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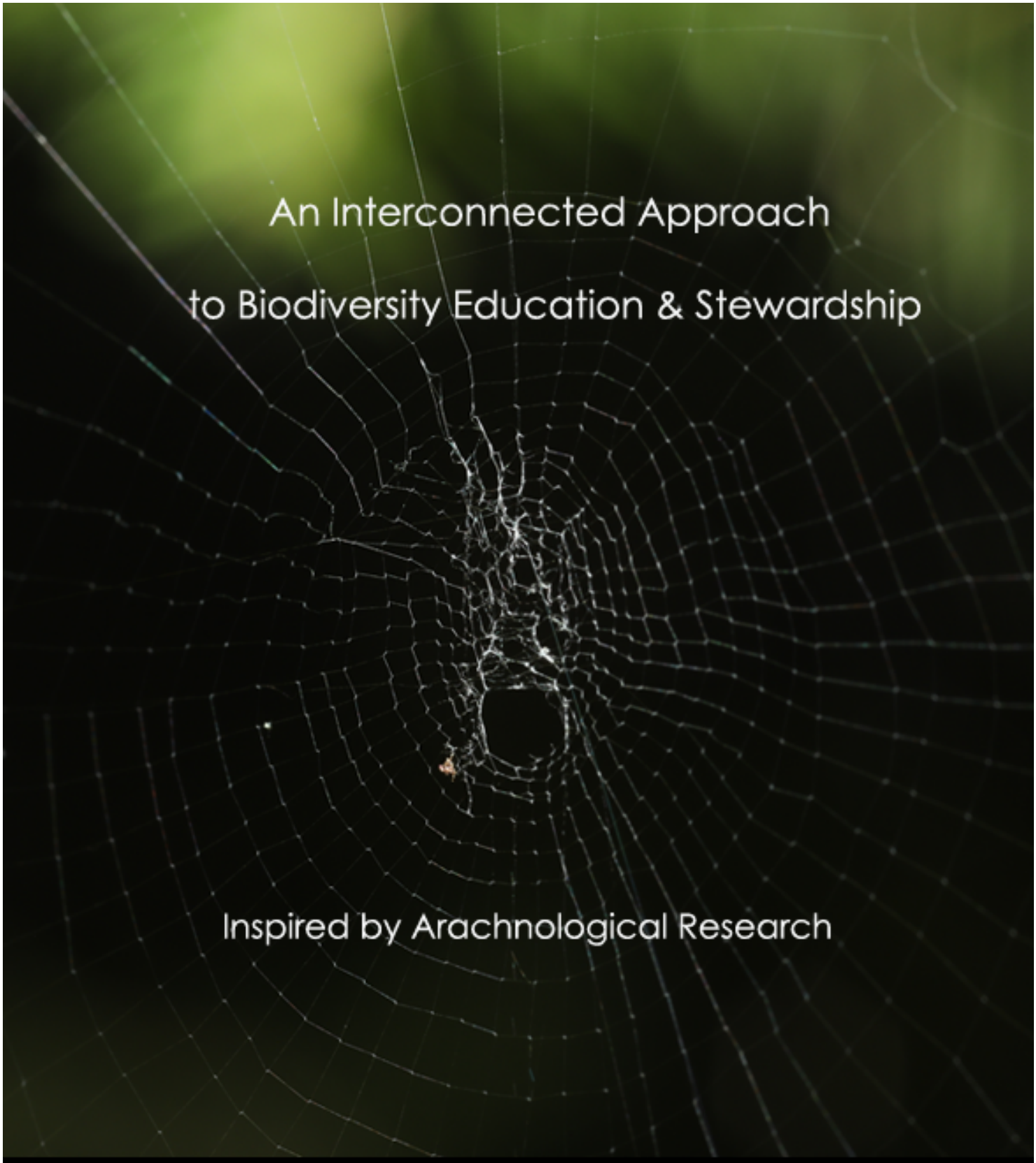

An Interconnected Approach to Biodiversity Education & Stewardship

Inspired by Arachnological Research

by S. J. Karikó

Thesis submitted for the degree of
Doctor of Philosophy in Biodiversity Management
Durrell Institute of Conservation and Ecology, University of Kent
Canterbury, United Kingdom

Note on the composition of the thesis: PhD by Published Works

This thesis is to be submitted for consideration for the degree of PhD by Published Works. This is where already published, but related, academic works are retrospectively combined to form the basis of a PhD thesis. In addition, a supporting statement must be included, explaining how these works link together to form a substantial body of original work.

In this case, in order to mirror the structure of a more conventional thesis, this interconnecting text has been organized with an introduction where I discuss the problem, my positionality and then my approach followed by a section on research formed by selected research papers and creative works, then concluding with a discussion.

The research section was selected from a wider body of work by the author; with a selection of these additional works listed in 'Notes on this Research'.

Declaration

I declare that this thesis has been composed by myself and has not been accepted in any previous application for the award of degree in any university. All quotations have been distinguished appropriately, and sources of information have been specifically acknowledged to the best of my knowledge.

It is understood that any copying or publication or other use of this dissertation or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Kent in any scholarly use which may be made of any material in my dissertation.

S. J. Karikó
2018

Dedication

To all my Teachers
especially the Spiders
and my Loved Ones

Acknowledgements

I would like to acknowledge the many who have lifted me up and the many who have challenged me as together they have shaped and strengthened this work. I would like to thank Dr. Ian Bride for his openness to this idea and to Dr. Robert Fish for his support in this process. I would also like to thank Nicola Kerry-Yoxall for her assistance with administrative logistics and the members of the SLAS team who explored ideas with me and provided support: Dr. Gina May, Steven Cope and Alison Foley. I also thank the reviewers who have sharpened my work through their comments and critique.

This work has evolved as an interconnecting web of creative collaborations. Many individuals have supported and been instrumental in the creation and completion of this research – they have inspired me, challenged me, and sustained me during this time. I recognize that this is just part of a long list…First I extend my heartfelt thanks to my husband Dan for his special support. Thanks also to my family, Attila and Joan, to friends and colleagues Janus K., Susan C., David F., Meg N., Laura L., Marsha C., George D., Cay C., Fran L., Jerry S., Jane L., and Dana W. for exploring and bringing my ideas to life as well as for their continued support, and to Jackie D., Carole H., Kathy M., Tiff B., Liz S., and Sara M.

I thank the United States and Madagascar National Park Services for facilitating my research. Please see individual papers and creative works for more specific acknowledgements and recognition of the funding sources that made this research possible.

I would also like to acknowledge the lands where I conducted the majority of my field research – the places where the seeds of many of these ideas were formed – Vatoharanana in Madagascar and the Tetons in Wyoming, USA – and the peoples who have and continue to steward them. Thanks also to the land where I was raised that supported my early education with lessons of Mrs. Newell's rocks, Grampa's compost pile and tomato plants, the hope of walking stick insects and sassafras trees, and spider webs.

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Figure 10: Mounds created and displayed in dialogue with the Lowell Lecture by Terry Tempest Williams at the Boston Public Library Massachusetts, USA, 29 March 2018.

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Abstract

When reflecting upon how the results of the past several decades of robust scientific studies and practitioners' work have not resulted in the type of engaged citizenry and political will to make significant changes to protect the environment, Gus Speth, former Dean of Yale School of Forestry and one of the Founders of the National Environmental Defense Fund called for "a cultural and spiritual transformation" (Crockett, 2014). Disciplines like the new discipline of planetary health that are concerned with "the health of human civilization and the state of the natural systems on which it depends" (Bosurgi and Horton, 2017; Rodin, 2015) are also calling for paradigm shifts (Myers, 2017).

But how do we create these transformational changes?

Humankind (but not all people equally) is disrupting natural systems and processes at a rate unprecedented in previous evolutionary history, acting with the might of a geologic force on the rest of nature. Biodiversity conservation education has historically applied a science-first model that has proved inadequate to make significant changes in how humans care for each other and steward the earth. In recent years, the field of conservation biology has begun incorporating the social sciences and psychology as well as recognizing and valuing indigenous knowledge – Traditional Ecological Knowledge (TEK) and Native Science (Cajete, 2000) – in response to the need for more effective solutions that take into account the impact of human behavior. Yet in the field of conservation biology the Arts have not been considered an equal partner for the field in research and education (A'Bear et al. 2017; Ardalan, 2013). In the broader educational landscape, the American National Academies of Sciences, Engineering, Medicine's (NASEM) 2018 consensus study "The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree" (Branches from the Same Tree) calls for an integration of disciplines and incorporation of the Arts as part of understanding and finding solutions to the challenges facing humankind in the 21st century. However the committee does not emphasize an understanding of biodiversity and humanity's place within the web of life, instead using the metaphor of the tree of knowledge and framework of workplace skills for the 21st century (NASEM, 2018). Additionally, field research stations have a long history of exploring this combination of scientific research, public engagement and the arts (Swanson, 2015).

In this interconnecting text, I begin with a discussion of the intertwined nature of current environmental challenges and opportunities, and how these problems are understood and characterized in bodies of literature. Then I consider current approaches to biodiversity conservation and education and respond to the widespread recognition for the need for paradigm shifts to address the intertwined challenges of the 21st century--challenges that cannot be separated out into single disciplines but require an integrated, multidisciplinary approach with accompanying collaborative skills to work across disciplinary and cultural boundaries. In response, I propose an interconnected approach that seeks to understand and make visible the often hidden connections among species

and systems to help us better understand the nature of these challenges and help us find solutions.

I focus on spiders as the connecting thread and framing metaphor for this research, as well as the focus of scientific study. Although not all spiders make webs, all produce silk, and they provide the metaphor of the web—a way to consider the myriad interconnections and relationships among the organisms in the web of life and how actions impact each other—rippling out across a web to vibrate even seemingly distant (yet connected) parts. Spiders can be found almost everywhere on earth (except in Antarctica to date), are being critical to ecosystem functioning, and comprise a highly diverse group of organisms (Hughes et al., 2010; Lewis, 2006). To explore these relationships and contribute to scientific understanding of invertebrates, I explore these questions by focusing on spiders.

The 'toolbox' my research draws from involves not only science, but also the creative arts (including participation in and co-creation of works of public art) and skill building (i.e., developing ways of teaching and learning about biodiversity, and offering negotiation training based on mutual gains theory) to enhance the possibility for finding innovative solutions and building networks of people with the capacity to work together. I identify some of the challenges facing biodiversity conservation and education, since many education systems and funding institutions are not necessarily set up to facilitate this type of understanding nor skill building, and I then propose an interconnected approach that embeds the arts and takes inspiration from nature. I outline this approach in detail and follow this with my own works, drawing upon the combination of my field experiences and research.

My research has resulted in scientific publications, museum exhibits, lectures, poems, movement labs, and educational experiences in formal and informal learning environments. These works contribute to the scientific understanding of the biodiversity of spiders, take a deeper look at the structural origins of color, describe new species to science, and take inspiration from these animals to create participatory educational opportunities. Taken together, they address three of the seven challenges for invertebrate conservation identified by Cardoso et al. (2011): (1) the public dilemma; (2) the scientific dilemma; and (3) the Linnaean shortfall, and also addresses the UN Aichi Biodiversity Target 1 "By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably" (UN Environment, 2016). I then discuss challenges and questions for further research. In this text, I argue for an approach to biodiversity conservation and education that takes inspiration from nature, embeds the creative arts as integral to research and discovery – not just in service to Western science – and explores how the arts can be a catalyst for change as well as a thread that brings people together. In so doing, I address the idea, often attributed to Einstein, that we cannot solve our problems with the same thinking that was used to create them; proposing that an interconnected approach be applied in the context of biodiversity conservation and education.

Introduction

"If grief can be a doorway to love, then let us all weep for the world we are breaking apart so we can love it back to wholeness again." Robin Wall Kimmerer

"There can be no purpose more inspiring than to begin the age of restoration, reweaving the wondrous diversity of life that still surrounds us." E. O. Wilson

This research draws upon over three decades of my scientific and creative exploration of the mysteries of nature. I offer this explanation of the depth and breadth of my work as a way for the reader to help contextualize the ideas and research presented herein.

My work has included large-scale sculptural installations using materials and forms intrinsic to my subject matter (such as bison bones or the design of a *Hyptiotes* spider web). I have studied the mating behavior of beetles - the role of female choice and coital courtship (Eberhard & Karikó, 1996), described new species of spiders new to science (Karikó, 2014), described (with a team) the structural origins of color of a vibrantly colored species (Karikó et al., 2018), and have created dynamic educational experiences that invite participation and many voices (Karikó, 1996).

I have been invited to create poetry for art exhibits and have included scientific literature when exhibiting the artwork I created for a postage stamp for the Malagasy Postal Service. My photographs are in the teaching collection of the (American) National Museum of Wildlife Art, and I have developed educational programs for students ranging from choreography students at the Juilliard School to students at the Program on Negotiation at Harvard Law School as well as conservation students at the University of Kent, U.K. (Karikó, 2012; Karikó, 2013; Karikó, 2018).

In each case I make the classes participatory, weaving learning about biodiversity with other concepts such as negotiation or the informants of movement or food. I seek ways to better understand the perspective of animals. Through the course of this work, I have experimented with ways to bridge findings out into larger audiences. I explore how to make things personal and relatable. I experiment with how to invite many voices to participate. I focus on how to interweave story with scientific information. For example, when I was invited to present at the "Stories Through Time" festival at Harvard's Museum of Natural History about relics, I highlighted living fossil spiders from Madagascar and incorporated a duet by modern dancers (Karikó et al., 2013).

My collected works explore interconnections between humans and other organisms. I am interested in human impact and have a desire to contribute in some way towards improving the irreducibly intertwined health of humans and our environment. I am aware throughout the process of conducting this research of my own impact—for example, my driving to the field and the invertebrate road kill this creates. I also consider impacts that I would like to imagine are helpful—the delight on children's faces when I share field footage of one of their neighbors (the mason spider) building an extraordinary structure carrying things with her jaws!

Early Influences

For many, a formative element threading through the course of their life's work often includes early childhood experiences in Nature. Within the field of conservation biology, writers and scientists such as Gerald Durrell, Loren Eiseley, Carl Safina, E. O. Wilson, Robin Wall Kimmerer, Patricia Wright as well as arachnologist Herb Levi all comment on the importance of early childhood experiences, whether it was an early interest in zoos, or exploring the Nebraska prairielands, or the ocean from an Uncle's boat, or discovering ant mounds, being drawn to the beauty and color juxtapositions of wildflowers, or learning to cherish the nearby woods or exploring the German countryside (Durrell, 1955; Eiseley, 1975; Safina, 2011; Wilson, pers comm.; Kimmerer, 2013; Wright, 2013; Levi, pers comm.). My own childhood experiences are a further example of this.

Like many children, I did not have a choice of where I wanted to live. If anybody had asked me, I would have said that I wanted to grow up in the pages of what I had seen in National Geographic— wide open spaces or lush looking places teeming with wildlife. Instead I grew up in a city.

My experiences growing up shaped my ideas about seeing and engaging with the more-than-human world. My family would rototill our city plot and grow some of our own food and flowers. I would negotiate with my parents to have some tomato plants to have as my own so I could do experiments on them, like trying to stimulate their growth through electroculture. Through these experiences I grew to connect with the land that supported us wherever we were. I grew to value learning in both formal and informal settings— for example learning in our backyard and connecting this with my schoolwork.

There have been numerous childhood experiences that have shaped my relationship with the concept of interconnectedness. In order to provide an example, I will cite my relationship with Mrs. Newell, with whom, beginning around second grade, nearly every day after school, I would go over to her house and wash rocks. Her husband, a retired engineering professor, would open the door and I would walk through his home laboratory (thereby sparking my later interest in historical scientific instruments). Washing the rocks – each one was like a story with labels that would transport us to other places – other worlds, and other times. Afterwards we would sit under a big painting that looked like "The Peaceable Kingdom" and would hold hands. If I was lucky, she would give me two fingers of papaya juice. When I was a little girl, Mrs. Newell, this very frail-looking elderly woman, was the only woman I had ever met who owned her own hammer. A tool that seemed intrinsic to the adventures that resulted in the collection of all of these storied, wonder-filled rocks that we now washed together.

From these experiences, I took away a deep fascination with the natural world and an appreciation of the painting that we sat under each day, and a fascination with women and tools. I eventually became an assistant carpentry instructor for girls. Once I began doing field research, I sought ways to expand my own toolkit by doing things such as getting trained as a wilderness Emergency Medical Technician (EMT) so I could (if possible) take care of my team and myself in the field. Later as part of my work, I began creating skills trainings such as offering negotiation workshops for field researchers.

When I was a little older, one of the first places I was allowed to walk to after school by myself was the city's art museum. There I would wander galleries, visit the courtyard

sculptures, and often go see the expressionist paintings. Among these paintings was a 19th century painting *Golfe Juan* in the pointillist tradition painted by Paul Signac (1896). I used to look closely at all the tiny dots—and observed how these different daubs of paint when viewed from a distance created a larger landscape. I would shift my viewpoint sometimes standing up close then moving across the room to one of the gallery benches. I think these experiences also contributed to my relationship and thinking about perspective. In my ensuing work there is a dynamic interplay between looking deeply and closely at the natural world and taking a broader view of the greater interconnections that make up the living picture of the world—shifting perspectives from a spiders' to that of deer and aspen to the broad view of soaring birds (Karikó, 2017).

In college (first semester, first year), I was selected for an individual seminar with Professor Herbert Levi (Herb), the Alexander Agassiz Professor of Zoology and then-Curator of Arachnology at the Museum of Comparative Zoology. I was introduced to the beauty and wonder of the small.

I saw Herb render ornate, intricate structures of key morphological features like epigyna and pedipalps (spider genitalia) for his taxonomic research. I watched him carefully examine spiders under the microscope then illustrate each one from multiple angles and magnifications. I was introduced to a world of arachnid beauty through these extraordinary sculptural forms. Spiders became a window to the world that continues to take me around the globe – from the rainforests of Madagascar to the wide-open spaces of the northern Rocky Mountains, USA.

Later when I was working in the field in Costa Rica I studied with evolutionary biologist and ethologist William Eberhard, who had recently published a book on the evolution of animal genitalia that covered an even broader range of an extraordinary extravagance of genital morphologies visible across taxa (Eberhard, 1985). I began field observations and described the mating behavior of two species of metallic flea beetles which provided supporting evidence to Eberhard's theory, that was new at the time, of female choice and the role of coital courtship in the evolution of animal genitalia. My field experiences created a deep sense of awe--to witness and record the incredible intricacies of the living world (far beyond anything I could have imagined) occurring all around me – at such a tiny scale. It got me to pay attention to the world in a new way.

To conduct this and subsequent fieldwork, I had to be very patient, very still, and very attentive. I had to learn how to take in lots of information not only through my ears and eyes but through all of my senses and then translate and integrate that information. One challenge was that when it came time to communicate my (scientific) findings, so much of the data and information that I took in through my body had very few outlets and yet it seemed important to better understand the role of humans and nature which seemed core to what I was witnessing around me in the field. Reflecting is part of knowledge creation and integration. What I was missing at the time, were places and spaces to integrate the information or data I took in from my senses and experiences, and to transform into useable, shareable knowledge. This was difficult to find within the academy however I did explore this personally through artwork and poetry: forms where emotion and observation and data can comingle to create something that registers differently than just scientific findings alone. This is different from how field research

findings are typically communicated through the scholarly/scientific literature. By doing so, I created the possibility to communicate in ways that support an emotional, caring connection with people and the natural world as well as a foundation for future questions and research.

I struggled to find spaces and places where I could learn not only from my own experiences but also from those of my mentors and peers – recognizing this as integral to my learning process. I pursued this on my own and integrated my own stories into invited talks upon my return such as at the Radcliffe Summer Science program (Karikó, 1993).

These many experiences shaped my lifelong curiosity in exploring the mysteries of nature and informing my research developing the interconnected approach that I will discuss.

Informing this Approach: My Positionality

During my expeditions to Madagascar to study spiders in the early 1990s, I had a visceral experience of the interconnectedness of political unrest, environmental impact and human health. I was in Madagascar during a time when much of the infrastructure in the rural areas was limited. Things like telephone lines running up in the north appeared to be a great material source for wire and hence were often cut down for villagers' use, while large aggregations of *Nephila* spiders would fill the voids with their golden silken lines (one time I counted approximately fifty-five meter-wide webs between two poles). At that time, the area where I was working was just being inaugurated into a national park and peoples who had traditionally used these forests for generations now needed to adjust to not being welcomed to come in for medicinal plants, building materials and food such as bush meat and honey (some of this has since changed). However I, as a western scientist, was allowed to live in the forest to collect data about spiders. It was also a time of great political instability, and I vividly remember travelling when they blew up the main bridge between the port town and the high plateau where most of the people lived, thus creating a shortage of supplies such as gasoil. I remember heading back to the capital, Antananarivo (Tana) and going through a tunnel of flames—the forest was being burned on both sides of the road. Near the rainforest where I was doing my fieldwork, an entire forest came down and was burned and made into charcoal to provide fuel people needed to cook, as the main diet was rice. I watched people carrying large sacks of charcoal up to the capital and when I arrived in Tana, people were lining the sidewalk, cooking over charcoal that had been trees just days before. I breathed in that air and my lungs burned.

I wanted to do something in response, and was unsure what to do. At the time, I designed a postage stamp in collaboration with the Malagasy Postal Service as a way to highlight the biodiversity of Madagascar, in-country and abroad, by focusing on an *Arachaeid* spider with the idea that perhaps, like the conservation Duck Stamps in the U.S., this could, in some way be beneficial. I also negotiated an international accord of collaboration through the signing of a venom accord (Wilson, 2002).

From my perspective at the time, experiencing this interconnection of political unrest, environmental change and human health made a deep impression on me and filled me with a sense of urgency to focus my own efforts towards contributing to environmental

and human health and wellbeing in some way. To make contributions that could contribute towards sustaining the biocultural diversity that supports life on earth.

I was surprised when I returned to the USA filled with a sense of urgency to do something – to create works that could make a difference, to seek out role models that could show me an integrated approach. I struggled to find a way to articulate what I had seen and experienced in the field as well as the sheer depth and breath of my adventures living in a remote bushcamp studying spiders and living among lemurs, chameleons, orchids, weaver birds and waterfalls as well as mongooses, large land snails, tree ferns, and terrestrial leeches.

Also, where were the places and spaces for integrating lessons from the field? Where could stories be reflected upon, interrogated, used for learning and shaping future work? Not just the data but the complex experiences that can allow us to better understand how cultures and places at seemingly distant parts of the world are connected. I also struggled to know how to talk about some of the things I saw and experienced - How to communicate these? With what language? What could I learn from these experiences?

But at that time, the mentors I asked and the ones they sent me to had not yet come to a place of calling for a merging of the humanities and sciences. Even my own mentor did not, for a variety of reasons, provide a role model of how to integrate the disciplines through bridging formal and informal learning about the natural world using both the sciences and the arts[1]. There appeared to be a lack of attention perhaps due to a combination of contributing factors including what is prioritized and valued within the existing educational frameworks. Herein seemed to be a path worthy of more exploration.

My approach to research is informed by conducting field research on spiders, an often feared and misunderstood organism that is abundant in ecosystems worldwide, as well as receiving two unexpected invitations early on in my career to create artistic works in the public realm where I observed that the arts had a way of bringing people together (even over contested issues like bison management in the American West) and creating possibility beyond my own imagination (*Homage*, 1996; *Spiders! KidzArt*, 1996).

Challenge and Opportunity

The challenges and opportunities of the 21st century are complex, intertwined and unprecedented in human history as a new era of changing climate caused by the accumulated actions of humans' impact nearly every facet of existence of life on earth.

This impact is described by evolutionary biologist E.O. Wilson as "HIPPO" in order of importance: Habitat destruction, Invasive species, over Population, Pollution, Overharvesting (UNESCO, 2010), while Jared Diamond refers to the four evils: habitat

[1] It was during the course of creating works for an exhibit at the Museum of Comparative Zoology special collections when I realized that my mentor had dedicated his life to the areas that I had been seeking to integrate for so long – arachnology, art, education and stewardship – he had actually been awarded a scholarship at the Student Art League in New York City. It left me curious as to why he had kept them so separate in his private and professional life and had not provided the integrated role model I was seeking. Why he had sent me to others when he himself was doing this work, albeit quietly.

loss/fragmentation, overkill, introduced species, and extinction chains (Diamond, 1984). The most recent report from the International Panel on Climate Change (IPCC) has found that despite warnings by the scientific community, the rate of carbon emissions continues unabated (Hoegh-Guldberg et al., 2018).

Natural disasters such as more powerful hurricanes, drought, flooding, desertification, and wildfires are increasingly common (Hoegh-Guldberg et al., 2018; Kimberlain et al., 2015). Habitats are being increasingly fragmented by incursions of new roads and highways spreading across the land that can be beneficial for transportation and commerce and also have great impact on biodiversity (Forman et al., 2003).

This epoch is being referred to by many as the Anthropocene (Ellis et al., 2018) due to the collective human impact acting with the might of a geologic force on the planet's global commons (Rickards, 2015), with some calling it the sixth mass extinction (Kolbert, 2014). There is little discussion exploring the reciprocal, mutually beneficial relationships humans have with earth, as plant ecologist and Potawatomi Nation Citizen Robin Wall Kimmerer points out in her book *Braiding Sweetgrass* (Kimmerer, 2013). It a critical time in human and planetary history where people who are alive today can fundamentally change the very nature of earth that will have implications for species survival (including our own). Understanding the interconnectedness of our human systems (governance, finance, health, education, transportation, agriculture) will be key to our collective future. The possibility for us to be in a dynamic, nurturing, reciprocal relationship with Earth remains. A shift is needed in order to live into the possibilities of this time.

Impact on Biodiversity←→Human Health and Wellbeing

Biodiversity forms the building blocks of life for the earth's ecosystems and is central to human health. The diversity of life is intrinsic to sustaining the regulatory systems that maintain life on earth – for example, pollinating crops for food production, cycling nutrients, and providing drinkable water.

With human health being critically linked to the health of our environment (Carson, 1962; De Souza et al., 2003; Li, 2012; Liu et al., 2007; Kolbert, 2014; Williams, 2014; Williams, 2017; Hartig et al., 2014; Myers, 2017; Frumpkin et al., 2017), our ability to understand our interconnectedness with biodiversity and to innovate solutions that sustain the systems upon which our own lives depend have become more critical than ever. What we do to our environment, we do to our own bodies: studies report an increase of environmental toxins, found in humans through exposure to pesticides, flame retardants, even jet fuel (Williams, 2012).

Disconnect

Human bodies have evolved in close connection with their environments-- taking cues from the natural world for physical development. It is only in recent years that humans have become a species living predominantly in man-made environments. As humans become a predominately urban species (UN, 2018), a growing body of evidence suggests that children are experiencing a growing disconnect from nature. In Louv's 2005 book *Last Child in the Woods* he points to the growing distance between young people and the natural world, discussing the implication of the important impact of nature for nearly every realm of development—environmental, social, psychological, and spiritual—and the implications for society. Studies by Howard (1997) and Schultz, Shriver, Tanaico and

Khazian (2004) also support the idea that disconnection can contribute to biodiversity loss and habitat degradation.

Preventable public health problems such as myopia in children especially from East Asian countries are increasing (Raminurthy et al., 2015; Li et al., 2017). Recent evidence from epidemiological studies identified an important factor for protecting young children from myopia: time spent outdoors to have enough outdoor exposure for the proper development of retina cells (Raminurthy et al., 2015). Further research is being conducted to understand the underlying mechanism for this positive effect (Ramamurthy et al., 2015; Williams, 2017).

Japanese doctors are now being trained in Forest Medicine and have begun prescribing forest time for youth. Forest rangers facilitate the practice of *shinrin-yoku* or "forest bathing" (Tsunetsugu, 2009; Williams, 2017). There are more than sixty official "Forest Therapy" trails with Japan's Forestry Agency where researchers are collecting data regarding the health benefits for trail uses and possible implications for national health care costs (Miyazaki, 2018; Williams, 2017). Additionally, spending time in forest settings has been shown to increase immune response and production of cancer fighting protein cells (Li, 2009).

Organismal Biology and the Web of Life

In the context of conservation and education, basic knowledge of the natural history and identification of species is considered fundamental to learning and understanding biodiversity (Lindemann-Mathies 2002; Randler and Bogner 2002; Gaston and Spicer 2004; Randler and Zehender, 2006; Randler, 2008). More needs to be learned about the organisms themselves that comprise the biodiversity of life. However, Mammola et al. (2017) say, "Organismal biology has been steadily losing fashion in both formal education and scientific research. Simultaneous with this is an observable decrease in the connection between humans, their environment, and the organisms with which they share the planet." In other words, humans are experiencing not only a disconnect from nature in the next generation, but also a decrease of interest in learning about the organisms that make up the rich web of life.

When reflecting on how the results of the past several decades of robust scientific studies and practitioners' work have not resulted in the type of engaged citizenry and political will to make significant changes to protect the environment, Gus Speth, former Dean of Yale School of Forestry and one of the Founders of the National Environmental Defense Fund calls for "a cultural and spiritual transformation" (Crockett, 2014).

A fundamental opportunity is largely missed to connect and understand the relationships between the social, political, environmental dimensions to these problems. This is due in some part to the specialized or "siloed" nature and approach of academic research institutions: current methods of teaching and learning, the evolution of specialized language utilized to communicate findings, the way research is funded, and the increasing specialization and separation of arts and sciences over many decades. It is widely accepted that the contemporary issues generated by human activity demand more than one discipline to effectively address them; they demand deep specialist

knowledge *and* the capacity to take a broad view and consider the less obvious web of contributing factors.

Yet despite efforts to create interdisciplinary, transdisciplinary and multidisciplinary teams and disciplines within the academy, the majority of knowledge creation continues in this isolated fashion with findings published in professional journals and research presented at specialist conferences that create barriers to integrating knowledge while simultaneously missing the interconnections between the fields and neglecting the interstitial spaces between.

As Bride suggests, simply accumulating and "disseminating" more scientific knowledge is insufficient for effectively encouraging "understanding of and appreciation for biodiversity" (2006 p. 1338), as well as for addressing today's environmental concerns. To address the challenges of a rapidly changing climate demand not only deep specialist knowledge but also the capacity to take a broad view and consider the not always obvious web of contributing factors. The threats of great biodiversity loss require us to think differently.

One facet that is lacking is an understanding of how all these things are connected. By studying them in isolation, we miss opportunities for understanding the complexity and intertwined nature of these systems and limit our own ability to create solutions to address these issues. Novacek (2008) argues that our current approach not only segregates things into different parts but also fundamentally "loses sight of the interconnectedness of these issues" (Novacek, 2008 p11573). These ideas of interconnectedness are not new. They are rooted in older ideas found in indigenous cultures that have often been marginalized.

Understanding the interconnectedness of our human systems will be key to our collective future as well being nimble to address unintended consequences and cultivating a culture of collaboration. How knowledge is parsed out and relegated to different fields and discussed in separate journals, interests groups, conferences, etc, contributes to it being challenging for people to fully grasp the complex impact of individual action, let alone imagine the force of collective human action, especially in systems that typically have been regarded as bountiful and boundless such as the sea, the air, and the land.

Biodiversity Conservation and Education

In the realm of biodiversity conservation and education, historically there has been a science-first model, with science elevated over other ways of knowing (Kelsey, 2003). The field maintained this science first approach for a surprisingly long time (given the impact humans contribute to the environmental crisis) before the potential of the social sciences was recognized. It was not until 2003 when Mascia et al. called for including the social sciences to address the human dimension saying, "we get the biology right, but our conservation interventions still fail to sustain target species and ecosystems" (Mascia et al, 2003 p.649). Shortly afterwards, Clayton and Brock (2003) also argued to include psychology, and in 2006 Saunders et al. stated that "a dynamic partnership between conservation biology and the social sciences will be critical for more sustainable

relationships between people and the rest of nature in the future." (p.704) (Saunders et al., 2006).

The United Nations Strategic Plan for Biodiversity 2011-2020 to conserve the world's biodiversity is articulated in twenty Aichi Biodiversity Targets to be achieved by 2050. My research addresses Target 1 which states, "by 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably" (UN Environment, 2016).

Art and Science

In many cultures the arts and sciences are not so divided which influences how people consider and interact with the living world. The ideas of ecological interrelatedness go back millennia and form the foundation of Native science (also referred to in some literature as Traditional Ecological Knowledge (TEK) or Native ways of knowing. For more on Native science see *Native Science: Natural Laws of Interdependence* by Cajete (2000)). Western science offers just one way of looking at the world. Native science, which like western science draws upon similar processes such as observation and analysis, also includes a deep sense of responsibility, reverence, reciprocity and respect toward all living things (Cajete, 2000). Native science shares this knowledge through many forms including ceremonies, stories, and dance - fundamental to indigenous ways of knowing (Cajete, 2000).

In the Western tradition, people like Leonardo da Vinci worked more seamlessly between what are now considered the fields of art and science. Historically, art has the power to influence culture. One example is Dürer's rhinoceros, which was a fictitious rendering of an animal he had never seen, but one that influenced people's perception and understanding of rhinos for centuries (Dürer, 1515). Additionally his prints also contributed to culture's understanding of health states like melancholia (Cosgrove, 2018).

After the WWI and WWII in the United States, there was an upsurge in examining humans' relationship with nature, with authors like Rachel Carson and Aldo Leopold writing *A Silent Spring* and "The Land Ethic" respectively (Carson, 1962; Leopold, 1949). More recently writings by Terry Tempest Williams' finding beauty in the mosaic of a broken world (Williams, 2008), David Abram's "Spell of the Sensuous" and his call to reexamine language (Abram, 1997), and the creative works by researchers like Brandon Ballengée who is documenting the impact on amphibians and creating public engagement and discourse on these issues for not only frogs, but also people (Ballengée & Sessions, 2009).

Art and Science represent two fundamental spheres of knowledge and learning that have not always been this separate as C. P. Snow discusses in his classic paper describing the two cultures (Snow, 1993). The National Academies of Sciences, Engineering, Medicine (NASEM) in the USA was originally founded with a mission to "investigate, examine, experiment, and report upon any subject of science or art" (*Act to Incorporate, 2018*), however over the course of its history it tended to focus on scientific endeavors at the expense of the arts. A recent colloquium, *Creativity and Collaboration: Revisiting Cybernetic Serendipity* at the American National Academies of Sciences stated its

ambition “to redirect the history of ideas, restoring the Leonardo-like close linkage between art/design and science/engineering/medicine” (*Creativity and Collaboration*, 2018) as well as a report that calls for a return to a more seamless approach (NASEM, 2018). According to the report, “The movement toward integration is occurring in part as a response to a higher education system that has become increasingly specialized and isolated by discipline” (NASEM, 2018).

There is a groundswell of activity to integrate knowledge in higher education described in the American National Academies of Science consensus study report “The Integration of the Humanities and Arts with Sciences, Engineering and Medicine in Higher Education: Branches from the Same Tree” (NASEM, 2018). In the broader educational landscape, this American National Academy of Sciences’ 2018 consensus report calls for an integration of disciplines and incorporation of the Arts as part of understanding and finding solutions for the challenges facing humankind in the 21st century. The committee refers to the complex challenges and suggests that the limited but promising evidence supports that an integrated pathway may be a stronger approach towards finding solutions and working together (NASEM, 2018).

However this consensus report does not emphasize an understanding of biodiversity and humanity’s place within the web of life, instead using the metaphor of the tree of knowledge and framework of workplace skills for the 21st century (NASEM, 2018). It focuses on different branches of human knowledge – largely from the Western tradition – and does not emphasize other ways of knowing like Indigenous knowledge nor what we can learn from other species; from the cooperation of trees (Simard et al. 1997; Wohlleben, 2016) and the resilience of lichen (Kimmerer, 2019) and from the framing metaphor of a spider’s web. How can we re-weave and create different ways of knowing from all of these realms?

Framed another way, in an interview in Institute for Electrical and Electronics Engineers (IEEE) Earthzine, Gregory Cajete (Tewa from Santa Clara Pueblo), Professor of Native American Studies at the University of New Mexico, asks a similar question: “how are we going to develop a kind of consciousness that allows us to work the future and work with the natural processes that are part of nature in a way that benefits both us as human beings but also benefits and cares for the finite resource which is the Earth?” (Racette, 2009).

Many are now exploring the junction of art and science through conferences, residencies, and project collaborations: Wellcome Trust (*Home*, 2018); The Power of Play: Cross-Pollination of Art & Science, UCross Foundation (Ucross, 2016); Scientific Delirium Madness by Djerassi Residence Artist Program (*Scientific Delirium Madness*, 2018); Collide: Arts at CERN (*Collide*, 2018); Artists in the Lab Program in Switzerland (*About Us*, 2017; Larsson et al., 2013); Le Laboratoire Cambridge (Edwards, 2008). New fields are emerging that address the intertwined nature of these challenges in different realms such as the recently developed field of planetary health (Horton, 2015) and Ecomusicology, which models an approach that focuses on the convergence and interactions of “the intersections of music/sound, culture/society, and nature/environment” (Allen & Dawe, 2016).

Among those who are working to create through deep exploration and engagement with groups of animals or individual species are artists such as María Fernanda Cardoso, who explores the realm of the smaller majority of animals "working on the edge of perception" and creating artworks that become "both narrative and humorous" (Tate, 2019). She has focused her attention on an often maligned and overlooked invertebrate in her live flea circus (1994-2000) that she performed worldwide at places like the Pompidou which engaged visitors with a fusion of performance, animal behavior and spectacle for years (Lusive, 2019).

Biologist E.O. Wilson hypothesizes that humans have an innate affinity for nature (Kellert & Wilson, 1993) and describes Biophilia as "the instinctive bond between humans and other living systems" (Wilson, 1984.) Nisbet et al. developed a tool for measuring "nature relatedness" (NR), and their research findings suggest that people demonstrated a high level of environmentally protective behavior when they had a high degree of "nature relatedness." (Nisbet et al. 2009; Nisbet et al. 2014). They describe the concept of NR as encompassing "one's appreciation for and understanding of our interconnectedness with all other living things on the earth" (Nisbet et al, 2009 p.718). Not only enjoying the pleasant aspects of nature, but also, "an understanding of the importance of all aspects of nature, even those that are not aesthetically appealing to humans (e.g., spiders and snakes)" (Nisbet et al., 2009 p. 718.). (For further discussion of nature relatedness, see Nisbet et al., 2009 and Nisbet et al., 2014). Presuming the concepts of Biophilia and nature relatedness are supported, and considering urban dwellers and children may feel apart from nature, perhaps the innate affinity towards nature is something that can still be nurtured and cultivated.

Creative Approaches

This calls for a change of culture — but who historically can help? Perhaps artists, as they have been important agents for social and cultural change. "The 'ArtScience Manifesto' argues that science and art together are, and always have been, necessary to rethink and solve emerging socio-ecological challenges, such as the maintenance of civil society and sustainable development" (Root-Bernstein et al., 2011, cited by A'Bear et al., 2017 p27).

Growing constituencies of academics and practitioners have argued that incorporating art into our approaches is vital to addressing the questions facing humankind in the 21st century challenges, for example Harvard Task Force for the Arts Report (*Task Force*, 2008); The Institute for Cross-Disciplinary Engagement at Dartmouth (*ICE*, 2018); and several examples noted by Lesen (2016).

Creative expression and imagination are common threads running throughout the disciplines. Educator Julia Marshall argues that the arts are well suited to cross disciplinary boundaries and that creative enquiry as a process can play a valuable role in the creation and integration of knowledge (Marshall, 2014). The Creative Education Foundation articulates the valuable role that creativity can play in "helping us imagine and create what's possible-rather than what is." (*CSPI 2019*, 2018).

Three recent graduates of Oxford's Center for the Environment call for creative approaches and incorporating environmental art and other creative forms into conservation education (A'Bear et al., 2017). As part of the National Geographic's Voices

for Biodiversity, Nezam Ardalan, a graduate in Conservation Biology from Columbia University, NYC, argues that incorporating art into conservation biology is necessary for the field to be more effective and impactful and reach broader audiences (Ardalan, 2013).

In his article published on the World Economic Forums' website in 2016, the artist Olafur Eliasson, speaks of the power of the arts and the responsibility of the artist saying that "Art offers one of the few places in our society today where people from various backgrounds can come together to share an experience while having different opinions…Art helps us identify with one another and expands our notion of we—from the local to the global" (Eliasson, 2016).

There is a long history and continued interest at biological field stations to help humans connect with the land as well as to explore the potential and possibility for discovery using more integrated approaches. Of this growing body of work, geologist Frederick Swanson reports in a paper commissioned for the centennial of the Ecological Society of America, that works at field stations address fundamental research questions as well as provide a valuable resource for studying the relationship of "science-society-nature" and potentially promoting "sustainability and stewardship" (Swanson, 2015).

The arts can help create ways to make nature personal and relatable to us beyond the scientific data. Including the arts offers a bridge between the sensed world and the world of the intellect. Conservation biology efforts can benefit from the connecting power of the arts as well as to nurture the kind of awe and respect that Myers (2017) mentions in his address to the Lancet.

Some of my sculptural installations, such as *Homage*, have shown me a form that could hold the complexity and nuance of environmental issues: the complex, layered history of the land; the dynamic relationships and interaction with other species; the hope for the future (Karikó, 1996). In these works, there is a space for emotion and I've observed how an invitation to create can gather people who don't ordinarily come together, invite them to participate, and give voice in ways beyond what I could have imagined.

Art has the possibility to help tell a fuller story, one that science cannot, due to science's culture and parameters on language, evidence, voice, etc. which does not always bridge out into society in an accessible way. Art in its own right, not just art in service of science, is an important component that can move people to understand and see things differently which can contribute to an aesthetic and emotional "literacy" regarding the natural world. Embedding the arts can create a sense of possibility, that when applied to problem solving can lead to discovery, and the by-products of these collaborations can lead to further innovation.

Neuroscience and Learning: Education and its relevance to Biodiversity Education

Recent advances in neurobiology have revealed that the previous suppositions that served as the basis for learning and teaching are not as they were once assumed to be, insofar as emotion plays a much greater role in human brain functioning and learning than previously thought possible (Immordino-Yang & Damasio, 2007). Behavioral scientists and recent functional MRI studies demonstrate that people make decisions

based on a combination of rational and emotional responses, not rational ones alone (Massey, 2012; Wong, Xue, & Bechara, 2011). Massey states:

> *"It's not that human beings are not rational—we are. The point is that we are not only rational. What makes us human is the addition of a rational mind to a preexisting emotional base. Sociology's focus should be on the interplay between rationality and emotionality, not on theorizing the former while ignoring the latter or posing one as the opposite of the other. Attempting to understand human behavior as the outcome of rational cognition alone is not only incorrect—it leads to fundamental misunderstandings of the human condition."* (Massey, 2012, p. 2).

Other research tells us that neurological pathways are formed very early in the brain and that early exposure can inform later perceptions upon which decisions and actions will be taken (Moore et al., 2011). This is important as it suggests that reaching children early in life could greatly impact their decision-making process later in life. Like many others before him, my spider mentor often attributed childhood experiences in Nature at his grandparent's country house as formative experiences. For him, it was time spent in the countryside in Eppenhain, Germany as a boy. Then later as a young man, his experiences with Aldo Leopold shaped the direction his lifelong contribution to biology would take in describing 1,254 species of spiders new to science (Leibensberger, 2016).

Power of Story

The human mind is wired for story. Cultures have passed down information for millennia orally, through story, song, etc.. Within conservation biology, several researchers have discussed how childhood experiences shaped their future direction in science, art and conservation – Loren Eiseley attributes a childhood spent on the prairies of Nebraska and the advent of public libraries and museums shaping his future work in both primatology and poetry (Eiseley, 1975). Robin Wall Kimmerer attributes her desire to study botany in part to learn "why asters and goldenrod looked so beautiful together" (Kimmerer, 2013). Gerald Durrell writes that according to his parents, his first word was not "Mamma" or "Dadda," but the word "Zoo" (Durrell, 1955). His early interest and experiences of going to the zoo as a boy influenced his work later in life as he dedicated himself to zoos focused on breeding endangered species and conservation work. Durrell educated through stories (not only through scientific writing but also prose, film, television and radio programs) where the human story was coupled with that of the animals (Durrell, 1953; Durrell, 1955; Durrell, 1958; BBC, 1958; BBC, 1961; Durrell, 1992). He did not separate out stories of nature from stories of human engagement with the natural world in his tales of his expeditions and his conservation work.

Education for the field of biodiversity has been shaped by Durrell and the establishment of interdisciplinary research initiatives such as the Durrell Wildlife Conservation Trust, the creation of the Durrell Institute of Conservation and Ecology in his name at the University of Kent (*History*, 2019), as well as his contributing numerous children's books which he wrote in his later years such as the book *Keeper* about a little dog that goes around the zoo learning about the different animals there (Durrell, 1991).

Childhood is an important time to nurture the connection and exploration of the natural world. Enid Blyton's book "The Children of Cherry Tree Farm" first published in 1940 tells the tale of city children going and staying in the countryside where they meet Tammyland who guides them into the wonders of the natural world through sharing stories of badgers and squirrels, frogs and rabbits (Blyton, 1940). Through its colorful illustration this book spoke to youth and is applicable to this time as more and more children are living in urban areas. Like this story, my own work strives to be a bridge between the experiences of youth and the natural world—to be a guide into the wonder of spiders and to explore the interconnections all around us, as well as to help foster the natural curiosity of children and to help devise ways to nurture a connection with the living world. In short, how to make learning about the natural world personal and fun!

The first Earth Optimism Summit, organized by Nancy Knowlton, the Sant Chair of Marine Science at the Smithsonian Institution's National Museum of Natural History, refocused the story about conservation and the environment from doom and gloom to one of sharing successes and seeding hope (Christen, 2017). Plenary Speaker and primatologist Patricia Wright spoke about stories of hope from her more than twenty-five years studying lemurs and doing conservation work in Madagascar. Wright shared stories of forest revitalization reporting on the growth of bamboo lemur populations and the return to nest of the rare scaly ground roller bird. She also discussed a long-term approach establishing Ranomafana National Park and developing relationships with local people and the importance of listening to their needs rather than doing what researchers think might be best (Wright, 2017).

Interconnected Approach

Taken as a whole, this research comprises an argument for the need for not only detailed disciplinary knowledge, but also for an interconnected approach that considers art as integral to inquiry and practice. It includes the arts as a part of knowledge creation and calls for nurturing creativity and human imagination in both training and practice in biodiversity conservation and management while valuing traditional knowledge. It recognizes the importance and value of an approach that seeks to promulgate a much better public understanding of the intimate interconnectedness of humans as part of nature and our environmental impacts while also contributing to the scientific understanding of the biodiversity of spiders.

My Approach

This research addresses the societal need for both an engaged citizenry as well as systemic changes in the relationship between humans and the impact on the habitat in which humans call home. It values nurturing creativity and stressing the idea that each person can be an agent for change and that together we can find solutions to meet the complex nonlinear intertwined challenges facing the biosphere today. It creates an invitation to look deeply and closely at the world around us and to get to know invertebrates, particularly spiders, and to experience the wonder and inspiration of these animals.

Interconnected Approach

An interconnected approach values deep narrow fields of inquiry as well as challenging the historically siloed approach of higher learning to create a model of inquiry that values multiple ways of knowing without privileging one discipline over another. It proposes an approach that invites many voices to participate.

By taking an interconnected approach, we can gain a fuller understanding of the complexity of the questions facing humankind today, explore unexpected connections, gain new perspectives, and discover more levers to address them. It can help cultivate the partnerships needed to work together to address the challenges and the unintended consequences of human actions in the world. By employing the power of story we can bridge other worlds, stand in each other's footsteps, be made aware of unintended consequences and perhaps mitigate unwanted outcomes. It can help humans change course, find solutions, and increase our capacity for empathy. Scientific methods can ask and test these questions, and the arts can influence and shape our understandings of the world around us--helping us reflect and shape the very questions we ask. The combination of art and science has the possibility to transform and generate new knowledge as well as communicate across sociopolitical lines, touch the human spirit, and speak in a language beyond words. Art is a universal language extending across cultures. It can help us focus on what we share in common especially in polarizing times.

Taken together, my research is an argument for the need for not only deep disciplinary knowledge but for an interconnected approach in order to face the complex intertwined challenges facing us today. It includes the arts as a part of knowledge creation and gives the arts a respected seat at the table. An approach that helps people understand the intimate interconnectedness between ourselves and the environment.

With human action driving rapid changes to our planet, it is also important to consider tools for helping our own species collaborate and negotiate more skillfully with each other.

This research is to be considered within the context of the fields of arachnology, biodiversity education and management, public and environmental art, museology and science communication, and negotiation.

To conduct this research, I have taken a multivalent approach that values multiple ways of knowing. It addresses the gap addressed by A'Bear et al. (2017) and Ardalan (2013)

who comment on the interdisciplinary training of conservation education and the surprising lack of the arts in the related teaching. What is proposed is an approach that values both science and art in shaping the questions and approaches to research, education, as well as engagement in dialogue with diverse audiences.

The 'toolbox' my research draws from includes science, the creative arts (including participation in and co-creation of works of public art), and skill building (ex. developing ways of teaching and learning about biodiversity while offering negotiation training) to enhance the possibility for finding innovative solutions and building networks of people with the capacity to work together to address the intertwined challenges of the 21st century.

My research has been conducted in multiple contexts engaging with teams in formal and informal settings, ranging from scientific laboratories to art/dance studios to museums to national parks.

I focus on spiders as the connecting thread and framing metaphor for this research, as well as the focus of scientific study. Although not all spiders make webs, all produce silk, and can provide the metaphor of the web—a way to consider the myriad interconnections in our world and how actions impact each other—rippling out across a web to vibrate even seemingly distant (yet connected) parts.

My research has resulted in scientific publications, museum exhibits, lectures, poems, movement labs, and educational experiences in formal and informal learning environments. These works contribute to the scientific understanding of the biodiversity of spiders, take a deeper look at the structural origins of color, and take inspiration from these animals to create participatory educational experiences. Taken together, they address three of the seven challenges for invertebrate conservation identified by Cardoso et al. (2011): (1) the public dilemma; (2) the scientific dilemma; and (3) the Linnaean shortfall, as well as the UN Aichi Biodiversity Target 1 "By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably" (UN Environment, 2016). In this text, I argue for an approach to biodiversity education and stewardship that takes inspiration from nature (particularly spiders), values multiple ways of knowing, embeds the creative arts as integral to research and discovery – not just in service to Western science – explores how the arts can be a catalyst for change as well as a thread that brings people together and offers skills training in negotiation. This approach considers how researchers contribute towards the well being of people and planet. In so doing, I address the idea, often attributed to Einstein, that *we cannot solve our problems with the same thinking that was used to create them;* what is proposed here is that an interconnected approach be applied in the context of biodiversity education and stewardship.

My research is categorized as follows: 1) Arachnology; 2) Ways of Seeing and Knowing; 3) Power of Story; 4) Participatory Educational Experiences; and 5) Creativity and Collaboration.

At the center of this research is an interconnected case study. It is a strategically curated research project grounded in fieldwork with many components including art/science

exhibits, scientific findings, educational programming, all of which invite viewers to explore unexpected connections which are the basis for knowledge creation and imagination (Marshall, 2014). This research also explores what factors might be conducive to learning, engagement and stewardship by providing people with many entry points for engagement.

I begin with my contributions to *Arachnology* – the scientific study of spiders – and the biodiversity of invertebrates through a lens of (Western) Science. In "The Glitterati: Four New Species of *Phoroncidia* (Araneae: Theridiidae) from Madagascar, with the First Description of the Male of *P. aurata* O. Pickard-Cambridge, 1877," I described four new species of tiny theridiid spiders from my expeditions to Madagascar. In the paper "Structural origins of coloration in the spider *Phoroncidia rubroargentea* Berland, 1913 (Araneae: Theridiidae) from Madagascar" published in the *Journal of The Royal Society Interface*, I co-led a team of scientists to look deeper and closer at the nano-, micro- and macro-scale of a species of *Phoroncidia* from Madagascar that has the ability to retain its coloration after being stored in ethanol for decades at a time.

I consider *Ways of Seeing and Knowing* at two levels. One is the conceptual level of ideas and knowledge creation, considering how frameworks impact how and what we see and the connections we make within these framework. The cultural framework impacts how we define and name what we see which may privilege certain ways of knowing yet leave us blind to other ways. Culture shapes the questions we ask and the resources that are allocated to support exploring those questions. The second level is in the physical realm of seeing and sensing: the ways of taking in and translating information from the environment, as well as the equipment and technologies that allow us to see at different scales and in different ways (eg. microscopes, computed tomography). What we see impacts what we discover. In the case of my research, different equipment and techniques allowed me to make different types of observations at different scales that led to new scientific understandings. This then led to different ways that I was able to share these understandings and incorporate them into educational experiences.

In the *Power of Story*, I look at how spiders have been part of human stories for millennia – for example the Lakota stories of Iktomi the trickster spider – and discuss how poetry and metaphor have been used as ways of teaching and learning in a more integrative way, such as a study putting poems in zoos (2013). My work in this section incorporates this and has grown out of personal observation and experience at field sites.

I designed *Participatory Educational Experiences* that explore the interconnected approach I propose by moving the ideas from a conceptual framework to an operational one. I present and discuss participatory educational experiences I designed and then offered in collaboration with others in formal and informal settings, ranging from museums to hospitals to classrooms.

Negotiation trainings grew out of my own field experiences of being confronted with high stakes situations and learning about the biodiversity of spiders who I see as high-stakes negotiators – especially certain species of male spiders, having to negotiate courtship and mating with female spiders.

Creativity and Collaboration are critical components of the proposed interconnected approach as well as critical to my own methods of conducting research. As I discuss the multivalent research project *Spiders! Interconnectedness, Innovation & Stewardship*, I examine the roles of creativity and collaboration and how highly diverse teams can lead to breakthrough discoveries with a discussion of a collaborative spider project that led to an unexpected outcome.

I conclude with a discussion of the strengths and weaknesses of the works, the challenges, lessons learned, and discuss questions and areas for further research, as well as giving consideration to obstacles to address in implementing an interconnected framework.

This approach considers not only the interconnectedness among discipline of knowledge but also the interrelationships between humans and other organisms, focusing on spiders.

Visualization Equipment and Techniques

To conduct this research, I used many different visualization tools and techniques. My access to different equipment shaped what I could see, discover and share. I will discuss this in more detail in the relevant sections.

Educational Theory and Models that Influenced My Approach

My work addresses the societal need for engaging the next generation by nurturing creativity and stressing the idea that each of us can be an agent for change (*Spider Super Hero Program.*). It creates an invitation to look deeply and closely at the world around us and to get to know invertebrates, particularly spiders, and to experience the wonder and inspiration of these animals.

The theoretical underpinnings and experiences that inform the participatory educational components I designed and implemented include my experience teaching ecology in an outdoor classroom setting among herds of bison and stands of aspen with eagles, kestrels and ballooning spiders overhead in the Jackson Hole region of the Greater Yellowstone Ecosystem (GYE) in northwestern Wyoming, USA. My experience was informed by what is now described as a learner-centered approach of Place-Based Education (Smith, 2002).

The foundation of the educational programs and research I conduct is informed by the Art-Centered Integrated approach from the Integrated Learning model which has its roots in two strands of theory: Progressive theory (based on the works of educators such as Dewey and Montessori), and the Critical Pedagogy of Freire (Marshall, 2014 p. 371; see Marshall 2014 for fuller discussion).

Negotiation

Negotiation training grew out of my own field experiences of being confronted with high stakes situations, and learning about the biodiversity of spiders who I see as high-stakes negotiators, especially male spiders having to negotiate courtship and mating with females who in some instances eat their mates. It grows out of my experience negotiating an international accord of collaboration, and then formalizing my own negotiation training at Harvard Law School's Program on Negotiation (PON). I draw from the theory and practice developed at PON (*PON*, 2018) while also including inspiration

from the spider world by incorporating examples presented in an interest-based/mutual gains framework drawing from fieldwork and ethology literatures focusing on arachnid behavior within the larger context of biodiversity literature.

With human action driving rapid changes to our planet, it is also important to consider tools for helping our own species collaborate and negotiate more skillfully with each other, for the cost to all other species on this earth is great when we humans can't get along.

Creative Works

The creative works were developed in an iterative manner adapting Liz Lerman's Critical Response Process (CRP) as a form of peer-review to shape the works. CRP is a multi-step process that combines the "power of question with the focus and challenge of informed dialogue" to rigorously and in a supportive manner, help creators actively and critically develop their own work (Lerman, 2003).

The Focus of this Research

Often times, conservation efforts are focused on species of vertebrates; however invertebrates comprise the vast majority of the animal biomass (dry weight) and species diversity (primarily the number of species) on the planet (Wilson, 1992; Black et al, 2001). There is still much to discover about the role of invertebrates in our biosphere: invertebrates are important from an ecological services perspective for many reasons, including pollinating our crops, creating and maintaining coral reefs, providing natural pest control, engineering our soil systems, filtering water, as well as many others (Lavelle et al., 1997). In addition to the invaluable role invertebrates play in nutrient cycling and ocean health, they are an important food source for other animals on the planet, including humans. Humans compete with invertebrates for many of our crops. The animals that we feed on do too. Invertebrates therefore offer a particularly interesting opportunity to study the intersection of humans and wildlife. In short, they are as evolutionary biologist E. O. Wilson says, "the little creatures that run the world" (Wilson, 1987).

My research is informed by organismic biology, specifically arachnology—the scientific study of spiders.

Why Spiders?

Although not all spiders make webs, the common image of spiders is usually associated with a web. In this way in the public realm, spiders provide the metaphor of the web: a way of thinking about our interconnectedness and how the 'ripples of the vibrations' caused by actions can resonate out into the surrounding world. Spiders also offer an invaluable subject of study not only because they can be found and observed nearly everywhere on our planet - with the exception of Antarctica (Lewis, 1996) and are critical to ecosystem functioning.

Spiders and Innovation

Spiders' biological diversity is rich territory for bio-inspired design, especially in regards to their venom and silk. Spiders are an important part of our agricultural systems not only for being a predator of many invertebrate pests such as aphids (Sunderland et al., 1986); their venom is being used to inspire pesticides that do not interfere with the bees'

waggle dance which is important for their survival (Nakasu et al., 2014), and critical during this time of bee colony collapse (Ellis et al., 2010). Spiders are also proving to be key species for indicating the bioaccumulation of toxins, metals and mercury (Wheater et al., 2000; Xiao-li et al., 2006; Jung et al., 2008). Spider silk – a fiber whose ratio of strength-to-density exceeds that of steel and is more flexible than Kevlar (Oyen, 2013) and something spiders have been creating naturally for approximately 400 million years on a "liquefied diet of dead bugs" (Brunetta & Craig, 2010) – is also providing creative impetus in the research and discovery of biomaterials (*Spider Man*, 2011; Dong et al., 1991), biomedical and biotech applications (Blüm et al., 2014; Chaim et al., 2011; Senff-Ribeiro et al., 2008, Veiseh, 2007), and military applications (McGarry, 2016; Lewis, 2009).

Studies show ways in which some spider species have evolved which have benefits for protecting humans from illness and disease. The jumping spider *Evarcha culicivora* (Wesolowska & Jackson, 2003), also known as the "skeeter eater" found in the Lake Victoria region of East Africa, demonstrates a preference and specialized strategies for preying on female *Anopheles* mosquitos which are known vectors for carrying and transmitting human malaria (Cross & Jackson, 2010). These spiders that indirectly feed on vertebrate blood were observed often feeding on female mosquitoes in the field (Wesolowska & Jackson, 2003), and subsequent laboratory studies found small juveniles demonstrated an innate, fine-tuned tactic for attacking mosquitoes in the *Anopheles* resting posture (Nelson et al. 2005). Additional studies demonstrate that large juveniles and adult *E. culicivora* will select female *Anopholese* mosquitoes that have had a blood meal by sight alone over other mosquitoes (Cross & Jackson, 2010). This blood gives the spider a certain "perfume" or scent that seems to be important in attracting mates, so the spider will continue to hunt prey for blood meals to replenish the scent even when satiated, providing an example of "selected attention" for olfactory and visual search images (Cross & Jackson, 2010).

Spiders and Conservation

Much of what we know about the nearly 48,000 recorded species of spiders (World Spider Catalog, 2018) is found in scientific journal articles that are difficult for general audiences and other specialists to access or even understand, due to the highly specialized language of the discipline. Efforts to conserve invertebrates are severely hampered by a lack of public understanding of the values of invertebrate biodiversity (Smithsonian, 2014). In 1990, Smithsonian Curator, Jonathan Coddington pointed out that spider conservation in particular suffers from a lack of available data, much of which is now outdated or unreliable (Coddington et al., 1990). The Spider and Scorpion Specialist Group (SSG) for the International Union for the Conservation of Nature (IUCN), of which I am a member, has been working to address this through a series of papers by Sini Seppälä et al. to provide species conservation profiles for two hundred species of spiders sampled from around the world – the largest sampling to date (Seppälä, et al., 2018a, 2018b, 2018c, 2018d; Vaughn et al., 2019).

Spiders also strike fear into the hearts of many people. The Zoological Society of London has a program designed for arachnophobia. What other animal has a decades-long program devoted to remedying a fear of them? The zoo's website reassures potential participants that they will not have to worry about seeing animals nor images of the

animal until the end of the program after they have experienced the program's combination of hypnotherapy with cognitive behavioral therapy. More than 3,000 people between the ages of seven and eighty-two since 1993 have paid money for treatment with more than 80% self-reported success rate (*Friendly Spider Programme*, 2017).

In a recent exhibit at the National Museum of Wildlife Art entitled *Invisible Boundaries*, photographer Joe Riis opened his talk about the exhibit by remarking how when people tell the story of the Greater Yellowstone Ecosystem (GYE), it is a story usually focused on predators (not the prey), the ungulates (elk, deer pronghorn antelope)--that he metaphorically called the heart of the ecosystem (Riis, 2018). Yet despite their position as predators, spiders are often overlooked by the public when considering the predators of an ecosystem like the GYE. Spiders are one of the smallest predators in an ecosystem, often positioned at the top of the invertebrate food web. As such, they help control insect and pest populations that could otherwise devour the plants that are food sources many other animals, such as the bison and elk, rely on. One study estimates the prey consumption of spiders to be as much as 400-800 million tons every year globally (Nyffeler & Birkhofer, 2017). As prey themselves, spiders can be an important food source for vertebrates such as birds, frogs, lizards and other animals (Bucher et al., 2015; Riechert, 1974). Many species of hummingbirds rely on spider silk to build their nests (Hansell, 1996; Young, 1971), as do many small passerine birds like the chaffinch (Storer & Hansell, 1992; Storer, 1991).

Much of the world's invertebrate populations are under threat, but they are not often thought about in public conservation efforts, nor do they form part of the conversation about biodiversity loss. Vertebrates typically remain the focus of education and conservation efforts by conservation organizations, research institutions, funding schemes, national park visitor education focus, etc. Recent articles in *Science* and *Nature* have pointed to the loss of biodiversity and the loss of invertebrate populations worldwide and raise the question of how and why this has happened on our global watch (Hallmann et al., 2017; Vogel, 2017). Like most terrestrial invertebrates, spiders are affected by habitat alteration such as deforestation, agriculture, grazing, urbanization, pesticides, anthropogenic or human-caused vibration as well as through alien species introduction (Skerl, 1997).

Spiders and Creativity

Spiders have captivated the human imagination since the beginning of time. Peoples from all corners of the earth have stories about spider: Lakota stories of *Iktomi* the Trickster (Zitkala-Sa, 1985; Thunderhawk, 2016); the Navaho Spider Woman (Lamphere, 1992); West African stories of *Anansi* (Boateng, 1983); the story in the Quran of Prophet Mohammed and the spider and the cave ("The Prophet", 2017); the Greek myth of *Arachne* (Kline, 2000); the Tarantella dance (Richardson-Boedler, C. 2001); the story of *Charlotte's Web* (White, 1952); and Hollywood's fascination with spiders ranging from *Tarantula* (Alland, 1955) to *Arachnophobia* (Kennedy & Vane, 1990) to *Spider-Man* (Goodman & Montagne, 1977; Feige & Pascal, 2017). Spiders have influenced architecture (Brownell, 2015; Cohen, 2012), clothing (ex: Godley and Peers' Nephila silk cape (Jones, 2012; *Spiders: Fear and Fascination*, 2018) and a tapestry premiered at the American Museum of Natural History (Kennedy, 2009)), iconic works of art such as Louise Bourgeois's Spider sculpture *Maman* (*Louise Bourgeois Spiders*, 2017), and even violin

strings made from spider silk (Osaki, 2012). The outdoor clothing industry has been racing to produce spider silk-inspired technical wear – in 2015 The North Face announced its Moon Parka (Rhodes, 2015), and Patagonia is partnering with Bolt Threads to develop jackets made from synthetic silk (Rao, 2016).

Exploring spiders can contribute to our better understanding of how our human actions impact our environments and ripple out into the world, give us inspiration for imagining solutions to challenges facing us today, and remind us of how to live in a good way with each other, through stories like Iktomi (Zitkala-Sa, 1985). Hunkpapa Lakota people used inspiration from the spider web when beading patterns into their saddlebags to provide protection (*Spiders: Fear and Fascination,* 2018).

Spider-related Exhibits and Projects

There is a growing body of works and exhibits that highlight spiders, ranging from museum exhibits (ex: *Spiders! Fear and Fascination,* Royal Ontario Museum, 2018; *Spiders!*, American Museum of Natural History traveling exhibit at the Boston Museum of Science, 2016; two mini-exhibits at Harvard's Museum of Natural History (***Spiders!*** within *Arthropods: Creatures That Rule*, 2012; *Orb-Weavers: Web Masters of the Spider World* 2017); *In with the Spiders*, ZSL London Zoo, 2018); to art exhibits by Maria Fernanda Cardoso (McDonald, 2018) and Tomás Saraceno (Saraceno, 2018); to festivals that invite the public to learn more about spiders (*SpiderFest*, Antelope Island State Park, 2018).

Spider groups that have inspired this research

This research is inspired by spiders in general, and more specifically by spiders from the following families: Archaeidae (especially *Eriauchenius workmani* O. Pickard-Cambridge, 1881); Theridiiidae (especially spiders in the genus *Phoroncidia* with a special focus on *P. rubroargentea* Berland, 1913); Thomisidae (especially *Misumena vatia* (Clerck, 1757)) and Corinnidae (esp. *Castianeira sp*. – the moundbuilding mason spider).

Research

Arachnology

In the context of conservation and education, basic knowledge of the natural history and identification of species is considered fundamental to learning and understanding biodiversity (Lindemann-Mathies 2002; Randler & Bogner 2002; Gaston & Spicer 2004; Randler et al. 2006; Randler (2008). As stated earlier, Mammola et al. comment that organismal biology is losing popularity at the same time that humans are becoming increasingly disconnected from the rest of nature (Mammola et al., 2017). In other words, humans are experiencing not only a disconnect from nature in the next generation, but also a decrease of interest in learning about the organisms that sustain life on earth.

Naming is one way that humans understand and form a relationship with the surrounding world. Kimmerer (2013) discusses the importance of naming as a building block for humans' relationships with other beings. According to her, "these are good things to know, to begin to discriminate the living world in to individuals, to discern the threads in the weave of the woods, to attune to the body of the land." Naming species is important for having a relationship with that particular type of animal and using binomial nomenclature facilitates having global dialogue and discussion, so that people know that they are talking about the same organism. This is especially true for animals with cosmopolitan distributions that can be found spread widely across the world.

Outside of the scientific community, there is some debate about the value of naming species. The poet Pattiann Rogers says that "naming is a form of honoring something" and feels that spending time in nature is more meaningful when one knows the names of the plants and animals around you (Kelly, 2017), whereas artist and naturalist James Prosek says that naming species is part of humanity's "overweening ambition to collect and control nature through classification" ("Symmetry & Myth", 2005).

My arachnological research addresses Aichi Target 1:"By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably" (UN Environment, 2016) and grounds the research that is presented in this text.

Phoroncidia

This taxonomic research paper contributes to formal scientific knowledge, describing four of the seven currently known species in the family *Phoroncidia* from Madagascar, and addresses Aichi Target 1 by raising awareness of the biodiversity of spiders. In so doing, it also participates in the Linnaean enterprise of naming and knowing. It can be argued that in order to protect something one needs to know it first, and in order to know it within the current systems of biodiversity classification and conservation, it must be named - even though the species that were formally described new to science in this paper could already be known by the indigenous people who have lived in and near the forests for millenia.

Since the late 1800s, when the genus *Phoroncidia* begins to appear in the arachnological literature, little has been learned about this genus' natural history and behavior (Pickard-Cambridge 1873c; Pickard-Cambridge 1877c; Butler 1882). Knowledge is limited to habitat notes such as: "found in bushes" (Emerton 1882), "on sandhills" (Marples 1955), "in pitfall traps in floodplain deciduous forests" (Draney, 1997). Eighty-one species are currently in the genus *Phoroncidia* in the family Theridiidae (World Spider Catalog, 2018). *Phoroncidia* species occur worldwide, but have so far not been recorded from northern Europe, the Polar Regions or western North America. In 1964 arachnologist Herbert Levi published "American Spiders of the Genus *Phoroncidia* (Araneae: Theridiidae)" (Levi, 1964), the most comprehensive diagnosis of the genus. In this paper, Herb described twelve new species – two are now in synonymy with ten remaining valid (World Spider Catalog, 2018). Based on my fieldwork in Madagascar, I described four species of *Phoroncidia* new to science:

The Glitterati: Four New Species of *Phoroncidia* (Araneae: Theridiidae) from Madagascar, with the First Description of the Male of P. aurata O. Pickard-Cambridge, 1877.

Abstract

Four new species of theridiid spiders in the genus *Phoroncidia* Westwood, 1835 are described from Madagascar: *Phoroncidia wrightae* sp. nov., *Phoroncidia vatoharanana* sp. nov., *Phoroncidia roseleviorum* sp. nov., and *Phoroncidia ambatolahy* sp. nov. Additionally, the male of *Phoroncidia aurata* O. Pickard-Cambridge, 1877 is described and imaged for the first time. New images are also included for the type species of the genus, *Phoroncidia aculeata* Westwood, 1835. The present study describes the first new species of *Phoroncidia* from Madagascar since 1913 and increases the number of described *Phoroncidia* from Madagascar from three to seven species.

Spiders! Interconnectedness, Innovation & Stewardship (Spiders!)

Central to my research conceptualizing and exploring an interconnected approach is an interconnected case study that puts into practice and interweaves many concepts of this approach to biodiversity education and stewardship: scientific research, creative enquiry, collaboration, connection-making, power of story, skill-building/negotiation, and participatory educational experiences.

Spiders! Interconnectedness, Innovation & Stewardship (Spiders!) is a multivalent research project integral to investigating an interconnected approach for biodiversity education and stewardship. At the center of this research is a strategically curated exhibit grounded in fieldwork that celebrates the biodiversity of spiders, explores unexpected connections, and examines what factors might be conducive to learning, engagement, and stewardship by providing visitors with many entry points for engagement.

In the Jackson Hole region of northwestern Wyoming, USA where this project was sited, I asked:

This research project is comprised of scientific and creative components that are grounded in fieldwork in northwestern Wyoming, USA, and created in commemoration of the centennial of the United States National Park Service (NPS) and in honor of my spider mentor, the late arachnologist Herbert Walter Levi and his wife and research partner Lorna. It was sited on land with a layered history – ancestral lands of the Shoshone, Bannock, Blackfoot, Crow, Flathead, Gros Ventre, Nez Perce and other indigenous peoples who had relationships with this land over millennia (*American Indians*, 2017) – and more recently by people of non-native descent. A large portion of the area is currently designated as public lands in what is today considered a 'living laboratory' commonly referred to as the Greater Yellowstone Ecosystem, "one of the last remaining large, relatively intact temperate ecosystems on Earth." (*Greater Yellowstone Ecosystem,* 2018). This is also a place where I have taught ecology, been commissioned to create large-scale public art installations and cultural events, designed educational programs often about the region's biodiversity over several decades (*Homage* 1996; *Spiders! Kidzart*, 1996; *Homage II,* 2009; *Endangered School,* 2012; *Wild Festival* 2014) as well as collaborating with Stanford Addison (Northern Arapaho) from the Wind River Reservation (*Unbroken Spirit East* 2008; *Unbroken Spirit West* 2009, "Got Warriors?" *High Country News*, 2009). All of these experiences have also informed this research. For *Spiders!,* it was my intention to combine not only the legacy of the Levi's arachnological research but also the art, education, storytelling and stewardship that were so important to both of them.

In order to create this interconnected case study, I developed a partnership with biologists Harold Bergman and Michael Dillon, the directors of the University of Wyoming-National Park Service Research Station, and Jane Lavino, the Sugden Family Curator of Education and Exhibits at the National Museum of Wildlife Art, then convened a highly diverse team to bring this idea to life. According to Lavino, typically an exhibit like this is usually accomplished by a team of curators and usually takes several years to bring to fruition (pers. comm).

Following a talk I gave at the International Congress of Arachnology (ICA) in 2016, I gathered a team of arachnologists to help write and edit exhibit text as well as taxonomic authorities to help identify spiders. As the research for the exhibit progressed, I compiled information packets about spiders from different habitats in the local area to give to possible collaborators for inspiration comprised of materials from the arachnological literature as well as my field photos. As well as co-curating the exhibition I also organized and facilitated partnerships between scientists, artists and chefs that resulted in the creation of artworks that, for example, invited conversation about biomaterial science and spider silk. Volunteers helped with program logistics and exhibit installation.

The opening event of *Spiders!* was at the National Museum of Wildlife Art and included presentations by scientists, artists and pastry chefs. Visitors were invited to "make-your-own-edible spider," view a spider sculpture made of chocolate created by Chef Oscar Ortega and other artwork such as photographs and scientific illustrations by Karikó and Levi, respectively.

The talks at the museum included:

- **Jane Lavino** "Welcome and Introduction" --Sugden Family Curator of Education and Exhibits, National Museum of Wildlife Art
- **Sarah Karikó** *"Spiders! Interconnectedness, Innovation & Stewardship"*
- **Butch Thunderhawk** (Hunkpapa Lakota) "*Iktomi (the trickster spider) in Lakota/Dakota Culture*"- ledger artist & tribal arts instructor, United Tribes College
- **Randolph V. Lewis** ***"****Spider Silk: Not Just Fibers Anymore*" – USTAR Professor of Biology, University of Utah
- **Maggie Raboin** *"Disassembling the Mason Spider Mound (Castianeira sp.)*" – UC Berkeley
- **Jenny Dowd "***Moments in the Lives of Spiders: What We See & What We Don't See"* – artist
- **DG House** (Cherokee) "*Life at All Four Corners"* – Artist-in-residence, Yellowstone National Park and Grand Teton National Park, First Honorary Ranger, Grand Teton National Park
- **Greta Binford** "*Spider Venoms! Interconnectedness, Innovation, and Inspiration for Stewardship"* – Associate Professor of Biology, Lewis and Clark College
- **Chef Bill Yosses,** Closing Remarks – Former White House Executive Pastry Chef

Figure 1: (Clockwise from top) Chocolate Spider Sculpture by Chef Oscar Ortega; close-up of chocolate mushroom; close-up of chocolate flower. National Museum of Wildlife Art, 2016.

The creative works were exhibited at the University of Wyoming-National Park Service (UW-NPS) Research Station's Berol Lodge on the banks of Jackson Lake and at the base of the Teton mountain range. This is a place where humans have taken inspiration from nature and where that has impacted people at a great distance from the park, such as when Secretary of State Baker and Soviet Prime Minister Eduard Shevardnadze conducted their meetings that contributed to the peaceful conclusion of the Cold War. There is a nearby plaque that infers the role nature played (*AMK*, 2016):

> *… I'd like to think that the Tetons towering nearby, Jackson Lake before us, and the rustic openness of the Berol Lodge facilitated much of it.*
>
> —U.S. Secretary of State James A. Baker, III

Taking inspiration from the history of this place—both the natural and built—we aspired to have this project ripple out into the world in a good way, with hopes of inspiring innovative thinking that could lead to stewarding our parks and planets for generations to come. While this may be a lofty aspiration and difficult to measure, our hope was that the aggregate of this research could create a beneficial effect, or at the least result in decreased killing of spiders. We felt the exhibit would be successful if visitors took inspiration from the spiders and this exhibit to explore and make unexpected connections to inspire new ways of thinking that could lead to innovative and collective stewarding of our parks and planet.

The exhibit included many creative works, including: artwork by Herbert Levi; a collaborative spider-specific installation *100 Spiders, 100 Years* conceived and installed by S. J. Karikó and Greg Houda (see Figure 2 for a full list of contributors); ledger art by Butch Thunderhawk; macro-photographs of arachnids by S. J. Karikó; paintings by DG House; mixed-media work by Jenny Dowd; a makeshift laboratory incorporating Levi's many arachnological tools (microscope to sweep net) and a selection of Levi's books (ranging from natural history to Picasso); animation created by S. J. Karikó and Ariana Kam with the 1,254 species of spiders Levi described new to science; glass sculptures of mason spiders by Wesley Fleming; textile art by Frances Levi, and additional works by local and international artists. Visitors to the exhibit could explore the beauty and wonder of spiders through these numerous installations. *Spiders!* challenged visitors to think about how this small, often misunderstood animal has inspired humankind for millennia – from the Lakota stories of Iktomi the trickster spider, to the strength and elasticity of spider silk, to the complexity of their venom.

Evaluation data were collected with the use of:

- Feedback forms for the opening talks and "Spider Super Hero" program
- A Pre- and post- questionnaire measuring perception of spiders
- Understanding of spider anatomy for program participants (via a pre- and post-drawing)
- Guest comment book
- Short questionnaire from the exhibit to assess visitor engagement (ex. visitors were asked whether they were thinking about something in a new way after engaging with the exhibit and if so what.)

Ways of Seeing and Knowing: Visualizing spiders in different ways

Drawing from the initial fieldwork, this exhibit presented multiple ways for visitors to engage with spiders; from observing live spiders under a microscope or spinning a

web; through field photos that allowed visitors to see spiders' features that would otherwise be invisible to the naked eye (e.g., "eyelashes" on a jumping spider, nearly transparent spiderlings emerging from an egg sac, the "face" of a crab spider); glass artist Wesley Fleming's sculptures of the mason spider and a male pedipalp in the tradition of the Blaushka's scientific glass models using flame-worked soda lime glass techniques; and artwork by Levi in the form of scientific illustrations of spider anatomy, especially the intricate, Baroque-like morphologies of epigyna, magnified in some cases more than a hundred times, that provided visitors the opportunity to see these ornate structures up close. Other techniques gave a window into the "inside story" of spiders through histological slices and microCT images created by Damien Laudier, and confocal micrographs by Jaakko Timonen showing the fluorescence patterns of local spiders. The relationship of humans and spiders in food systems was explored at the opening event at the National Museum of Wildlife Art through a sculpture made of chocolate, and closing remarks by Chef Bill Yosses in which he spoke about the history of chocolate, our interconnectedness, and spiders.

100 Spiders/100 Years

Figure 2: 100 Spiders/100 Years

Conception and Design: S. J. Karikó and Greg Houda
(with instrumental conversations with Tristan Rocher)
Construction and Installation: Greg Houda and Judy Herman
Spider Collecting: S. J. Karikó, Daniel Rossman, and Frances Levi
Loan of Agassiz Jars facilitated by: Adam Baldinger
Spider Transfer: Greta Binford

Materials: pine, glass, Agassiz jars, and arachnids from Grand Teton National Park and surrounding areas (Research Permit No. GRTE-2015-SCI-0065).

This collaborative installation featured one hundred spiders from the region exhibited in an assortment of Agassiz jars – "hand blown flint glass apothecary jars created over a century ago" – used to house the natural history collections assembled by Louis Agassiz at the Museum of Comparative Zoology (*Christmas*, 1975). The piece was positioned and installed so as to interplay with the view of the mountains in the background as a key visual element, providing a continually-changing experience as the light crossed the sky during the course of the day and reflected the Teton Range in the curved glass of the jars with the spiders inside. People could view the spider up close, and it became a favorite "selfie" spot in the exhibit. The Agassiz jars opened up possibilities for discussing the historical and future roles of museums for research and public engagement regarding 21st century challenges.

Role of Equipment: Looking Deeper and Closer: Structural Color In Nature

The advancement in imaging equipment has impacted the course of scientific discovery. The discovery and naming of the cell by Hooke was only possible because the microscope allowed him to observe cell walls in cork tissue. His book *Micrographia (1665)*, contains a collection of the detailed observations he made with his microscope, (Hooke, 1665). Hooke's work and that of Sir Isaac Newton laid the foundation for understanding the structural basis for the origins of colouration in the natural world (Newton, 1672).

Arachnids (such as spiders, scorpions and mites) traditionally receive less attention in terms of structural coloration, although they have inspired humankind for centuries: the spider silk gloves exhibited at the Academy of Science in Paris prompted the commissioning of physicist Reaumur to investigate and attempt to create a silk textile industry in the 1700s (Cooke, 1984); recent research on arachnid venom that is used to create a "tumor paint" to light up cells in pediatric brain tumor patients (Parish-Novak et al., 2015; Fidel et al., 2015; Veiseh et al., 2007), as well as many other silk-related research initiatives (Lewis, 1998; Becker et al., 2003; Lewis, 2006; Blackledge & Hayashi, 2006; Ayoub et al., 2007; Brunetta & Craig, 2010; Zhao et al., 2010).

Arachnids, especially spiders, are vividly colored and patterned and some species even display capacities for dynamic color change (Seligy, 1972; Graf & Nentwig, 2001; Insausti et al., 2008; Thery & Casas, 2009; Wunderlin et al., 2013; Drake, 2016), providing important and interesting models for studying color production in nature. Spiders utilize a variety of coloration strategies, and understanding the structure-optical property relationship of spiders can potentially provide new optical design strategies for bio-inspired optical devices (Foelix, 1982), as well as offer important insights into their biological functions, especially given the fact that spiders generally have fair to poor vision and rely on communicating through vibratory and chemical cues (with the exception of some groups of spiders such as jumping spiders (Saltidicae) (Elias et al., 2012).

While describing new species of *Phoroncidia* from Madagascar, I noticed that among the nearly three quarter of a million spiders preserved in ethanol in the museum's collections, nearly all had lost their coloration – with the exception of *Phoroncidia rubroargentea*. What was happening? To better understand this, I co-led a team to look deeper and closer at the nano+micro+macro scales and examine the structural origins of color of this spider species. Using correlative optical, structural and chemical analysis, we identified the colour-generating structural elements and characterized

their optical properties. Findings from this research were published in *The Journal of the Royal Society Interface* and featured *P. rubroargentea* on the cover. This research was also presented as an oral presentation at the 2018 European Congress of Arachnology (ECA): Tiny spider, big color: structural origins of coloration in the spider *Phoroncidia rubroargentea* Berland, 1913 (Araneae: Theridiidae) from Madagascar.

Structural origins of coloration in the spider *Phoroncidia rubroargentea* Berland, 1913 (Araneae: Theridiidae) from Madagascar

Abstract

This study investigates the structural basis for the red, silver and black coloration of the theridiid spider, *Phoroncidia rubroargentea* (Berland, 1913) from Madagascar. Specimens of this species can retain their colour after storage in ethanol for decades, whereas most other brightly pigmented spider specimens fade under identical preservation conditions. Using correlative optical, structural and chemical analysis, we identify the colour-generating structural elements and characterize their optical properties. The prominent silvery appearance of the spider's abdomen results from regularly arranged guanine microplatelets, similar to those found in other spiders and fish. The microplatelets are composed of a doublet structure twinned about the [02$\bar{1}$] axis, as suggested by electron diffraction. The red coloration originates from chambered microspheres (approx. 1 µm in diameter), which contain structured fluorescent material. Co-localization of the red microparticles on top of the reflective guanine microplatelets appears to enhance the red coloration. The spider's thick cuticular layer, which encases its abdomen, varies in its optical properties, being transparent in regions where only guanine reflectors are present, and tanned, exhibiting light absorption where the red microspheres are found. Moreover, colour degradation in some preserved spider specimens that had suffered damage to the cuticular layer suggests that this region of the exoskeleton may play an important role in the stabilization of the red coloration.

Figure 3: Cover image, Journal of the Royal Society Interface (Caption: Jewel-like Spider: Multiple views of *Phoroncidia rubroargentea* Berland, 1913 (Araneae: Theridiidae), a tiny jewel-like spider found during an expedition in Madagascar, display a stunning coloration pattern produced by a combinatorial strategy based on structural color, pigmentation, and fluorescence. Moreover, its vibrant color is retained, even when preserved in ethanol for decades, which is in stark contrast to most other species whose colors rapidly degrade under the same preservation conditions. *J. R. Soc. Interface* **15**: 20170930 Image Credit: *Sarah Karikó, James C. Weaver, Ling Li*. Spider: *Phoroncidia rubroargentea* from the Collections of the California Academy of Sciences CASENT 9057540.)

Moving Pictures

Many things happen too fast for the human eye to see and comprehend. In the 1880s, the details of how animals moved was a mystery. In 1877, Eadweard Muybridge's Zoopraxiscope allowed people to witness things normally unseen, settling a debate by providing visual proof that horses have all four hooves off the ground during certain gaits (Herbert, n.d.).

In the exhibit *Invisible Boundaries: Exploring Yellowstone's Great Animal Migrations* (created by the Buffalo Bill Center of the West in 2016), Joe Riis's photography plays an important role in not only documenting ungulate migration but also raising awareness among communities in such a way that is inspiring action. He used camera trap technology to both gain a better understanding of ungulate migratory routes and also inspire diverse groups of people (public and private land managers, community members, department of transportation, etc.) to find ways to develop solutions that work for both humans and wildlife by making visible the migratory routes. One location in Sublette County had 274 human-wildlife traffic collisions between 2006 and 2008 (Koshmrl, 2012) that are dangerous and often lethal for both the animal and the driver. By being able to make visible and measure the migratory routes, communities worked together to build underpasses and overpasses to protect both migrants and humans. Wyoming is now providing an example for other states that are following suit (Riis, 2018).

Figure 4: Female *Castianeira sp.,* a moundbuilding mason spider, 2016. Found by Maggie Raboin during fieldwork in 2010.

Photography was key to my recording the first instance (to our knowledge) of mating behavior in the field for the mound building mason spider *Castianeira sp*. in Wyoming, USA. The technical team at Canon USA helped address some of the challenges encountered in the first field season by creating a combination of lenses and extension tubes that I used the second and third field seasons, allowing me to decrease my impact on these sensitive animals by standing farther back to film them. Technically it allowed me to film in detail and at high resolution and analyze the footage using BORIS software to examine behavioral patterns such as mating and mound building behaviors. For example, *how* the females were building and with which body parts they were hauling objects for constructing their mounds.

2016: Camera Field Set-up

2016: The camera set-up I used this field season allowed the silk scaffolding that holds together objects in mason spider mounds to be visualized for the first time.

2017: Camera set-up that allowed me to be further back from the spiders to film their behavior, thereby decreasing my impact on these sensitive animals.

2017: Still from first instance of mating behavior recorded in the field for *Castianeira sp.* Male approaching female while she is building her mound.

2018: Camera Set-up with extension tubes for nocturnal documentation of egg sac construction.

2018: Documenting a female mason spider spinning her egg sac at night.

Figure 5: Camera set-ups used for documenting the mason spider and images from the field

Imaging techniques are also critical to research and discovery

For mason spiders, it was my observing and recording (to our understanding) the first time, the mating behavior of this species in the field. For the structural origins of color, it was understanding at macro-, micro- and nano-scale the structures and their relationships to each other. At some level, discoveries were directly correlated to access to the imaging equipment and the specific equipment varied year by year.

Year 1:

- Macro-photography revealed the silk lattice that holds the objects together in the mound
- Photodocumented the impact that laying eggs, spinning egg sac and building mound had on females' abdomens

Year 2:

- Decreased researcher impact on these sensitive animals through different equipment set-up
- Collected data on mound building behavior and increased understanding of how females carry objects
- Recorded first field footage of mating behavior of this species (to our knowledge)
- Images contributed to engagement and learning opportunities with artists, children, and the general public to learn more about this spider species
- Contributed to understanding the mound building sequence

Year 3:

- Found another population on a cobble beach
- Collected data on egg sac construction and mound building
- Recorded egg sac and mound building behavior including nocturnal activity
- Analysis ongoing

At the 31st European Congress of Arachnology (ECA) in Vác, Hungary, I presented these findings in a poster highlighting the first instance of mating behavior recorded for the mound building mason spider *Castianeira sp.* (Karikó et al., 2018) as well as a praise poem which describes mound building behavior in a different way than in the traditional scientific literature.

Karikó, S., Raboin, M., Karikó, A., Elias, D. 2018. Love on the Rocks: Mating Behavior of the Mound Building Mason Spider *Castianeira sp.* (Corinnidae) [poster]. *European Congress of Arachnology 2018*, Vac, Hungary.

Poster Abstract: In this study we provide the first description of the mating behavior of the mason spider *Castianeira sp.* (Araneae: Corinnidae), a mound building species from the Greater Yellowstone Ecosystem in Wyoming, USA. Females construct egg sacs in a rock nook, then cover them with materials they gather during hundreds of collecting trips. Prior to 2017, neither males nor courtship had been observed in the field. Using videos, we examined mating behavior using Behavioral Observation Research Interactive Software (BORIS), and our observations suggest a simple mating behavior pattern with the male approaching the female while she is building her mound followed by short palpal insertions (ranging approx. 5-76+ seconds) with little

pre- or post-copulatory interactions. These natural history observations expand the understanding of the mason spider's life cycle and mating system including: how and when mating occurs, whether or not females mate multiple times, and its impact on the number of egg sacs produced during the season. Further study is needed to understand the cues (chemical, visual, vibrational/seismic) males and females use during courtship and mating and what role (if any) female silk or the mound plays in finding mates.

I was also interested in exploring whether humans can take inspiration from nature—in this case spiders—to spark dialogue and reflection that might catalyze community engagement in service of stewardship in considering the complex intertwined challenges of the 21st century. Concurrent with the poster viewing at the European Congress of Arachnology, congress attendees were invited to respond to this research we presented by reading the praise poem, then building their own mound inspired by *Castianeira sp.* and to reflect on three questions.

In so doing, we were interested in exploring whether humans can take inspiration from nature—in this case spiders—to spark dialogue and reflection that might catalyze community engagement in service of stewardship in considering the complex intertwined challenges of the 21st century. Within this framework, I offered an open invitation for viewers to explore and create personal responses to contribute to a potentially larger dialogue at the European Congress of Arachnology and possibly beyond. The arachnological responses and mounds are currently being compiled and written up for sharing more broadly.

Mating Behavior

The mason spider mating behavior research expanded upon my earlier research on invertebrate mating behavior in which I described for the first time the complex, relatively stereotyped series of events comprising mating behavior of two species of neotropical flea beetles. My field observations of the outside story coupled with Eberhard's data from particular stages in sperm transfer (the inside story) suggested that copulatory courtship may play a crucial role in inducing critical internal female responses to allow sperm transfer to occur during mating. These findings were published in a paper "Copulation behavior inside and outside the beetle *Macrohaltica jamaicensis* (Coleoptera, Chrysomelidae)" in the Journal of Ethology (Eberhard & Karikó, 1996, pp.59-72).

Courtship during coitus challenged the predominant thinking about sexual selection and female choice at the time, and these findings provided support for Eberhard's theory on sexual selection and the evolution of animal genitalia and his hypothesis on copulatory courtship representing attempts by males to influence cryptic female choice (Eberhard, 1985, 1994), suggesting "that an aspect of sexual selection by female choice not considered by Darwin may be more important than previously appreciated and that the common practice in evolutionary studies of measuring male reproductive success by counting numbers of copulations may sometimes be misleading because of cryptic female choice during and after copulation" (Eberhard, 1994, p.711). This research contributed to a growing body of evidence that describes and supports females' ability to shape the mating outcomes thereby challenging the traditional assumption of female passivity (Eberhard, 1996).

In contrast to my research on the complex mating behavior observed and described for these flea beetles, field observations of copulatory behavior of the mason spider *Castianeira sp.* suggests a simple behavior pattern and points to questions for future research as described in the poster abstract above.

Misumena vatia

Different camera setups allowed for different perspectives to learn about the same animal. For example, in Figure 6, these images of the crab spider *Misumena vatia* (Clerck, 1757) (Thomisidae) show how she can change color depending on where she is on the flower (from yellow to white). Additionally, the macro photos of *Misumena vatia* also demonstrate a relationship that I was unfamiliar with and have not found reference to in the arachnological nor ecological literature regarding females using aspen leaves in constructing their egg sacs.

A. *Misumena vatia*, yellow phase, inside the flower of an arrowleaf balsam root.

B. *Misumena vatia*, white phase, on the hirsute stem of an arrowleaf balsam root.

C. *Misumena vatia* using the leaf of an apsen to construct an egg sac.

D. Close up of *Misumena vatia.*

Figure 6: Different ways of seeing the crab spider *Misumena vatia.*

Impact: Reverberating Out into the World

The impact of the photos from this research have had wide reach. Photographs I created both in the lab and the field have been exhibited far beyond the original *Spiders!* exhibit, including in the travelling components of the exhibit as well as in professional talks and in teaching several educational programs I designed and will describe later, such as in the negotiation curriculum taking inspiration from the spider world, as well as at a family art making event at the University of Wyoming's Art Museum.

Part of Museum Education

One of my portraits of *Misumena vatia* (Fig. 6D) became part of the National Museum of Wildlife Art's Education Department's teaching collection and became part of the teaching component for the exhibit "Tiny: Charismatic Minifauna" from the Permanent Collection. Jane Lavino, Sugden Curator of Education reported:

> *This 6 month exhibit has been very popular with school groups. Since it opened in October 2017, 96 school groups totaling approximately 1,900 elementary school children have toured the exhibit and participated in the accompanying education programs. The focus of the education programming has involved teaching what a big impact the small animals have on the health of their ecosystems. The theme of our exhibition interpretation has been "Look Closer, Think Bigger." Children have learned, for example, that bees pollinate crops and provide a service valued at an estimated $29 billion dollars per year. Grasshoppers frequently eat plants that are toxic to cattle, and spiders prevent thousands of insects per year from overrunning out homes and gardens. Spider silk is also inspiring the next generation of parachutes and bullet proof vests. An etching by Pablo Picasso "L'Araignee" or The Spider 1942 was the focal point for conversations about spiders within the exhibit. Students also spent time in the Museum classroom learning more about spiders specifically. A large photograph of a crab spider by Sarah Kariko hangs in our Museum classroom and is part of our Education Collection. This was perfect for discussing the anatomy of a spider: number of eyes, legs, tarsus, fangs, cephalothorax etc. Students then made their own spider sculptures. The results were fantastic! (Lavino, 2018)*

Link to *TINY: Charismatic Minifauna from the Permanent Collection*: https://www.wildlifeart.org/exhibits/tiny-charismatic-minifauna-from-the-permanent-collection/

Invited Exhibits

Women in Science: My mason spider research was included in an exhibit about the history and impact of women in science at Harvard and highlighted contributions of women in science today in the lobby of the Northwest Building at Harvard University. In addition to photographs of the mason spider and myself in the field, a mason spider mound created by a female *Castianeira sp.* from Wyoming (and collected by Maggie Raboin) was displayed on a glass pedestal as both a work of art and a feat of architectural engineering. The Northwest Building is located near the Harvard Museum of Natural History and houses a wide range of laboratories (neuroscience, systems biology, and genomics), classrooms, offices, a café, and a scientific machine shop so a wide range of students, staff and researchers walk by as they enter the building each day (*Women in Science*, 2018).

Kids's Collect Exhibit at the National Museum of Wildlife Art

Two of my field photographs and my praise poem for the mason spider were included in the exhibit "Kids Collect" at the National Museum of Wildlife Art during the summer of 2018, providing a conceptual bridge between the idea of children collecting and the

museum's mission focusing on wildlife by highlighting a local female collector, the mound building mason spider *Castianeira sp.*

Museum of Comparative Zoology
One of my macro photos of a male jumping spider, *Habronattus americainus* (Keyserling, 1885) (Salticidae) taken as part of the *Spiders!* project was selected to be displayed outside the Agassiz Room in the Museum of Comparative Zoology.

Power of Story: Power of Poetry: The Importance of Language
"In the twenty-first century, it is often scientists who first hear them. The stories of buffalo and salamanders belong to the land, but scientists are one of their translators and carry a large responsibility for conveying their stories to the world." Kimmerer (2013, p.345)

Humans have been described as a "Poetic Species" (Hass & Wilson, 2014). Deutscher (2008) describes metaphor as not only a form of language but also the chief mechanism of how the human mind functions to "describe and even grasp abstraction." Marshall discusses metaphor as one of the building blocks for creativity, learning, and imagination (Marshall, 2011). In this way, metaphor is important for creativity, for imagination, and for understandings the surrounding world.

It has been shown that poetry and metaphor can play an essential role in biodiversity conservation education in informal settings. For example, a recent study piloted the addition of poetry to the Central Park Zoo in New York City, then expanded the program to five more zoos throughout the United States as an experiment to see how it might impact visitors. Findings from this study suggest that the visitors to the zoos with poetry in them left with a deeper conceptual knowledge of the conservation-related themes the zoo was hoping to convey (Preston, 2013 p.66).

Unintended Consequences and the Power of Story
If one considers the history of pesticides one will find that there have been both positive and negative impacts on humans and the environment. In the early days of agriculture, in places such the Fertile Crescent, the Mesopotamians used methods such as "smokes," tar, and pyrethrum – made from dried Pyrethrum daisies –to deal with this competition that humans have had with other organisms for food (Unsworth, 2010). It wasn't until the 1940s when the synthetic pesticides began to be widely used—including DDT.

The application of DDT provides a story of both Noble prize winning research as well as unintended consequences. When DDT was first developed, researchers found that the chemical could be applied not only for crops, but also on the mosquitoes that transmitted diseases such as malaria, yellow fever and typhus. The physician, Dr. Paul Müller, received the Nobel Prize in Medicine in 1948 for his role in discovering the insecticidal properties of DDT (*Paul Müller*, 2018). In the 1950s application of synthetic pesticides allowed cheaper food prices, thus allowing more people to have access to food. However, there have been, and continue to be, wide reaching unintended consequences.

In the United States the North American population of bald eagles, the American national bird, nearly became extinct since DDT affected the strength of their eggshells so that the shells collapsed when adults sat on them to incubate the chicks (Carson,

1962). In 1962 Rachel Carson released *Silent Spring*, the title of the book being perhaps one of the most famous metaphors in the environmental movement. Her book takes aim at the deleterious effects of synthetic pesticides and DDT in particular, not only on wildlife but also humans (Carson, 1962). Eventually the United States passed a law banning DDT in 1972 (even though it continued to export DDT into the 1980s). Despite the ban on DDT, and the recovery of the Bald Eagle, DDT is the most common persistent organic pollutant found in the global environment according to the Stockholm Convention on Persistent Organic Pollutants and "has been detected in food from all over the world" (*12 initial POPs*, 2008).

Carson's book can be considered an example of finding what Lubcenko calls "helpful and accurate analogies and metaphors" (Lubcenko in Gabrielson, 2015 p. 7339-7340) that became a powerful call to arms resulting in citizen and policy maker mobilization and eventually inspired environmental protection laws such as the Endangered Species Act (Griswold, 2012).

In the field of conservation, there has been a recent shift from a 'doom and gloom' narrative to highlight what is working and to inspire positive change. The inaugural Earth Optimism Summit sponsored by the Smithsonian Institution was an effort to spread positive stories to invigorate and work towards positive solutions for Earth (Christen, 2017). The stories highlighted messages of hope from leaders such as plenary speaker primatologist Patricia Wright inspiring stories of conservation work and overcoming challenges in the rainforests of Madagascar with the resulting increase of ecosystem vitality (Wright, 2017) to cultural geographer Carolyn Finney's sharing stories of inspiring work by African American conservationists from her book *Black Faces, White Spaces: Reimagining the Relationship of African Americans to the Great Outdoors* that are typically relegated to the margins (Finney, 2014, Earth Optimism, 2017). What we see and the stories we tell shape how and what we understand.

Stories and storytelling were important component of *Spiders!*. This took place at many levels from the opening talks at the National Wildlife Art Museum, to the stories through objects in the makeshift laboratory at the exhibit, to the challenge to visitors to explore unexpected questions within the exhibit. We aspired to make the exhibit personal and relatable through the different stories and offering various ways of "seeing" spiders. Different elements provided multiple points of entry into the material for people to explore and relate to. My own role as storyteller was through curating the exhibit, creating artworks such as the macro field photographs as well as being a docent to the exhibit where I answered questions and highlighted different threads while also leaving space for visitors to explore and make their own connections. In this way, *Spiders!* created a space in which to explore spiders through many different mediums and voices, and created the possibility to make new connections and interweave them into a new understanding of these animals and our interrelatedness.

The story of Herb and Lorna Levi was told through the makeshift laboratory set up in the exhibit space through a collection of scientific equipment, their books (on music, spiders, natural history, art), photos of them from 1950 in the field, his microscope, his Olympia typewriter for spider manuscripts (with its specialized keys along with an invitation to type a message), spider illustrations of theridiid spiders, his drawing supplies, and a sweep net for collecting spiders. There was also an animation paying

homage to Levi's taxonomic contribution to arachnology, created with his epigynal and palpal drawings arranged into fluttering fields of flowers that transform into other scenes highlighting the localities the Levis worked in around the globe.

Stories and poems can be important vehicles for teaching through metaphor. "Metaphors have been used in a variety of different ways in story forms to convey information and knowledge over generations. Story telling essentially is the first foundation of teaching anything. Human beings are story makers and story tellers" (Cajete, 2009, p. 2). Guiding stories like Iktomi were created to teach people in intergenerational settings how to act in relationship with others (each other and other beings) in order to survive (Zitkala-Sa, 1985; Goble, 1994).

For *Spiders!* Butch Thunderhawk created a series of ledger art that featured spiders and depicted Iktomi, the trickster spider whose stories are important to Lakota people in helping teach how to live in balance in a good way together. He also spoke about spiders' importance in Lakota/Dakota culture for designwork. Through Thunderhawk's talk and ledger drawings, visitors learned about the importance of spider in the designs of the Lakota such as for war shirts and shields as well as the stories of Iktomi (ex. Thunderhawk's drawing depicting *Iktomi and the Ducks*).

Poetry

As Kimmerer suggests, 21st century biologists are privileged to witness stories from the field that few others get the opportunity to see. Therefore, field researchers are well positioned to be translators of these stories from the natural world (Kimmerer, 2013 p.345). Like many other field biologists, fieldwork brings me into intimate relationship with not only my study animals but also all the other organisms in their habitat and the larger issues of the ecosystem. My own exploration with the genre of poetry led to two poems. The first poem, '*Populus tremuloides:* We Are One,' was published in the environmental humanities journal *The Trumpeter: The Journal of Ecosophy* based on my experiences in the habitat of *Misumena vatia* in response to events that took place during my field work:

Karikó, S.J. 2017. Populus tremuloides: We Are One. *Trumpeter, 33*(1), 100-103. Available at: http://trumpeter.athabascau.ca/index.php/trumpet/article/view/1510/1730

This poem is about the interconnected web of life – listening to other species, and articulating the connections between and among us (ex: "listening to the deer's ears"). This call to listen to other species to learn from them, such as the real world example where birds provided an early warning signal to humans in Oklahoma when they sensed an earthquake and took flight before it occurred. This mass exodus was visible on local radar minutes before the quake hit (Hopewell & Fritz, 2016). Humans can consider learning from and listening to other species that can sense the disruption humans are creating in some areas and integrate this knowledge into human action. This needs to be done in such a way that we do not just flee the approaching earthquake but are able to chart a future course that cares for the living earth and takes the wellbeing of other species into account.

Populus tremuloides: We Are One

S. J. Kariko

Watch the deer's ears—
are they both towards you?
Is one angled back? Look around,
see what she's listening to,
they can sense things.

Learn to read the ears of the deer.
Listen for when birds stop calling, when
songs change, calls shriek out,
shrill across the sky.

Look where trees are torn up,
ant mounds clawed apart,
no guarantee our team will stay safe,
so look to the ones we can learn from—
watch the deer's ears.

After the nurse was found
partially eaten and cached, to be
finished later by the mother bear,
and at least one, if not both of her cubs,

we listen on cobbled banks, our bodies
electric seeing fresh tracks
we spring at the ping of a pebble
falling on the shore.

Now, mountains disappeared for more than a week,

smoke slows me down ‘til I end up
at the clinic seeking relief—
more steroid inhalers to bring breath back in.

This smoke—
from wildfires two to three states
away, ponderosa and fir, cedar and
spruce, beetle-killed, sap-filled—
exploding across highways even
lakes.

This smoke—
of young firefighters
perished in these blazes,
whose ash and spirit is
mixed
with lodgepole and owl and ground
squirrel and telephone poles and their
vehicles— all traveling cross our country now
to where I sit, here, in this aspen grove.

Aspen, they are one.
Standing together, a single organism,
sharing ancient roots, some 80,000 years strong.
Aspen come back first.
Need fire to compete with
conifers.

Their green-white bark
blackens around where
branches sprout out,
deer rub velvet off,
elk incise toothy

lines and young
cubs climb.

These storied trunks reach all at once into thick sky,
fingerling branches entwined under a now orange
moon, leaves hanging on edge, ready to move at the
slightest… They dance—

whirling together,
on long flattened
petioles, such delicate
attachments,

Populus tremuloides.

Standing just below
leaf and wind,
story and sky,
we listen for the deer's
ears from now—until
when?

At the clinic, they tell us
that even if we begin driving east today
we'll still have two days through smoke.
I try to imagine this: our country

blanketed—while grizzly cubs
are driven to a zoo, to be
fed by humans, for
the rest of their
lives.

Populace tremuloides

Inspired by events while conducting field research in the living laboratory of what is currently called the Greater Yellowstone Ecosystem. Written with a tender heart for the nurse, the bears, the firefighters, and all of their loved ones; and in celebration of Pando—*possibly the oldest living stand of aspen trees on our planet.*

A second poem 'Words I Think of When I think of You,' a praise poem for *Castianeira sp*., is inspired by observing female mason spiders building mounds in hot rock canyons. In this poem I work to translate my field experiences observing and recording female mason spiders building mounds and recording the first instance of mating behavior in the field for this species. It starts with a list of words I think of when I think of "you" (the mason spider). In the praise poem, I use direct address employing the word "you" thereby avoiding the human-centered focus and promulgation of objectification as well as acknowledging spiders as living beings not relegating spiders to the language of objects. (Kimmerer proposes using the terms "ki" and "kin" instead of the objectifying word 'it" or 'its" to enliven the language when addressing the other-than-human world (Kimmerer, 2013)). This praise poem has been used in many educational programs at places, ranging from the Durrell Institute for Conservation and Ecology at the University of Kent, UK to the European Congress of Ararchnology in Hungary to the Harvard Divinity School and the National Museum of Wildlife Art, USA.

Spiders! Reimagined

Figure 6: Poster for *Spiders! Interconnectedness, Innovation & Stewardship* featuring female *Misumena vatia* just as she has finished spinning her egg sac in an aspen leaf.

In September 2017 the *Spiders! Interconnectedness, Innovation, and Stewardship* exhibit traveled to the University of Wyoming's Berry Biodiversity Conservation Center in Laramie, Wyoming (Fig. 6). The exhibit was re-imagined for the modern atrium gallery in part by:

- Inviting additional artists
- Creating new works and site-specific pieces
- Developing playful educational programming
- Creating and offering negotiation training drawing inspiration from the spider world
- Being invited as special guest for a family-friendly art-based event with museum educators at the University of Wyoming Art Museum to weave together inspiration from the combination of the museum's *Changing Faces* mask exhibition and the Berry Biodiversity Conservation Center's *Spiders!* exhibit

The format for the opening event included talks by scientists and artists and a make-your-own edible spider as part hors d'oevres/part spider anatomy lesson. In addition,

videos highlighted the creation process of some of the sculptures as well as sharing footage of mason spiders in their habitat.

For the exhibit in the atrium, many pieces from the previous year's exhibit were installed and several new works by local artists were added, including *100 Spiders/100 Years Re-imagined* by Renee Williams and a mixed media sculpture created using synthesized and real spider silk in a sage brush by Dorothy Tuthill. I collaborated with pressmaster Ted Ollier to design and letterpress print a limited edition print of Chef Yosses' closing remarks from 2016 that was displayed alongside an educational panel with a nearly life-size photo of the sculpted chocolate spider by Chef Ortega.

This iteration of the exhibit had a greater focus on the mason spider with a new installation around two boulders (installed in the floor of the building) of forty-five different mason spider mounds created by female *Castieneira sp*. that I photographed in the field. They were low and at childrens' eye level so the kids could scramble on the rocks to explore the photos during the *Spider Super Hero Program*—and they did!.

For *Spiders! Revisited*, eight macro photographs were selected and blown up to approximately 36" x 36" and mounted on panels lining the wall by an ascending staircase. The combination of the staircase and the positioning of the spiders at eye level or hovering above the humans walking throughout the gallery offered people a unique perspective of the arachnids that were the focus of the exhibit. In the completed exhibit feedback forms, all commented on the impact of these large format spider photographs.

Different treatments of the same animal allows the viewer multiple perspectives of understanding and also points to the role of the photographer to directing the viewer's gaze to shape the viewer experience through selecting what remains in the frame and what is outside. The collection of images of *Misumena vatia* (Fig. 5) showed the multiple techniques used to photograph and capture images of the spiders: one image is from a laboratory setup where the spider was placed on white background; in the field the spider was photographed *in situ* as well as moving through its habitat with attempts made to disturb the animals as little as possible. As mentioned earlier, one of these photos was used in the follow-up teaching component for the exhibit *Tiny: Charismatic Microfauna from the Permanent Collection* at the NMWA.

In addition, three educational components were developed for this iteration: a negotiation training taking inspiration from the spider world in collaboration with Professor Steve Smutko of the Ruckleshaus Institute; I was invited as a guest for a family friendly art-making event at the University of Wyoming Art Museum; and I led another iteration of the *Spider Super Hero Program*, offering four classes to approximately eighty students from first and second grade, adapted to highlight local spider fauna.

Seeing spiders in different ways created unexpected connections when the *Spider Super Hero Program* was held at the University of Wyoming's Biodiversity Institute. Zimbabwean artist Lazarus Gawaza's bead and wire sculpture of a sun spider or solfugid – a close relative of spiders – was exhibited on one of the permanent boulders in the exhibit space and it would appear to glow when the sunlight streamed in through the high row of windows. First and second graders were drawn to this

sculpture on the boulder, then became fascinated by the accompanying monograph by Tharina Bird et al. published by the American Museum of Natural History (AMNH) (Bird et al., 2015). This two hundred-plus page technical monograph contains many full color plates of solfugid morphology, featuring extraordinary cheliceral (or jaw) morphology. This type of publication is often difficult to find, even in specialized taxonomy libraries and online, let alone in public libraries or as browsing material for school children (See Figure 8).

Educational Experiences

From this research, I have developed several participatory educational experiences: the *Spider Super Hero Program,* negotiation workshops taking inspiration form the spider world, and "Create. Reflect. Connect.: Inspiration from the Mound Building Mason Spider *Castianeira sp.*" (Create. Reflect. Connect).

Spider Super Hero Program

Spiders are often relegated to fear or fascination. They are not typically highlighted in conservation campaigns. What spiders can do is bring us face to face with otherness. Recent neurological research tells us that neurological pathways are formed very early in the brain and that early exposure can shape our responses later in life and inform perceptions upon which decisions and actions will be taken (Moore et al., 2011).

Inspired by *Phoroncidia rubroargentea*, a tiny vibrantly colored spider from Madagascar, I designed the *Spider Super Hero Program,* a participatory educational program first for Pediatric Oncology and Hematology at a hospital in Boston, Massachusetts, USA. I took families on an imaginary "magic carpet ride" around the world where we met spider super heroes who shared their adaptations, or super hero powers (ex. ballooning over skyscrapers and mountains, living underwater, hiding in plain sight, dazzling dancing, special spitting and lassoing with scented silk). Then on our way back to the hospital from our imaginary adventure, participants were invited to identify a real world challenge they could use a little extra help with and to design their very own spider super hero to help out with this real world challenge. In the case of *P. rubroargentea* who inspired this program, her adaptation could be that even if you are getting chemo or having other treatment to your body, she could remind us that it is possible to stay beautiful inside and out, no matter what.

Incorporating music by having a flutist play the "magic" flute for each country that we traveled to was another way of creating multiple entry points for engagement and connection. For example, one of the children who was quiet during the program spent a lot of time afterwards with the flutist examining the flute – making connections through the instrument and music (brought together by the spider). Having music as a central part of this program also provided another way of connecting for participants in the group that might not have happened if we did not include this musical element. At the hospital, we also gave each participant a handmade satin spider super hero cape.

Participants were asked to write the first three words they thought of when they heard the word 'spider' at the beginning and end of this program. An example of the type of shift that was recorded is from "scary," "creepy" and "quiet" to "cool," "smart," and "funny." (See Fig. 7.)

With funding from a Creativity Garden Grant, a nationwide project of the Association of Science-Technology Centers generously supported by Disney, this program was expanded to first through fourth graders, through collaboration with Harvard's Museums of Science and Culture. For this, I taught seven programs in collaboration with Wendy Derjue-Holzer, Director of Education for Harvard's Museum of Natural History, which provided us an opportunity to iterate and improve the program throughout the course of the semester.

Abstract From the Creativity Garden website (*HMSC*, 2017):
Come meet some spider superheroes. They can jump huge distances, weave intricate webs, live underwater, change colors, or be mistaken for jewels. Forget your fears as you explore the fascinating ways spiders live. Leave with a self-designed superhero spider. This program will combine the riches of museum collections with the creative vision of participants. Students will work with Artist/Scientist Sarah Karikó of Gossamer Labs and Museum Educator Wendy Derjue-Holzer to explore this intersection of art and science.

The focus of this iteration was to combine the ideas of spider biodiversity with real life human challenges. From this junction, participants created their own superhero drawing from both dimensions. Each of these components was something the children had encountered before in their lives and could learn more about during the program. The students drew upon their own creativity and imagination to synthesize the learning into their own superhero to help out with a real world challenge. One child highlighted the spider's ability to spin silk in creating a super hero spider that would spin clothes for families in need. Another created a super hero spider whose adaptation addressed the public health concern of smoking by helping people quit by using its eight legs to jump and take cigarettes away. This series of programs reached an additional 102 participants from the greater Boston area. By targeting this age group, the program worked to make biodiversity more relevant to a younger generation.

Additionally, this gave the museum the opportunity to offer seven programs, allowed the education department to serve a greater diversity (socioeconomically) than the museum's typical visitor profile, and helped connect it with new individuals and communities while also strengthening or re-establishing their relationships with local community groups.

https://news.harvard.edu/gazette/story/2016/05/spiders-to-the-rescue/

To date, several iterations of the *Spider Super Hero Program* have taken place:

- Pediatric Oncology and Hematology at a Boston area hospital, Spring 2014, (and again in Spring 2016)
- Harvard's Museum of Science and Culture (7 programs supported by a Creativity Garden Grant, a nationwide project of the Association of Science-Technology Centers generously supported by Disney), for 1st to 4th graders, Spring 2016
- Mask-making family event at University of Wyoming Art Museum, Fall 2017
- University of Wyoming Laboratory School at the Berry Biodiversity Conservation Center at the University of Wyoming 1st and 2nd graders, Fall 2017

Figure 7: Participants were asked to write down three words they think of when they hear the word spider, 1) before the program begins, and 2) at the end of the program. This response shows a noticeable shift in words.

For the 2016 iteration of the *Spider Super Hero Program* at Harvard's Museum of Natural History, I was interested in finding a way to document participants' super heroes and decided to create catalog pages based on the books used to catalog historical natural history collections. I invited students in a letterpress printing class to create a catalogue page for recording spider super heroes. Taking inspiration from historic museum catalogs, the printers made pages that were then used by the young participants. This provided a learning opportunity not only for the children in the program to see and use catalogue pages but also for the students in the printing class to learn about historic museum collections, to learn more about the biodiversity of invertebrates (especially spiders) when visiting the collection, as well as getting an introduction to the design and history of catalogs used for historic natural history collection.

These catalogue pages were then sent to artist Butch Thunderhawk. He spoke with his community about sharing the stories of Iktomi and the significance of Spider for the upcoming *Spiders!* exhibit, then created five illustrations on the catalogue pages in the ledger book tradition: some of Iktomi (like "Iktomi and the Ducks"), some showing the importance of spider in Lakota culture and design through depicting spider on war shields, and other artworks depicting spider with the lightening beings and dragonflies. These original works were displayed at *Spiders! Interconnectedness, Innovation and Stewardship* as a way of sharing this knowledge.

Figure 8: Clockwise from top: *Spiders! Interconnectedness, Innovation & Stewardship* installed in the Berry Biodiversity Center atrium; Teaching spider Super Hero Program to 1st and 2nd grade students; Participants from SSHP reading the monograph "High resolution images for Cheliceral morphology in Solifugae (Arachnida): primary homology, terminology, and character" survey a monograph about sun spiders or solifugids by arachnologist Tharina Bird et al. published by the Bulletin of the American Museum of Natural History, with Levi's scientific illustration in the background.

Teaching the *Spider Super Hero Program* within the *Spiders!* exhibit in collaboration with Associate Director of the Biodiversity Institute Dorothy Tuthill expanded the possibilities for students' learning about spider biodiversity. Children had multiple ways of seeing and knowing a spider: for example, a crab spider through the program's' PowerPoint, then looking throughout the exhibit to find other ways of representing this spider (from DG House's painting "Life at Four Corners," to my macrophotos, to Jenny Dowd's mixed media pieces). The children also had the opportunity to run around and explore the exhibit –scrambling on the boulders near the installation of mason spider mounds and standing close-up to Levi's scientific illustrations to examine them .

The Center for Childhood Creativity (CCC) in its report, "Inspiring a Generation to Create: Critical Components of Creativity in Children," identifies seven components of creativity: imagination and originality; flexibility; decision-making; communication and self-expression; motivation; collaboration; and action and movement (Hadani et al., 2015). The *Spider Super Hero Program* includes many of these components, focusing especially on imagination and originality, communication and self-expression and collaboration.

Skills Building: Negotiation Training

To implement ideas and strategies inspired by an interconnected approach and to conduct collaborative multi-disciplinary research demands a diverse toolkit including effective communication and collaboration skills – skills that are often not taught. There are few places to practice negotiation skills, nor how to have difficult conversations (though this goes beyond the material covered in my research). This research also takes into account how difficult it can be for people to work together over complex and highly emotional challenges such as human-wildlife issues, water rights, species loss, the impacts of a rapidly changing climate and the impact on health and wellbeing. It has been my experience that these skills can be learned and practiced through interactive negotiation simulations and games based in a mutual gains conceptual framework that also help identify personal strengths and blind spots.

Drawing upon my experience negotiating the first venom accord with the Malagasy government, and then formalizing my negotiation (and mediation) training at Harvard Law School's Program on Negotiation (PON), this research investigated ways to teach skills for negotiating through developing practical hands-on trainings to help people find areas of agreement and solve problems together. As a way to share and practice tools I have organized several negotiation skills training workshops, some of which include taking inspiration from spiders.

As part of the opening events for the *Spiders!* exhibit at Berry Biodiversity Institute at the University of Wyoming, I collaborated with Professor Steve Smutko, Spicer Chair in Collaborative Practice at the University of Wyoming's Ruckleshaus Institute in co-designing and teaching a negotiation workshop that wove anecdotes from the fascinating world of spiders into a professional training to improve participants' negotiation skills along with participant's own approaches to seeking negotiated solutions to complex problems in the lab, the field, the studio, the workplace and at home. The curriculum is drawn largely from the mutual gains approach to negotiation theory developed at PON for over thirty years (PON, 2018). The workshop was designed to provide an opportunity to learn about negotiation theory through simulations while taking inspiration from the spider world ("Taking Inspiration from the Spider World", Berry Biodiversity Conservation Center, University of Wyoming, Laramie, WY 2017).

The negotiation trainings led to an invitation to a *Collaborative Governance Research Retreat* in Grand Teton National Park at the University of Wyoming/National Park Service Research Station sponsored by the University of Wyoming Ruckleshaus Institute and the University of Utah Law School. The objectives of this retreat were to:

1. Facilitate information sharing across leading thinkers in the field
2. Bring people together to work toward a shared research agenda and key next steps to advance the field of collaborative governance scholarship
3. Share research topics and ideas
4. Join key scholars in conversation about moving the field forward

Create. Reflect. Connect.: Inspiration from the Mound Building Mason Spider *Castieneira sp*.

My fieldwork collecting data on *Castianeira sp.* who build mounds with hundreds of objects in hot, rocky canyons inspired me to write a praise poem about this spider.

This poem and the short film about the mason spider, which includes the first instance of mating in the field, became the cornerstones for designing this participatory educational experience. "Create. Reflect. Connect.: Inspiration from the Mound Building Mason Spider *Castianeira sp.*" (*Create. Reflect. Connect.*) which has been conducted in several settings, ranging from Creative Conservation students at the Durrell Institute for Conservation and Ecology at the University of Kent, UK to most recently at the European Congress of Arachnology in Hungary. Participants are invited to build their own mound using nearby materials and are asked to respond to three questions for reflection.

It was observed that most participants filled out their answers to the questions after they built their mound. Perhaps the act of handling materials and assembling the mound provided insight into their own responses.

Figure 9: Mounds created and displayed in dialogue with the Lowell Lecture by Terry Tempest Williams at the Boston Public Library Massachusetts, USA, 29 March 2018

Selected *Create. Reflect. Connect.* Events

- Durrell Institute for Conservation and Ecology University of Kent, Canterbury, England, Spring 2018
- Lowell Lecture Series at Boston Public Library, Massachusetts, USA, Spring, 2018 (See Fig.9.)
- European Congress of Arachnology, Vác, Hungary, Summer 2018

Cross-Pollination: Creativity & Collaboration

In an article in the Harvard Business Review, Fleming reported on his research on cross-pollination which suggests that breakthrough ideas are more likely to arise from teams whose individual's disciplines are widely diverse. The study also found that these teams had more "failures" but the successes were more groundbreaking (Fleming, 2004).

In recent years many cross-disciplinary approaches have been employed that blur the boundaries of science, art, and the humanities. One example is the *The Ucross-Pollination Experiment*. This partnered four pairs from the fields of art and science in an effort to promote collaboration beyond their respective academic specialties. The partners were asked to view the Ucross environment through both their partner's

discipline and their own. The partners presented their work to the public including creating an art exhibit (Ucross, 2014).

Michael Dillon, an entomologist and assistant professor at the University of Wyoming said that participants were not allowed to create the "standard science-art" project where the artist has to interpret the science, or "make it pretty" (Dayton, 2015). He was paired with choreographer Rachel Shaw, and their collaboration produced unexpected and potentially high-impact finding through "Labanotation," a choreographic technique for recording and analyzing movement (Guest, 2014). It was this notation technique that led to their discovery at the junction of biomechanics, functional morphology and labanotation on how common pesticides impact the bumblebees system and ability to pollinate (Dayton, 2015).

Sweet Send-Off Stridulating Organ Project

When convening a team to create a tribute to my spider mentor's memorial, the collaboration resulted in a teammate using the spider data we generated to contribute a major medical innovation. He presented these findings to both the U. S. Defense Advanced Research Projects Agency (DARPA) and National Institute of Health (NIH) who viewed it as a breakthrough for neuroscience data visualization that could be applied to other fields.

This team consisted of a group of highly diverse individuals, ranging from a biomedical researcher turned entrepreneur, to the former White House executive pastry chef, to Curator Emeritus of the Royal Museum for Central Africa, to one of the Research Fellow physicians working with Red Sox pitchers at Beth Israel Deaconess Medical Center, arachnologists (myself included), an IBM Fellow, and spiders! This unexpected finding provides further support for Fleming et al.'s research on cross-pollination, and our findings are currently in preparation for publication.

Notes on this Research

The research section was selected from a larger body of work by the author.

Synthesis: Exploring the Interconnected Web

"I saw human communities restored along with nature. This is not a mystical phenomenon; it is a fact of human existence. Human beings cannot thrive in a place where the natural environment has been degraded." Wangari Maathai Nobel Laureate *(2005 p. viii)*

In this research, I have tried to answer the question, "How can we open ourselves to inspiration from nature and create a space to cultivate creativity to imagine new ways to connect and work together; to care for ourselves, each other, and our planet in order to help us meet the complex, intertwined challenges and opportunities facing humankind today?

Due to my research experience with invertebrates, I use spiders as a model and as inspiration. Spiders provide not only the metaphor of the web but real world inspiration as orbweaving spiders create intricate structures out of silk—a material both strong and flexible—produced from within their own bodies (Brunetta & Craig 2010). The spider then stays connected to the center of the web, either through a line of silk held from within a retreat, or by positioning her body in the center to sense further into the surrounding world. From there, she can take in information from all parts of the web. She "listens" to see (since typically spiders have poor vision (Levi & Levi, 2001)) from the center of her web.

I have focused on the connecting thread and framing metaphor of the web for this research, which is grounded in my study of spiders. This metaphor provides a way to consider the myriad interconnections and relationships among organisms in the web of life and how actions impact each other—rippling out to vibrate even seemingly distant (yet connected) parts. In this metaphor, human imagination can be analogous to spider silk in that it comes from within, is innate to the humans species as silk is to all spider species, and helps us envision beyond what appears in front of us.

That's the first lesson I have drawn from a spider web, that everything is connected. How we position ourselves and what we pay attention to matters.

We live in an interconnected world. The World Wide Web and social media have connected human societies in ways unimaginable only decades ago. Yet despite this technical interconnectedness, many report that humans are losing our connection with Nature (Louv, 2008; Cajete, 2015; Myers, 2017; Williams, 2017).

Understanding this interconnectedness requires more than one discipline or branch of knowledge, yet our institutions largely focus on separate branches of knowledge, and privilege discourse over other ways of knowing and engaging. Respectful, civil discourse has eroded in recent years in many parts of the world, often making it challenging for people to come together in society.

I have developed an interconnected approach (currently for biodiversity education and stewardship that can also be applied to other fields) to better understand and make visible the often-invisible connections among species and systems. This approach interweaves taking inspiration from Nature, embedding the arts, indigenous knowledge, and western science with public engagement. It offers skill building in negotiation to provide additional training and practice to support collaboration and the challenges of humans working together as well as being grounded in fieldwork. It integrates many disciplines and ways of knowing – melding art and science,

communicating and participating, and incorporating the power of storytelling using different forms ranging from scientific papers to public art installations, exhibits, and interactive learning experiences.

This approach calls for a dialogue of ideas from different disciplines to address both the human and biological realms and effectively prepare the next generation in cultivating a relationship with the natural world, recoupling knowledge with responsibility and care for biocultural diversity of our planet. To study these interconnections and be able to respectfully put ancient ways and new information together, being careful not to appropriate from other cultures.

These ideas reflect older ideas of a living world and interrelationships found in many indigenous cultures: ideas that are often marginalized but have survived and remain vital despite attempts at eradication and are especially important at this critical time. Conservation biologist and author, Gleb Raygorodetsky shares stories from indigenous groups around the globe as an "Archipelago of Hope" – stories serving like guideposts or living examples for "how to keep the earth healthy for future generations." (Raygorodetsky, 2017).

There is a growing movement of integration of knowledge as well as recent efforts in Sustainability and STEAM (Science, Technology, Engineering, Arts, and Mathematics) and SHTEAM (Science, Humanities, Technology, Engineering, Arts and Mathematics). Unlike the recent National Academy of Sciences 2018 consensus study report "The Integration of the Humanities and Arts with Sciences, Engineering and Medicine in Higher Education: Branches from the Same Tree," my work goes beyond this finding. It includes the many branches of human knowledge including ways of knowing beyond the Western tradition and additionally calls for humans opening to learning from other species.

This interconnected approach addresses the gap discussed by A'Bear et al. (2017) who comment on the interdisciplinary training of conservation education and the surprising lack of the arts in the related teaching, save as an *ad hoc* or to explicate science. It seeks to promulgate a much better public understanding of the intimate interconnectedness between humans and other species, especially invertebrates, inhabiting a shared environment. By employing the power of story we can bridge other worlds, stand in each other's footsteps, be made aware of unintended consequences and perhaps mitigate unwanted outcomes. Such a process can help humans change course, find solutions and increase our capacity for empathy. Scientific methods can ask and test these questions, and the arts can influence and shape our understandings of the web of life and provide opportunity to connect – helping us reflect and shape the very questions we ask, the connections we make, and the way information gets synthesized to impact decisions and actions at the personal and public scale. The arts can transform and generate new knowledge as well as communicate across sociopolitical lines, touch the human spirit, and speak in a language beyond words. Art is a universal language extending across cultures. It can help us focus on what we share in common. By including the voices and ideas of children as a vital element and emphasizing creativity, this approach is well positioned to make meaningful contributions towards addressing the 21st challenges with thinking differently and addressing Einstein's remark about finding ways to solve our problems with different thinking than that which was used to create them. An interconnected approach can help create the conditions for "different thinking" to

address and innovate solutions to the 21st century challenges as well as through negotiation trainings increasing zones for agreement. It also provides the possibility to find imaginative and collaborative solutions to the interdependent challenges facing biocultural diversity today and prepare the leaders of tomorrow with tools to address them.

An interconnected approach simultaneously takes a broader view on the interconnections while also being grounded in deep observation in laboratory and field settings and incorporates a more seamless interplay of arts and sciences, exploring communicating and storytelling and listening to create an engaged citizenry and collective caring for each other and our planet.

Findings

The works I have presented show how an interconnected approach may be applied and how looking through this lens could cultivate the capacity for creating the connections which facilitate collective action to work towards these ends.

Nudging the Boundaries of the Disciplines

I believe it is also important to present findings within their respective disciplines to nudge the boundaries of the disciplines. The literatures of the disciplines define the fields in a way, and the fields impact the culture of the next generation of scientists and researchers, which impacts the future of research, teaching, and learning. By finding ways to engage within the disciplinary siloes, I am also nudging the containers and the walls—although this is often the most difficult boundary to cross. For example at the European Congress of Arachnology in Hungary I presented the poster, "Love on the Rocks: Mating Behavior in the Mound Building Mason Spider *Castianeira sp.* (Corinnidae)" that described the first recorded instance of mating behavior in a potentially new species of spider (Karikó et al., 2018b). I dedicated the middle third of the poster to a praise poem I had written for the spider and an invitation for making to which several of the international arachnologists responded. Little mounds inspired by the mason spider turned up in the poster session, in the conference hall, in the courtyard – made by scientists from Austria, India, Israel, Hungary, and Uruguay. This interactive poster presentation explored expanding the format for sharing findings as well as creating an invitation to contribute to a potentially larger dialogue of ideas at the Congress.

At the International Congress of Arachnology in Golden, CO, I spoke in the session honoring my spider mentor Herbert Levi. I discussed his research on *Phoroncidia* and how it influenced my own research, as well as the upcoming exhibit in honor of his contribution to arachnology and the work he and his wife Lorna contributed towards conservation and education, *Spiders! Interconnectedness, Innovation & Stewardship* in which about two dozen international arachnologists contributed, along with invited artists and chefs (Karikó, 2016). However, the challenge remains as to how to share these kinds of works within the field's peer reviewed literature or conference proceedings.

My purely scientific research resulted in easily measurable, quantitative findings. My research on *Phoroncidia* describes four species new to science, adding to the scientific understanding of these spiders and contributing to the body of knowledge used to generate and assess conservation profiles. This research also included a compilation of

natural history and behavioral information on *Phoroncidia* since the 1800s. Researchers, educators and conservation practitioners can then subsequently use this type of information.

An example of this is a conservation assessment I participated in as a member of the Spider and Scorpion Specialist group for the International Union for the Conservation of Nature (IUCN) where we assessed two hundred species of spiders, drawing from the arachnological literature to create the largest spider conservation profile assessment to date (Seppälä *et al*., 2018a; Seppälä *et al*., 2018b; Seppälä *et al*., 2018c; Seppälä *et al*., 2018d; Vaughn *et al*., 2019).

The research on the structural color of *Phoroncidia rubroargentea* (Berland, 1913) from Madagascar revealed a combinatorial coloration strategy based on structural origins of color, pigmentation, and fluorescence. The team I co-led determined the structural elements (regularly arranged guanine microplatelets in the silver region composed of a doublet structure; chambered microspheres in the red region with florescent material; as well as structural elements (tanned and homogeneous layers) of the thick cuticular layer) and characterized their optical properties using correlative optical, structural and chemical analysis. We found that the combinatorial effect of the clear homogeneous cuticular layers with the chambered microspheres collocated over the mirror-like layer of the guanine microplatelets contribute to the vibrant red color (Karikó *et al*., 2018).

During the course of my research on trying to understand the mystery of the vibrant color of a tiny spider from my expeditions to Madagascar, this spider, *Phoroncidia rubroargentea* provided inspiration for my *Spider Super Hero Program* – first developed as a gift for a doctor and offered to children and families getting treatment in a oncology and hematology department at a local children's hospital.

The *Spider Super Hero Program* brings the opportunity to learn about biodiversity into unexpected settings, for example, in hospitals. It also provides a coming together for cross-generational storytelling amongst the participants. It provides the opportunity to create and make with their hands their very own spider super hero, and invites participants to look more closely and deeply at a wide variety of adaptations (or super hero powers). It provides the invitation to think about empowerment – that the answers lie from within – to stress human creativity and sends a message that everybody has that capacity which can be nurtured.

Doing a program such as this in an active hospital setting with very ill children and their siblings and parents was both challenging and rewarding. One of the challenges was finding the right tone and language for engaging a very wide age range from toddlers to teenagers with parents and grandparents. Children had to come in and out during the course of the program for treatment so designing a program that was flexible enough to accommodate this was important. The *Spider Super Hero Program* explores conditions of how to nurture the innate creativity within each participant. It focuses on children and supporting them to cultivate and maintain curiosity about the natural world.

Spiders! Interconnectedness, Innovation, & Stewardship succeeded in bringing together diverse communities to share scientific and cultural knowledge. Results of visitor questionnaires showed that people were thinking about things in new ways,

which can be argued, is a precursor for innovating solutions. Works of art presented new ways of seeing the same animal, giving multiple entry points for connection and understanding and caring. My collaborators from many disciplines were introduced to the biodiversity of spiders and were challenged to think about connections in their own fields and lives, whether that is collaborative governance or orthopedic surgery or food. These types of discussions and explorations can contribute to creating new collaborations and an awareness that can lead towards stewardship (Karikó *et al*., 2016).

My work demonstrates the transformative possibility when convening teams of deep disciplinary knowledge from diverse backgrounds (Fleming, 2004) in the example of the *Sweet Send-Off Stridulating Organ* project where our work to create a tribute project led to an innovative breakthrough in neurological imaging (Karikó et al. in prep.).

In the words of neuroscientists, the act of making activates different brain functioning than discourse alone. From my experience creating large-scale public art installations, beginning with *Homage* (as mentioned earlier) through the *Spiders!* research, my experience and observations have led me to ask the following question: Would people be able to increase the options generated for finding solutions together by embedding the creative arts?

For example, bison management has long been a divisive issue in the American West. To celebrate the return of the bison in a community that had extirpated the native herd, I was commissioned to create a large-scale sculptural installation as part of a community gathering organized in part by the Northern Rockies Conservation Cooperative. My experience of having people gather and help create artworks (such as *Homage, Interspecies Invitational Installation*) led to unexpected observations about who came and participated (crossing sociopolitical lines together), questions about how making something together might have contributed to a different (gentler? reflective?) tone than I have observed in other forms of discourse, as well as having children participate in the dialogue.

Importance of Language

Scientific language does give very precise language based on close observation; technical terms and a myriad of anatomical names for describing all the minute parts of say, a spider – epigynum, lyreform organ, setae, conductor, cymbium, etc. The parameters of peer reviewed science call for precise language that works towards objectivity and creates a distance between the researcher and her subject of study, but leaves out emotion and does not motivate the type of engagement and action to meet the challenges of our time. There is a need for communicating in ways that integrates information and emotion for broader understanding leading to wider impact.

A question that has been the subject of research for decades is whether the language we speak shapes the way we think? Language impacts our perceptions of knowledge. Recent research by cognitive scientist Lera Boroditsky (Boroditsky, 2011) supports Sapir-Whouf's theory (Kay & Kempton, 1984) that language shapes our thinking. Our challenge is to find ways to translate findings from the field in a way that resonates with a broad range of people and makes it personal and relatable. The arts help us connect emotionally which is pivotal for leadership and action in these times.

Poetry has the capacity to make metaphoric leaps, to engage the emotions, and to, as Elizabeth Alexander said in conversation with Krista Tippet, get "at undergirding truths" "which is something distinct from mere fact" (Tippett added) (Tippet, 2019). For as Tippett says, "the words we use shape how we understand ourselves, how we interpret the world, how we treat others." (Tippett, 2019). This is important as Gus Speth, former Dean at the Yale School of Forestry, highlighted in his call for transformation and the poet Mary Oliver saying we need more than reports. MacArthur Fellow, ecologist and author Carl Safina dedicates his work not to science journalism but rather to write in a way to make an emotional connection between scientific findings and people, and whose title "Stony Brook University Professor of Nature and Humanity" embodies this critical relationship.

The art of story telling is also a powerful tool to bridge science and human understanding. When considering the power and importance of stories, it is also important to consider creating and making spaces to share stories, dialogue, reflection, interrogation as well as ways to incorporate them into teaching and learning. My poem "*Populous Tremuloides*: We are One" is a way to share field experiences and the connections I was making during a summer when the fires in the American west were not national news despite its smoke covering two thirds of (what is currently referred to as) the United States (Karikó, 2017).

I formalized my experiences into a poem and published it in the *Trumpeter: Journal of Ecosophy*. By doing this, the poem is positioned to have potentially different impact for discussion within not only informal but possibly formal settings. By communicating through poetry, authors can combine sequences of events and experiences with emotion in such a way as to hopefully elicit an emotional connection to the experience.

Writing and sharing this poem allowed time and a place to reflect and explore some of the interconnectedness I experience in the field as well as a way to share my experiences with colleagues upon my return. In my experience, I have found few places within the field of sciences' formal learning settings to share and learn from field experiences. Typical speaker series on campus do not often include spaces for careful interrogation of the surrounding stories and connections to the fieldwork that can be critical for addressing the complex challenges facing humans as well as invertebrates today. What happens with one field team in a given locality often impacts and influences the experiences of subsequent teams and the local people and environment.

Descriptive Language: Word Choice Matters

Words and labels do make a difference. In considering the writing about spiders in the family Archaeidae, some refer to them with the common name of 'Assassin Spider' (Wood, 2008), while others use words with different connotations such as 'Pelican Spider' *(Pelican spiders,* 2018), 'Long-necked Spiders' (used here), or 'living relics' (Karikó, 2013). These words can influence public attitudes and subsequent actions.

Results from the three word spider association testing suggest that the *Spider Super Hero Program* and *Create. Reflect. Connect.* contribute to shifts in perception of spiders (See Figure 7 for an example from the first *Spider Super Hero Program*). Themes that emerged from participant input included:

- If initial words in the “pre- /post-“ questionnaire were more arachnophobic or negative towards spiders (for example one participant’s initial words included “terrifying”), the responses in the follow-up responses were observably less so (ex: “beautiful”).
- If the initial words began neutral or arachnoplhilic in nature – for example “legs” – they often demonstrated a shift towards more descriptive words correlated with the specific spider species being highlighted such as “colorful” for programs including *Phoroncidia rubroargentea*.

Many English language dictionaries provide definitions of “Nature” as apart from versus a part of nature (see Definitions). Many scientists, naturalists, and writers have referred to early childhood experiences playing an important role in their relationship/perception of nature and shaping the course of their lives. It makes an impact how nature is depicted including the words used to describe animals such as spiders. There is a need for a new language for these times—a language describing Nature that can cultivate caring and connection as well as develop ways to re-couple knowledge creation with caring and responsibility.

Fieldwork requires another type of listening: a learning to listen like the spider in the center of her web…to take in the signs and information with all senses. From my early fieldwork studying the mating behavior of metallic blue and purple flea beetles in Costa Rica to my more recent research studying egg sac construction by female mason spiders, I have had to learn how to tune my body to be alert to cues and sensory information while staying very still as to not impact the sensitive animals I am studying. I practice how to be very patient and alert since what I am waiting to observe could happen at any moment and once it begins, I have to stay focused and attentive to fine details and record the ensuing events with careful attention for sometimes hours. To conduct this research, I am also up through the night into dawn and am observing the rhythms and movements of other species as they move through the land where I stand. These observations can then be used to better understand the interconnections in a given locality and time frame.

Measuring Impact

Success in science is often measured by peer-reviewed articles (impact value) and grant dollar amounts. In the arts, success is often measured by world premieres, successful completion of projects, and by works being acquired for permanent collections.

To that end, my work has been recognized in the following ways: scientific papers were published within peer-reviewed scholarly literature including a cover article; my artwork for a spider postage stamp was printed for use in Madagascar and also exhibited in the art shows *Science Peer Reviewed* and *We Deliver* (one artwork including this stamp was acquired for the Waskowmium collection); an image of *Misumina vatia,* a crab spider, is part of the teaching collection at the National Museum of Wildlife Art; another spider photo has been selected for the Museum of Comparative Zoology.

The works of Naess (1973) (as well as subsequent researchers such as Bragg (1996)) who developed the ideas of interconnectedness and Deep Ecology did so despite lacking evaluative instruments tools to confirm their hypotheses, although current

research efforts are now able to do so (Nisbet et al., 2009). The American National Academy of Sciences' 2018 consensus study report also states that measuring impact remains an issue common to many efforts at the junction of art and science (NASEM, 2018). My qualitative data suggests the promise of this interconnected approach to biodiversity education and stewardship, but to be able to reliably measure impact of this approach, new evaluative instruments need to be developed.

One way that the work will be successful is if participants take inspiration from the spiders and make unexpected connections that inspire new ways of thinking and create positive contributions towards stewarding our planet. This lofty aspiration remains difficult to measure. In some instances I was able to measure shifts in the perception of spiders as a result of my talks and educational programs by looking at responses to pre-post questions (see above). Other examples of self-reported change in perception of spiders include the following in response to the question posed at the *Spiders! Interconnectedness, Innovation & Stewardship* exhibit: "Are you thinking about something in a new way, and if so what?"

> *"The amazing diversity of our local spiders surprised me."* B.R., Jackson, WY
>
> *"Pollination of cacao by midges I had no idea! (Spent a lot of time on my boss's cocoa plantation in St. Lucia)* M. Q., Wilson, WY
>
> *"Spider silks surprising applications, the biochemistry/pharmacology of spider venoms, Native American lore regarding spiders, and the wonderful pure science of an in vitro investigation of the Mason spider. I'll think twice before I step on my next spider…."*
> F. H., Ph D, local; M. A. H., local
>
> *"The Science and Art interconnectivity-for communicating ideas like interconnectedness and protecting biodiversity.*" E.A., Seattle
>
> *"How artists interpret things we take for granted."* R. L., Logan UT
>
> *"Spiders—think twice now when asked to "take care of the spider!!"* L. K., Jackson, WY
>
> *"Yes. I think the theme of interconnectedness will stick with me. Also the medical and industrial applications of spider science."* Oakland, CA
>
> *"New appreciation for spiders!"* anon.

However, these measurements are self-reported in the moment and do not evaluate how long the perception is held and if in fact it has led to demonstrable action. I was unable to find or obtain a resource or instrument that can objectively evaluate responses and output results using a reliable scale that has its own integrity, nor could I find a third party evaluator to diminish impact of bias and make the findings more robust. Developing a tool that can accurately do this could be the focus of future work to confirm this interconnected approach meets its intended goals.

For future research, the question remains as to how to develop evaluative instruments to measure the impact. The National Academies of Sciences 2018 "Branches from the Same Tree" reports, "despite this measurable impact, the evidence to date supports the importance and further support and exploration of this integration of knowledge" (National Academies of Sciences, Engineering, and Medicine, 2018).

An additional way the impact might be measured is through receiving invitations into other fields to traverse professional boundaries, such as the invitation to the scholarship retreat with professors and practitioners from law to political science. The very nature of this approach positions it for what Fleming (2004) suggests are teams positioned for the possibility of breakthrough thinking and findings.

And even though this is not a formal measure, I often receive personal communications sharing shifts in thinking differently about spiders after educational programs, even years later. I have shared the praise poem I wrote about the mason spider and that poem has elicited responses ranging from an unexpected round of applause during a lecture with university students to inspiring a community poetry event for a spider festival in a state park. This anecdotally suggests that this poem has the ability to move and connect people in ways that scientific literature often does not.

In the process, I have interwoven biodiversity of spiders through an interconnected approach to lawyers, political science professors and neuroscientist, dancers/choreographers, collaborative governance practitioners, orthopedic surgeons, pastry chefs, and composers. By doing this, I can contribute to expanding the awareness of biodiversity and thinking in different fields.

Challenges

Reward System and Values

One challenge to this work that I have encountered is the current reward system, which values publications and other metrics. There is an attitude in the culture (in which I live) of more, more, more - more publications, more money, more power, more stuff. Environmental Studies Professor David W. Orr (2012) states:

> *"The plain fact is that the planet does not need more successful people. But it does desperately need more peacemakers, healers, restorers, storytellers, and lovers of every kind. It needs people who live well in their places. It needs people of moral courage willing to join the fight to make the world habitable and humane. And these qualities have little to do with success as we have defined it."*

How to question and develop and redefine a personal and societal concept of "enough" is a fundamental question for these times.

Whereas ecologists and educators McBride et al. (2011) call for Renaissance scientists to "*ensure that future leaders of the scientific enterprise are well equipped with the tools to conduct science as skilled collaborators, to address the key interdisciplinary questions that arise from complex environmental challenges facing society, and to better communicate their science with diverse audiences well beyond their scientific peers.*" p. 466. The Leopold Leadership Program was named in honor of the father of

wildlife ecology first to train and now to develop researchers who can "translate knowledge into action" (*Leopold Leadership Program*, 2018). As director Chris Field says, "*Collective leadership is critical in our transition to a sustainable planet; yet we underinvest in helping researchers to cross boundaries. The Leopold Leadership Program seeks to enable current scientists to lead systems change like never before."* Lubcenko reports that many first Leopold Fellows are now deans and in positions of power to help re-imagine and shift the culture of science to support this change (Gabrielson, 2015).

Because I collaborate with people from different disciplines, the reward systems that some collaborators might be held accountable to often do not include the type of work these collaborations embody, so my collaborators must find spare time and resources to participate. Also, these works often do not fit easily into standard publication formats. The recent emphasis from the US National Sciences Foundation to include "broader impacts" as a criteria for evaluation to successfully be awarded a grant demonstrates a change in thinking.

A challenge specific to the *Spiders!* exhibit in 2016 was that it occurred during the Berry Forest Fire which was located only a few miles from the UW-NPS Research Station. The fire-impacted visitation as people had to choose to drive toward/into a forest fire to experience the exhibit. It also presented curatorial challenges as we were right at the incident command center and it was uncertain if we were to be evacuated, so part of the exhibit was de-installed at the end of each day. In addition, there was an active bat population in the Berol Lodge, so each evening the works had to be covered with tarps and uncovered each morning before the exhibit opened (Cote et al., 2018).

Shifting Culture

In society there remains an opportunity to shift the value system and awareness of the dominant culture to include a connection with Nature as a basis for decision-making. When Chief Oren Lyons, Faithkeeper for the Haudenosaunee, was invited to the United Nations in Geneva, he asked, "Where is the chair for the eagle? Where is the chair for the bison?" (Pukan, 2016). In the subsequent decades, we as a people have not travelled that much farther in cultivating a widespread understanding of and respect for our interrelatedness.

The shifting of values and concentration of effort towards adopting a focus of academic knowledge creation towards addressing the foundational question of how to care for our planet remains a challenge, as this threatens the survivability of ecosystems, human societies, and many other organisms on earth. A more seamless approach to knowledge creation and application could unite the power of human imagination and available resources towards creating lasting and effective solutions. The scientific community, which tends to embrace a "technological" solution to humanities problems, has the opportunity to embrace this new approach using art as a way to solve problems and not see it as a threat to scientific objectivity.

Opportunities

Art and science allow us to see the world through different lenses. An interconnected approach allows us to bring them together to provide a possible pathway to align our efforts at this critical moment in human history, towards this moment in time, when humans are choosing which path the earth will take. This approach I'm presenting

provides a possible bridge or a pathway to help us come together to cultivate a sustainable balance on Earth where humans and nature can co-exist and thrive.

In wider society worldwide, people are rising up and voicing their concerns. Especially children. Youth around the globe are stepping out, for example speaking to the UN like Greta Thunberg (Lin, 2019), suing the American government (*News for Kids*, 2019), staging a strike in Canterbury (Mak, 2019) and testifying before the State House with handmade wildlife art (Scagliotti, 2019). Higher education and the institutions that support research have room to play an important role. Part of that role is shifting the focus of research from an anthropocentric lens to one that cultivates a caring connection and re-couples knowledge production with responsibility and reward systems that support these efforts for stewardship.

The China Dream project, led by MIT graduate Peggy Liu, works to steer the aspirations and impact of the lives of 800 million millennials in China towards a sustainable lifestyle (Dunn, 2016). Liu explains that her approach towards making these aspirations part of the social norm involves talking "to people's hearts and not just their heads; it's not just about technology or implementation or policies," she continues. "That's why we've increasingly turned to storytellers from a wide range of disciplines—musicians, artists, designers, video-game developers, comedians, faith-based leaders." (2016). The China Dream program aims to "reimagine prosperity" and reduce the environmental impact of China's growing middle class, which is expected to total 800 million people by 2025 (Dunn, 2016).

In Closing

At this critical juncture in time, there is a precipitous disruption between humanity and the rest of nature. An interconnected approach engages "hearts, minds, hands" that values making and creating which are often not part of teaching and learning in higher education within the field of conservation biology nor in decision making processes. By creating with our hands, humans activate and light up even more parts of our brain and body providing greater access and possibilities for making connections.

Taken as a whole, my research has formulated an argument for the need for not only deep disciplinary knowledge, but also for an interconnected approach that includes the arts as a part of knowledge creation and a way to connect people with each other and to the living world. It calls for nurturing creativity and human imagination in both training and practice in biodiversity education and stewardship while valuing traditional knowledge and putting this into action at this critical junction. Bringing art and science together allows us to see the world through a different lens and have a more complete picture. Skill building gives people the tools to work together to realize benefits for humanity and a healthy earth for future generations.

In this research, I have given many examples of how to bridge knowledge out into the world. This research recognizes the importance and value of the intimate interconnectedness of humans as part of nature and our environmental impacts that can be re-imagined and synthesized into beneficial action. An interconnected approach also provides the possibility to find imaginative and collaborative solutions to the interdependent challenges and opportunities facing biocultural diversity today and prepare the leaders of tomorrow with tools to meet them.

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Appendix A: Definitions

Biodiversity: As noted by van Weelie and Wals (2002), there are many meanings ascribed to the term "biodiversity." In the context of education, the term can be viewed as complex and considered poorly defined. For this study I will use the following as defined in the Stanford Encyclopedia of Philosophy (Faith, 2016):

> *"Biodiversity" is often defined as the variety of all forms of life, from genes to species, through to the broad scale of ecosystems (for a list of variants on this simple definition see Gaston 1996). "Biodiversity" was coined as a contraction of "biological diversity" in 1985, but the new term arguably has taken on a meaning and import all its own. A symposium in 1986, and the follow-up book BioDiversity (Wilson 1988), edited by biologist E. O. Wilson, heralded the popularity of this concept. Ten years later, Takacs (1996, p.39) described its ascent this way: "in 1988, biodiversity did not appear as a keyword in Biological Abstracts, and biological diversity appeared once. In 1993, biodiversity appeared seventy-two times, and biological diversity nineteen times". Fifteen years further on, it would be hard to count how many times "biodiversity" is used every day by scientists, policy-makers, and others."* (*2010 Biodiversity Target,* 2018).

Collaborative Governance:

> "*Collaborative governance refers to community and public policy decision making processes and structures that enable participants to work together to enhance their communities and shape sustainable public policy decision. Collaborative governance does this by engaging participants collectively and constructively across the boundaries of the public, private, and civic sectors to leverage the unique attributes and resources of each for the greatest impact. The collaborative approach to governance can encompasses any method, model or process that is deliberative and consensual including civic engagement and service, public engagement, collaborative network management, public consultation, multi-stakeholder collaboration, collaborative public management, dispute resolution, and negotiation."* (*UNGC*, 2018)

Conservation Biology:

> *"Conservation biology, said to be a "mission-oriented crisis discipline" (Soulé 1986), is a multidisciplinary science that has developed to address the loss of biological diversity. Conservation biology has two central goals: 1. to evaluate human impacts on biological diversity and 2. to develop practical approaches to prevent the extinction of species (Soulé 1986, Wilson 1992). The field seeks to integrate conservation policy with theories from the fields of ecology, demography, taxonomy, and genetics. The principles underlying each of these disciplines have direct implications for the management of species and ecosystems, captive breeding and reintroduction, genetic analyses, and habitat restoration."*(Gerber, 2010)

Education: UNESCO believes that education is a human right for all throughout life and that access must be matched by quality. The Organization is the only United Nations agency with a mandate to cover all aspects of education. It has been entrusted to lead the Global Education 2030 Agenda through Sustainable

Development Goal 4. The roadmap to achieve this is the Education 2030 Framework for Action (FFA)"

IN UNESCO's mission: "Education transforms lives and is at the heart of UNESCO's mission to build peace, eradicate poverty and drive sustainable development. UNESCO's view on biodiversity education (UNESCO, 1987) is demonstrated in following quotation:

> "*Along with the challenge of climate change, the loss of biodiversity is humanity's main battleground for sustainability. Biodiversity is the foundation for healthy ecosystems and sustainable human development. It touches on all aspects of our lives – from our security to our welfare, from our social relations to our health.*
>
> "*Mainstreaming biodiversity into education and learning is one of UNESCO's priorities. Education brings sustainability to development efforts; it is the way to shape new ways of seeing the world, new practices and behaviors and makes biodiversity conservation possible. Education for Sustainable Development (ESD) is practiced in order to preserve biodiversity and test options for reconciling preservation with the growth of human activities."* (*Biodiversity and Education,* 2017)

Environmental Art: "*Environmental art is art that addresses social and political issues relating to the natural and urban environment* " (*Environmental art,* 2018).

Health: "*Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" (Constitution of the World Health Organization, 2006).

Interconnectedness: The Oxford Dictionary defines interconnectedness as "*The state of being connected with each other*."*/'the interconnectedness of all things in the universe'/'a growing awareness of our global interconnectedness'/* (*Interconnectedness* [Oxford Dictionary]*,* 2018).

Oftentimes the term is applied to understanding global interconnectedness in terms of "the Interconnected Global Economy: Challenges and Opportunities" (Lagarde, 2013) or of humanity and focuses global interconnectedness or interconnectedness of humanity.

Though the academic term "interdisciplinary" is often used to describe efforts that combine multiple disciplines, I am intentionally using the word "interconnectedness" to be inclusive of those disciplines that are not yet considered within the academic framework as well as examining the spaces and connections between them. Interconnectedness gives us a way of thinking and a reminder of our connections with each other and the larger world around us.

Metaphor: From the Oxford Dictionary: "Origin: Late 15th century: from French métaphore, via Latin from Greek metaphora, from metapherein 'to transfer'."
1. A figure of speech in which a word or phrase is applied to an object or action to which it is not literally applicable.
2. A thing regarded as representative or symbolic of something else."

(*Metaphor* [Oxford Dictionary]*,* 2018)

Native Science:

> "'*Native Science' is a historic and simultaneously contemporary body of understandings and practices focused on perpetuating a dynamic yet sustainable relationship with the natural world. It is this understanding of 'relationships' that synergistically bind natural forces, human community and other forms of life that has formed the historic foundation for Indigenous people's ability to survive and even thrive in almost every habitat on Earth. An open exploration of the cultural history of 'Indigenous Science' offers perspectives and insights that can help us collectively work toward solutions at this time of global environmental crisis."* (Cajete, 2008)
>
> *"From my perspective, native science really is a body of knowledge that has been accumulated by a group of people, Indigenous people, through generations, that deals very specifically and is very much founded on how that group of people has developed an intimate relationship with the plants, the animals, the places in which they have lived. It is also how the communities have integrated that knowledge within themselves, how that knowledge has been expressed in their language, their art, their music, their dance and their practical technologies for living in places in which they have evolved. Interdependence is a principle that expresses itself in the context of native science.*
>
> *(Expressions can be seen in the life of an Indigenous group of people, the ways in which a group of people calibrates their agricultural cycle around key times of observation of the sun with regard to the equinoxes and solstices, how they understand when plants and animals are best to be harvested, when to go hunting, how to serve plants in certain kinds of condition for medicine and how to use those same plants, say for creation of shelter or as food. So there are many kinds of ways in which native science expresses itself in traditional native cultures. You almost have to be very specific in focusing on a particular group of people to be able to understand how the natural world is integrated in their life style and the expressions of cultures of those people.)*" (Racette, 2009).

Nature: In considering the term Nature, there are many variants (highlighting added for emphasis):

- Oxford Dictionary: The phenomena of the physical world collectively, including plants, animals, the landscape, and other features and products of the earth, as opposed to humans or human creations. (*Nature* [Oxford Dictionary], 2018)
- Collins Dictionary: Nature is all the animals, plants, and other things in the world that are not made by people, and all the events and processes that are not caused by people.
  (*Nature* [Collins Dictionary], 2018)
- Cambridge Dictionary: all the animals and plants in the world and all the features, forces, and processes that exist or happen independently of people, such as the weather, the sea, mountains, reproduction, and growth. (*Nature* [Cambridge Dictionary], 2018)

- Dictionary.com: the material world, especially as surrounding humankind and existing independently of human activities. (*Nature* [Dictionary.com], 2018)
- Wikibooks: Nature is everything that was not made by man (All human developments are summarized as culture) (*Nature* [Wikibooks], 2018).

In considering the multiple definitions of "nature" in both popular and academic writings, I agree with authors such as Saunders who points out "A fundamental challenge for many cultures is developing ways to talk about humans as a part of nature, not separate from nature" (Saunders et al 2006 p702).
Perhaps coining a new term to represent humans as a part of and not separate from other species and the environment is important to addressing environmental attitudes. Odenburgh (2016) notes, "environmental attitudes have changed over time—we value environmental goods and services less and less in the United States. Thus, we must focus on what people care about and focus on motivating them through these valuations."

While it is important to impact a cultural shift when societies see their own connection to and being a part of the natural world, could this lead to understanding the interconnections and lead to different stewardship decisions?

Additionally, while it is important to define how things are different from each other (in their uniqueness and what separates them one from other), it is also important to understand the connections: could a new linguistic term encompass and communicate both of these concepts? Perhaps the lack of this in the language is contributing to some societies growing disconnect from their natural environment.

Species: There are many ways to define a species. For the context of conservation biology, I will use the following concept as defined in Principles of Conservation Biology: Recommended Guidelines for Conservation Literacy from the Education Committee of the Society for Conservation Biology∗

> *"a species is considered a group of organisms that can actually or potentially interbreed with one another or a group of organisms that share common traits and common descent." Furthermore, "Species are not unchanging over time; rather, they evolve in response to the forces of selection, gene flow, and chance. The classification of an individual organism into a particular species may change over time, reflecting our developing understanding of evolutionary and ecological relationships."* (Trombulak et al., 2004).

Stewardship: For the context of this research I use the United States Environmental Protection Agency's definition of Environmental stewardship: "the responsibility for environmental quality shared by all those whose actions affect the environment" (*Environmental Stewardship*, 2016).