival or recovery of large predatory fishes. *Philosophical Transactions: Biological Sciences,* 360(1453), 13-20.

National Academies. (2017). Roundtable on science and technology for sustainability website. Retrieved on February 17, 2017, from sites.nationalacademies.org/PGA/sustainability/PGA_048724

National Academy of Sciences. *(2017). Proceedings of the National Academy of Sciences of the United States of America*. Sustainability science website. Retrieved on March 22, 2017, from sustainability.pnas.org/page/about

National Oceanic and Atmospheric Administration. (2017, January). Global and regional sea level rise scenarios for the United States. Technical report NOS CO-OPS 083. Silver Spring, Maryland: Department of Commerce. Retrieved on April 1, 2017, from https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

National Research Council. (1996) *Colleges of Agriculture at the Land Grant Universities: Public Service and Public Policy.* Washington, D.C.: National Academy Press.

National Research Council. (1999). *Our Common Journey: A Transition Toward Sustainability.* Washington, D.C.: National Academy Press.

National Science Foundation. (2005). *Complex environmental systems: pathways to the future.* A report of the Advisory Committee for Environmental Research and Education. Washington, D.C.: National Science Foundation.

National Science Foundation. (2009). *Transitions and tipping points in complex environmental systems.* A report of the Advisory Committee for Environmental Research and Education. Washington, D.C.: National Science Foundation.

National Science Foundation. (2017a). Science, engineering and education for sustainability (SEES): NSF-wide investment website. Retrieved on February 17, 2017, from http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707

National Science Foundation. (2017b). Innovations at the Nexus of Food, Energy and Water Systems (INFEWS); program guidelines website. Retrieved on February 5, 2017, from https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505241

Natural Resources Defense Council. (2017a). About us website. Retrieved on March 20, 2017, from https://www.nrdc.org/

Natural Resources Defense Council. (2017b). Sustainable cities website. Retrieved on March 20, 2017, from https://www.nrdc.org/issues/sustainablecities

New England Resource Center for Higher Education. (2017). Carnegie Community Engagement Classification website. Retrieved on March 22, 2017, from http://nerche.org/index.php?option=com_content&view=article&id=341&Itemid=618#CEdef

Obama White House Council on Environmental Quality. (2017). Federal agency strategic sustainability performance plans website. Retrieved on March 20, 2017, from https://obamawhitehouse.archives.gov/administration/eop/ceq/sustainability/plans

Olson, L., Arvai, J., & Thorp, L. (2011). Mental models research to inform community outreach for a campus recycling program. *International Journal of Sustainability in Higher Education,* 12(4), 322-337.

Ostrom, E. (2009, July 24). A general framework for analyzing sustainability of social-ecological systems. *Science,* 325, 419-422.

Ostrom, E., Janssen, M. A., Anderies, J. M. (2007, September 25). Going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America,* 104(39), 15176-15178.

Palmer, M. (2012). Socioenvironmental sustainability and actionable science. *BioScience,* 62(1), 5-6.

Parkin, S. (2000, November). Sustainable development: the concept and the practical challenge. *Civil Engineering,* 138, 3-8.

Patz, J., & Vargo, J. (2015, June 29). Sustainable cities work for climate change. *The Huffington Post.* Retrieved on March 23, 2017, from http://www.huffingtonpost.com/jonathan-patz/sustainable-cities-work-for-climate-change_b_7174242.html

Pearce, J. M. (2009). Appropedia as a tool for service learning in sustainable development. *Journal of Education for Sustainable Development,* 3(1), 45-53.

Pfeffer, J. (1993). Barriers to the advance of organizational science: paradigm development as a dependent variable. *Academy of Management Review,* 18(4), 599-620.

Phillipson, J., Lowe, P., Proctor, A., & Ruto, E. (2012). Stakeholder engagement and knowledge exchange in environmental research. *Journal of Environmental Management,* 95, 56-65.

Pittman, J. (2004). Living sustainability through higher education: a whole systems design approach to organizational change. In P. B. Corcoran and A. E. J. Wals (Eds.), Higher education and the challenge of sustainability: problematics, promise and practice (pp. 199-212). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Price, D. J. de S., & Beaver, D. de B. (1966). Collaboration in an invisible college. *American Psychologist,* 21(11), 1011-1018.

Philpott, K., Dooley, L., O'Reilly, C., & Lupton, G. (2011). The entrepreneurial university: examining the underlying academic tensions. *Technovation,* 31(4), 161-170.

Proctor, E. K., Landsverk, J., Aarons, G., Chambers, D., Glisson, C., & Mittman, B. (2009). Implementation research in mental health services: an emerging science with conceptual, methodological, and training challenges. *Administration and Policy in Mental Health and Mental Health Services Research,* 36, 24-34.

Rapport, D. J. (2007). Sustainability science: an ecohealth perspective. *Sustainability Science,* 2, 77-84.

Ray, E. J. (1999). Outreach, engagement will keep academia relevant to twenty-first century societies. *Journal of Public Service and Outreach,* 4(1), 21-28.

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., . . . Stringer, L. C. (2009). Who's in and why? a typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management,* 90, 1933-1949.

Reid, R. S., Nkedianye, D., Said, M. Y., Kaelo, D., Neselle, M., Makui, O., . . . Clark, W. C. (2016). Evolution of models to support community and policy action with science: balancing pastoral livelihoods and wildlife conservation in savannas of East Africa. *Proceedings of the National Academy of Sciences,* 113(17), 4579-4584.

Rees, W. (2003, March-May). Impeding sustainability? The ecological footprint of higher education. *Planning for Higher Education,* 88-98.

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155-169.

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, 48, 369-384.

Rockefeller Foundation. (2017). Building greater resilience and more inclusive economies, home page website. Retrieved on February 17, 2017, from http://www.rockefellerfoundation.org/

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., … Foley, J. A. (2009, September 24). A safe operating space for humanity. *Nature,* 461, 472-475.

Rowe, D. (2007, July 20). Education for a sustainable future. *Science,* 317(5836), 323-324.

Saldaña, J. (2011). *Fundamentals of qualitative research.* New York: Oxford University Press

Sandmann, L. (2008). Conceptualization of the scholarship of engagement in higher education: a strategic review, 1996-2006. *Journal of Higher Education Outreach and Engagement,* 12(1), 91-104.

Sandmann, L., Saltmarsh, J., & O'Meara, K. (2008). An integrated model for advancing the scholarship of engagement: creating academic homes for the engaged scholar. *Journal of Higher Education Outreach and Engagement,* 12(1), 47-63.

Savan, B. (2004). Community-university partnerships: linking research and action for sustainable community development. *Community Development Journal,* 39(4), 372-384.

Savan, B., & Sider, D. (2003). Contrasting approaches to community-based research and a case study of community sustainability in Toronto, Canada. *Local Environment,* 8(3), 303-316.

Schlossberg, M., & Larco, N. (2014). The Sustainable City Year Program: a new, radically simple model for publicly engaged scholarship. *Public: A Journal for Imagining America.* 1(1 and 2), an e-journal. Retrieved on March 23, 2017, from http://public.imaginingamerica.org/blog/article/the-sustainable-city-year-program/

Scholz, R. W., Lang, D. J., Wiek, A., Walter, A. I., & Stauffacher, M. (2006). Transdisciplinary case studies as a means of sustainability learning: historical framework and theory. *International Journal of Sustainability in Higher Education,* 7(3), 236-251.

Scholz, R. W., & Steiner, G. (2015). Transdisciplinarity at the crossroads. *Sustainability Science,* 10, 521-526.

Shahadu, H. (2016). Towards an umbrella science of sustainability. *Sustainability Science,* 11, 777-788.

Shandas, V., & Messer, W. B. (2008). Fostering green communities through civic engagement: community-based environmental stewardship in the Portland area. *Journal of the American Planning Association,* 74(4), 408-418.

Sharp, L. (2002). Green campuses: the road from little victories to systemic transformation. *International Journal of Sustainability in Higher Education,* 3(2), 128-145.

Shriberg, M. (2003). Is the "maize-and-blues" turning green?: sustainability at the University of Michigan. *International Journal of Sustainability in Higher Education,* 4(3), 263-276.

Simpson, R. D. (2000). Toward a scholarship of outreach and engagement in higher education. *Journal of Higher Education Outreach and Engagement,* 6(1), 7-12.

Smith Lever Act of 1914, 7 U.S.C. §343 (1914).

Sneddon, C., Howarth, R. B., & Norgaard, R. B. (2006). Sustainable development in a post-Brundtland world. *Ecological Economics,* 57, 253-268.

Soil and Water Conservation Society. (2017). *Journal of Soil and Water Conservation* website. Retrieved on March 20, 2017, from http://www.jswconline.org/

Spanier, G. B. (1997). Enhancing the capacity for outreach. *Journal of Public Service and Outreach,* 2(3), 7-11.

Springer. (2017a). *Transportation* website. Retrieved on March 20, 2017, from https://link.springer.com/journal/11116

Springer. (2017b). *Sustainability Science* website. Retrieved on March 21, 2017, from https://www.springer.com/journal/11625

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, 'translations' and boundary objects: amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science,* 19(3), 387-420.

Steelman, T. A., & Rivera, J. (2006). Voluntary environmental programs in the United States: whose interests are served? *Organization and Environment,* 19(4), 505-526.

Sterling, S. (2004). Higher education, sustainability, and the role of systemic learning. In P. B. Corcoran & A. E. J. Wals (Eds.), *Higher education and the challenge of sustainability* (pp. 49-70).

Stephens, J. C., & Graham, A. C. (2009). Toward an empirical research agenda for sustainability in higher education: exploring the transition management framework. *Journal of Cleaner Production,* 18, 611-618.

Stephens, J. C., Hernandez, M. E., Román, M., Graham, A. C., & Scholz, R. W. (2008). Higher education as a change agent for sustainability in different cultures and contexts. *International Journal of Sustainability in Higher Education,* 9(3), 317-338.

Swart, R. J., Raskin, P., & Robinson, J. (2004). The problem of the future: sustainability science and scenario analysis. *Global Environmental Change,* 14, 137-146.

Talwar, S., Wiek, A., & Robinson, J. (2011). User engagement in sustainability research. *Science and Public Policy,* 38(5), 379-390.

Taylor & Francis. (2017). *Agroecology and Sustainable Food Systems* (previously *Journal of Sustainable Agriculture*). Retrieved on March 20, 2017, from http://www.tandfonline.com/loi/wjsa21

Thompson, R., & Green, W. (2005). When sustainability is not a priority: An analysis of trends and strategies. *International Journal of Sustainability in Higher Education,* 6(1), 7-17.

Thompson Reuters. (2017). *Web of Science:* the complete citation connection website. Retrieved on March 26, 2017, from http://wokinfo.com/citationconnection/

Tregidga, H., Kearins, K., & Milne, M. (2013). The politics of knowing "organizational sustainable development." *Organization and Environment,* 26(1), 102-129.

Tugend, A. (2017, April 1). A voice from Paris on climate change. *The New York Times.* Retrieved on April 2, 2017, from https://www.nytimes.com/2017/04/01/us/a-voice-from-paris-on-climate-change.html?rref=collection%2Ftimestopic%2FGlobalWarming&action=click&contentCollection=science&region=stream&module=stream_unit&version=latest&contentPlacement=2&pgtype=collection&_r=0

Turner II, B. L., & Robbins, P. (2008). Land-change science and political ecology: similarities, differences, and implications for sustainability science. *Annual Review of Environment and Resources,* 33, 295-316.

United Nations. (2017). Sustainable development knowledge platform: sustainable development goals website. Retrieved on March 25, 2017, from, https://sustainabledevelopment.un.org/index.php?menu=1300

United Nations Educational, Scientific and Cultural Organization. (2017). Education website: the UN Decade of Education for Sustainable Development (2005-2014). Retrieved on March 20, 2017 from https://en.unesco.org/themes/education-sustainable-development/what-is-esd/un-decade-of-esd

United Nations Environment Programme. (2017, February). Annual report, 2016: engaging people to protect the planet. Nairobi, Kenya: United Nations. Retrieved on March 11,2017 from http://web.unep.org/annualreport/2016/index.php

University Leaders for a Sustainable Future. (2017a). About website. Retrieved March 20, 2017, from http://www.ulsf.org/about

University Leaders for a Sustainable Future. (2017b). *Talloires Declaration* website. Retrieved on March 20, 2017, from http://www.ulsf.org/talloires-declaration/

University of Minnesota. (2017a). Center for community-engaged learning, what is service-learning website. Retrieved on February 17, 2017 from http://www.servicelearning.umn.edu/info/whatis.html

University of Minnesota. (2017b). University Plan, Performance, and Accountability Report, 2016. Retrieved on February 17, 2017, from http://www.academic.umn.edu/accountability/pdf/2016/2016_Accountability_Report.pdf

University of Minnesota. (2017c). About us website. Retrieved on February 17, 2017, from http://twin-cities.umn.edu/about-us

University of Minnesota, Human Research Protection Program. (2017). Human research protection program website. Retrieved on March 16, 2017, from http://www.research.umn.edu/subjects/

University of Minnesota, Office of the Provost. (2017). Interdisciplinary centers and institutes website. Retrieved on February 16, 2017, from http://academic.umn.edu/provost/interdisc/cigp.html

University of Minnesota, Office of the Vice President for Research. (2017). Research advancement; funding opportunities website. Retrieved on February 11, 2017, from http://www.research.umn.edu/advance/funding.html

University of Minnesota, Resilient Communities Project. (2017). The resilient communities project. What is RCP? website. Retrieved on February 17, 2017, from http://rcp.umn.edu/home/what-is-rcp/

University of Oregon. (2017a). Sustainable cities initiative website: sustainable city year program. Retrieved on March 23, 2017, from http://sci.uoregon.edu/about-sci

University of Oregon. (2017b). Sustainability cities initiative, history of epic-network website. Retrieved on March 23, 2017, from http://sci.uoregon.edu/homepage

University of South Carolina, School of Earth, Ocean and Environment. (2017). Outreach programs website. Retrieved on March 23, 2017, from http://seoe.sc.edu/outreach-programs

U.S. Department of Education, National Center for Education Statistics. (2016). *Digest of education statistics, 2014,* chapter 2. Fast Facts. Retrieved on March 22, 2017, from http://nces.ed.gov/fastfacts/display.asp?id=84

U.S. Department of Transportation. (2015). Partnership for sustainable communities: an interagency partnership among the U.S. Department of Housing and Urban Development, Department of Transportation, and the Environmental Protection Agency website. Retrieved on February 16, 2017, from https://www.sustainablecommunities.gov/

U.S. Environmental Protection Agency. (2014, August). *Partnership for Sustainable Communities: Five Years of Learning from Communities and Coordinating Federal Investments. Fifth Anniversary Report.* Office of Sustainability Communities (1807T). Retrieved on March 23, 2017, from http://www.sustainablecommunities.gov/sites/sustainablecommunities.gov/files/docs/partnership-accomplishments-report-2014-reduced-size.pdf

U.S. Green Building Council. (2017a). U.S. Green Building Council history website. Retrieved on March 20, 2017, from http://www.usgbc.org/

U.S. Green Building Council. (2014b). LEED for neighborhood development website. Retrieved on March 20, 2017, from http://www.usgbc.org/nd.html

van Weenan, H. (2000). Towards a vision of a sustainable university. *International Journal of Sustainability in Higher Education,* 1(1), 20-34.

VanWynsberghe, R., & Andruske, C. L. (2007). Research in the service of co-learning: sustainability and community engagement. *Canadian Journal of Education,* 30(1), 349-376.

Velazquez, L., Munguia, N., & Sanchez, M. (2005). Deterring sustainability in higher education institutions: an appraisal of the factors which influence sustainability in higher education institutions. *International Journal of Sustainability in Higher Education,* 6(4), 383-391.

Vincent, S., & Focht, W. (2009). U.S. higher education environmental program managers' perspectives on curriculum design and core competencies: implications for sustainability as a guiding framework. *International Journal for Sustainability in Higher Education,* 10(2), 164-183.

Vincent, S., & Focht, W. (2011). Interdisciplinary environmental education: elements of field identity and curriculum design. *Journal of Environmental Studies and Sciences,* 1, 14-35.

Waas, T., Verbruggen, A., & Wright, T. (2010). University research for sustainable development: definition and characteristics explored. *Journal of Cleaner Production,* 18, 629-636.

Wade, A., & Demb, A. (2009, Spring). A conceptual model to explore faculty community engagement. *Michigan Journal of Community Service Learning,* 5-16.

Wals, A. E. J., & Jickling, B. (2002). "Sustainability" in higher education: from doublethink and newspeak to critical thinking and meaningful learning. *International Journal of Sustainability in Higher Education,* 3(3), 221-232.

Weaver, P. M., & Rotmans, J. (2006). Integrated sustainability assessment: what is it, why do it and how? *International Journal of Innovation and Sustainable Development*, 1(4), 284-303.

Weerts, D. J. (2005, October). Validating institutional commitment to outreach at land-grant universities: listening to the voices of community partners. *Journal of Extension,* 43(5). Retrieved on October 17, 2014, from http://www.joe.org/joe/2005october/a3.php

Weerts, D. J., & Sandmann, L. R. (2008). Building a two-way street: challenges and opportunities for community engagement at research universities. *The Review of Higher Education,* 32(1), 73-106.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: a reference framework for academic program development. *Sustainability Science,* 6, 203-218.

William and Flora Hewlett Foundation. (2017). Environment program website. Retrieved on February 17, 2017, from http://www.hewlett.org/programs/environment

World Commission on Environment and Development. (1987). *Our Common Future.* Oxford, Great Britain: Oxford University Press.

Wright, T. (2002). Definitions and frameworks for environmental sustainability in higher education. *International Journal of sustainability in Higher Education,* 3(3), 203-220.

Wright, T., & Horst, N. (2013). Exploring the ambiguity: What faculty leaders really think of sustainability in higher education. *International Journal of Sustainability in Higher Education,* 14(2), 209-227.

Yarime, M., Trencher, G., Mino, T., Scholz, R. W., Olsson, L., Ness, B., Frantzeskaki, N., & Rotmans, J. (2012). Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and stakeholder collaborations. *Sustainability Science,* 7, 101-113.

Zilahy, G., Huisingh, D., Melanen, M., Phillips, V. D., & Sheffy, J. (2009). Roles of academia in regional sustainability initiatives: outreach for a more sustainable future. *Journal of Cleaner Production,* 17, 1053-1056.

APPENDIX

University of Minnesota Institutional Review Board Study Confirmation

Carla Carlson <carlsonc@umn.edu>

1510E78825 - PI Carlson - IRB - Exempt Study Notification

From: irb@umn.edu Fri, 30 Oct 2015 16:13:28 -0500 (CDT)
To: Carla Carlson <carlsonc@umn.edu>

TO: mand@umn.edu, carlsonc@umn.edu,

The IRB: Human Subjects Committee determined that the referenced study is exempt from review under federal guidelines 45 CFR Part 46.101(b) category #2 SURVEYS/INTERVIEWS; STANDARDIZED EDUCATIONAL TESTS; OBSERVATION OF PUBLIC BEHAVIOR.

Study Number: 1510E78825

Principal Investigator: Carla Carlson

Title(s): The Emergence of the Field of Sustainability Science: Influences on Faculty Research, Teaching, and Community Engagement in Sustainability

This e-mail confirmation is your official University of Minnesota HRPP notification of exemption from full committee review. You will not receive a hard copy or letter.

This secure electronic notification between password protected authentications has been deemed by the University of Minnesota to constitute a legal signature.

The study number above is assigned to your research. That number and the title of your study must be used in all communication with the IRB office.

Research that involves observation can be approved under this category without obtaining consent.

SURVEY OR INTERVIEW RESEARCH APPROVED AS EXEMPT UNDER THIS CATEGORY IS LIMITED TO ADULT SUBJECTS.

This exemption is valid for five years from the date of this correspondence and will be filed inactive at that time. You will receive a notification prior to inactivation. If this research will extend beyond five years, you must submit a new application to the IRB before the study?s expiration date.

Upon receipt of this email, you may begin your research. If you have questions, please call the IRB office at (612) 626-5654.

You may go to the View Completed section of eResearch Central at http://eresearch.umn.edu/ to view further details on your study.

The IRB wishes you success with this research.

We value your feedback. We have created a short survey that will only take a couple of minutes to complete. The questions are basic, but your responses will provide us with insight regarding what we do well and areas that may need improvement. Thanks in advance for completing the survey. http://tinyurl.com/exempt-survey