EXPLORING THE COMMUNICATION OF CLIMATE CHANGE SOCIOSCIENTIFIC ISSUES IN AQUARIUM EXHIBITS

by

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DEDICATION

To all the informal science educators, biologists, zookeepers, and scientists who stopped and took the time to talk to a little girl who was crazy about sharks. You fostered a passion for science where the formal science classroom could not.

Hail King Arthur! Long live the king!

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LIST OF ABBREVIATIONS

Abbreviation	Description
AZA	Association of Zoos & Aquariums
BIAZA	British & Irish Zoos & Aquariums
CC	Climate change
CITIES	Convention for International Trade in Endangered Species
EAZA	European Association of Zoos & Aquaria
ISE	Informal science education
ISI	Informal science institutions
IUCN	International Union for Conservation of Nature
SSI	Socioscientific issues
SSIF	Socioscientific Issues Framework
WAZA	World Association of Zoos & Aquariums

ABSTRACT

Anthropogenic pressures humans have placed on the planet create complex, socially embedded scientific problems that are not easily solved. Aptly known as socioscientific issues (SSI), these issues are often controversial because their open-ended nature is greatly influenced by the multiple socio-cultural dimensions and entities involved. As the environmental issues of today continue to grow, so too does the need for a more scientifically literate society. However, creating a science literate society is challenging when the average person spends less than 5% of their life in a formal science classroom. Reaching people in informal places they visit to learn about science is an important step toward improving scientific literacy. The socioscientific issues framework (SSIF) is an instructional approach used in formal classrooms designed to improve science literacy by engaging students in real-world science contexts, while also increasing development of questioning, argumentation, empathy, and moral reasoning skills. Because of its cross-disciplinary nature and societal impacts, this project explores using the SSIF as a lens for understanding how informal science institutions (ISI) communicate SSIs as part of their science education mission. To accomplish my research goals, first, I adapted the SSIF for exhibit design application in informal settings. Then, I used the updated SSIF to guide an exploration of in-person and virtual aquarium exhibits focused on communicating the science of climate change. Through a survey of 420 in-person exhibits across nine countries, I found only three in-person and one virtual exhibit featured climate change messaging throughout the exhibit while 30 in-person and 20

virtual exhibits mention climate change or a human-induced impact associated with climate change at least once. None of these SSI exhibits presented climate change science in ways that warranted being classified as representative of a holistic SSIF instructional approach. I documented patterns in exhibit communication approaches across aquariums. I found a disconnect between theory and implementation of best practices. This project provides insight into how existing exhibits in aquariums communicate the SSI of climate change as well as identifies what aspects of the SSIF can be found in those exhibits, contributing to this gap in the literature. SSIs are complex issues and while ISIs may want to present the issues such as climate change to visitors, they may not choose or be able to for a variety of reasons. The intention of my project is to bring to the surface the need for communicating climate change and other SSIs in contexts local and relevant for visitors. Incorporating the SSIF into the places people visit to learn science outside of the classroom (i.e., ISIs) has the potential to contribute to a science literate society, but only if exhibits are effectively designed.

I. INTRODUCTION

The world's oceans play a vital role in sustaining life on Earth. Our oceans produce 50-80% of the planet's oxygen, absorb 50-times more carbon dioxide than the atmosphere, and act as a regulator for the Earth's climate and weather patterns (National Oceanic and Atmospheric Administration [NOAA], 2018). A pillar in the world's economies, the marine resources provided by our oceans support the livelihoods and act as the main source of protein for over three billion people globally (NOAA, 2018). From islands of floating garbage and thinning sea ice to overexploited fish stocks and invasive species, the anthropocentric pressures caused by human populations has led to the creation of complex, socially embedded, scientific problems that are difficult to solve (Rand et al., 2010). Known as socioscientific issues (SSI), these problematic and often controversial issues are challenging to solve due to their open-ended nature and complex ties across social dimensions (Sadler, 2004; Zeidler & Keefer, 2003).

Climate change can be a particularly polarizing SSI (Chinn et al., 2020). Featuring politicians over scientists, the media's portrayal of climate change greatly influences public opinion and attitudes about the SSI (Chinn et al., 2020). While politicians argue about climate change over the nightly news (Chinn et al., 2020), extreme weather patterns impact the communities of the world (Herman, 2018). People often feel far removed from climate change because it is difficult to see the immediate effects of greenhouse gases released into the atmosphere (Clayton & Myers, 2015; Moser, 2010). What people fail to realize is how they may already be experiencing the impacts of climate change (Clayton & Myers, 2015; Herman, 2018).

Finding solutions to address SSIs such as climate change has increased the need for a more scientifically literate society (Roberts & Bybee, 2014). In a scientifically literate society, a person uses content knowledge that is consistent with the norms of the scientific community, has a basic understanding of how science works, understands what information counts as evidence and how to interpret that evidence, and recognizes connections between science and society (Roberts & Bybee, 2014). Ultimately, scientifically literate person uses science to make informed decisions in their daily life.

The Importance of Informal Science Institutions

Despite living in a technological-driven information age, where access to science information can happen with the swipe of touch screen or click of mouse, the need for a more science literate society only continues to grow. Recent headlines regarding the Covid-19 infodemic further shine a spotlight on this need (Gallotti et al., 2020). Creating more science literate citizens is challenging to do when less than five percent of the average person's life is spent in a formal science classroom (Falk & Dierking, 2010). Learning from the formal classroom alone is not enough to support lifelong science literacy (Falk & Heimlich, 2009). The bulk of a person's science learning stems from informal learning experiences that happen outside of a formal science classroom (Bell et al., 2009; Falk & Dierking, 2010). Informal Science Institutions (ISI) such as zoos, aquariums, and museums, are important contributors towards the science literacy of their communities (Bell et al., 2009). As one of the largest places people go to get science information outside of the formal science classroom, ISIs can augment lessons learned in the formal classroom and/or stimulate new science interest through hands-on, experiential learning opportunities they provide for their visitors (Falk &

Dierking, 2016). These learning experiences are important to science, technology, engineering, and mathematics (STEM) fields. Early exposure and prolonged engagement in the types of free-choice learning that happen at ISIs can greatly influence interest in science (Lin & Schunn, 2016), as well as retention in STEM degrees and careers (Cuddeback et al., 2019). With millions of people around the world visiting ISIs annually (Gussett & Dick, 2011), these institutions are tasked with providing unique science learning experiences in formats that are easy to comprehend and engaging.

The Purpose of Exhibits

One of the largest ways ISIs such as zoos and aquariums, reach visitors is through exhibits. Exhibits have the power to serve as a communication bridge, connecting visitors with science and the natural world through artifacts, organisms, and/or other resources that help visitors generate personal meaning (Bacher et al., 2007). Exhibits tell the cultural stories of our societies, acting as mirrors of what our communities deem as valuable and worth preserving (Veverka, 2011) and these stories can stand alone or be enhanced through the presence of an informal science educator. Ideally, exhibits move beyond providing information, grabbing visitor attention, provoking thought, and stimulating interest in the subject/issue presented through unique and creative ways (Beck & Cable, 2002; Tilden & Craig, 2009). Through careful planning and thoughtful design, exhibits have the power to increase visitor empathy and stir desires to engage in conservation action (Godinez & Fernandez, 2019). Exhibits can also be used to introduce and engage visitors in learning about SSIs (Clayton et al., 2014; Esson & Moss, 2010). While SSIs with an environmental focus are often mentioned in ISI exhibits (Idema, 2021

Chapter III), research as to how SSIs are communicated and the effectiveness of that communication is limited (Yun et al., 2020).

The Socioscientific Issues Framework in ISI

The Socioscientific Issues Framework (SSIF) is an instructional-based tool used by formal educators to engage students in science learning set in real-world contexts (Presley et al., 2013; Zeidler & Nichols, 2009). Engaging in SSIF-based learning creates scientifically literate citizens through the development of subject matter knowledge, intellectual reasoning, decision making, character and reflective judgement, argumentation, and moral reasoning (Zeidler et al., 2009). As a result of engagement, learners can become more inclined to participate in conservation, especially if the SSI of focus is environmental (Burek & Zeidler, 2015). The SSIF has the potential to be a valuable asset for teaching visitors about climate change and other SSIs in zoos and aquariums through its cross-disciplinary nature and the ability to enhance science understanding in real-world contexts (Nisbet, 2009; Sadler et al., 2016). However, the use of SSIF in ISIs is understudied (Yun et al., 2020).

Problem Statement

Effective conservation of the world's oceans requires scientifically literate citizens who understand and can navigate the social complexities surrounding climate change and other SSIs. Aquariums are important contributors to the science literacy of their communities through their ability to connect visitors with science and nature in fun and engaging ways. However, research on how they communicate SSIs through in-person and virtual exhibits is limited (Yun et al., 2020). Another issue surrounding SSI communication in ISIs are the many different terms used to describe SSIs (e.g., critical issues-based science, hot button topics, hot science, issues-based science, sociocultural science, science in contexts, wicked problems, etc.) (Yun et al., 2020). The variety in terminology makes finding appropriate literature to support ISI practitioners as they plan and design exhibits and programming challenging.

Purpose of the Research

Because of its cross-disciplinary nature and societal impacts, my research explores the use of SSIF as a lens for understanding how ISIs communicates SSIs to support their science education mission. To achieve my research goals, I adapted the SSIF for exhibit design application in informal settings, creating a shared language around SSI-based instruction for ISIs that is grounded in empirical research and theory. I then used the updated SSIF as a guide for exploring in-person and virtual aquarium exhibits that focus on the SSI of climate change.

Research Questions

The questions guiding my research are:

1. How do aquariums present climate change to visitors through their in-person exhibits and virtual exhibits?
    a) What SSIF characteristics are present in existing in-person and virtual aquarium exhibits about climate change?
    b) How do aquariums localize a climate change message for visitors through their in-person and virtual exhibits?
    c) How do aquariums make a climate change message relevant for visitors through their in-person and virtual exhibits?

2. What trends exist within interpretive exhibit design for presenting climate change impacts on marine/aquatic ecosystems?

Key Terms

Aquariums - zoos that house collections of aquatic and marine organisms in simulated, naturalistic habitats.

Exhibits - a combination of organisms and/or artifacts, themed content, and messaging on display for public viewing.

Informal science institutions (ISI) - a place or organization that provides opportunities and experiences for learning about science, technology, engineering, and mathematics (STEM) outside of a formal science classroom.

Socioscientific issues (SSI) - social issues that are often complex and controversial, tied to science.

Socioscientific issues framework (SSIF) - an instructional-based approach traditionally used in the formal classroom to engage students in learning science content set in real-world contexts.

Virtual exhibits - combination of themed content, messaging, and organisms arranged on an online platform, typically an ISI website, for public viewing.

Dissertation Style

I structure my research in a portfolio style (Crowther & Hill, 2011) using three publications as individual chapters that allow me to provide tangible evidence of what I have learned over the course of my Ph.D. experience. Chapter II of my dissertation serves as a conceptual framework for my studies. This chapter has been accepted for publication in the book, *Applying Learning Theories in Research Outside the Classroom: How*

People Learn Science in Informal Environments. In the chapter I discuss the components of the SSIF, adaptation of the framework for use in informal settings, previous applications of the framework in the literature, how I have applied the framework to my own research, and the SSIF's importance to research in ISI. Chapter III of my dissertation is an exploration into how aquariums communicate climate change through their in-person exhibits. In this chapter I use a SSIF checklist as a tool for gaining insight into how aquariums may already be using characteristics of the SSIF to communicate climate change messaging to visitors. Additionally, I explore how aquariums localize and make climate change messaging relevant for visitors through their exhibits, as well as identify existing trends found across exhibits. Chapter IV of my dissertation examines how aquariums communicate the SSI of climate change through virtual exhibits. Applying the research questions from Chapter III to virtual exhibits, I use the SSIF checklist to understand what climate change messaging looks like in a different type of exhibit space. Chapter V summarizes the key takeaways from Chapters III and IV and discusses what my findings mean in the scope of research on ISI exhibits. Chapter V also discusses potential implications for practice as well as next steps for my research.

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II. SOCIOSCIENTIFIC ISSUES AND THE POTENTIAL FOR FOSTERING ENGAGEMENT THROUGH EXHIBITS

Jenn L. Idema & Kristy L. Daniel

Introduction

With declines in species and natural resources, surges in pollution and climate changes (Cafaro, 2015), the anthropogenic pressures humans have placed on the Earth has led to the creation of complex, socially embedded, scientific problems that are not easily solved. Aptly known as socioscientific issues (SSI), these issues are often controversial and largely problematic because their open-ended nature is influenced by the multiple socio-cultural dimensions and entities involved (Sadler, 2004; Zeidler & Keefer, 2003). Finding solutions to address SSIs has increased the need for a more scientifically literate society (Roberts & Bybee, 2014), however, creating this type of society is challenging. Less than five percent of the average person's life is spent in a formal science classroom (Falk & Dierking, 2010), and the need for reaching people outside of the classroom in the spaces they frequent to learn about science continues to grow (Bell et al., 2009; Yun et al., 2020).

More than 700 million people worldwide visit zoos and aquariums each year, placing them in the position to educate and connect their visitors with science information and the natural world (Godinez & Fernandez, 2019). Zoos and aquariums can direct the experiences of their visitors through, "real objects, people, places, or animals; learning is voluntary and is stimulated by the needs and interests of the learner; and they provide a very learner-centered experience which involves exploring and examining, making choices, making personal connections, developing one's own way of understanding, and controlling one's own learning environment," (Packer & Ballantyne, 2010, p 25). Essentially, informal science institutions (ISI) function as mirrors of our societies. They reflect back to their visitors the world's natural histories and cultures, preserving what our societies believe to be worth saving, as well as presenting visitors with information about the current issues impacting today's societies in formats that are easy to comprehend and engaging (Bell et al., 2009). As a result, ISIs are prime places for presenting and learning about SSI as through artifacts and/or species, these institutions can illustrate and connect visitors with the impacts of SSI on different species, the environment, and society.

One of the largest ways ISIs such as zoos and aquariums reach visitors is through exhibits. Once defined as collections of species housed in glass tanks and barred cages (Hutchins & Smith, 2003; Patrick & Tunnicliffe, 2013), the exhibits of the 21st century look vastly different than their predecessors. The exhibits of today mimic natural habitats, where visitors can observe species interacting with each other and engaging in natural behaviors similar to how these species could be viewed in the wild (Patrick & Tunnicliffe, 2013). This type of exhibit design in and of itself sends a message to the visitor that habitat conservation is integral for species (Hutchins & Smith, 2003). Exhibits strengthen conservation messages further through the use of interpretive signage and interactive hands-on components visitors can manipulate to learn more about an issue and/or the species housed within the exhibit (Bruce & Bryant, 2008; Serrell, 2015; Shani & Pizam, 2010). Through engagement with the exhibit, visitors can generate personal meaning for the information and species presented (Bacher et al., 2007; Beck & Cable, 2002). Beyond initial costs and maintenance, exhibits can also be one of the most cost-effective ways ISIs can engage visitors (Bitgood, 1989; Graham, 2020) as visitors can access information, interact with species, and learn science with or without an informal science educator being present. The zoos and aquariums of today strive to create and uphold the image that they are centers for conservation, education, and learning, claiming success through the number of educational experiences and opportunities to connect with the natural world they offer to visitors (Carr & Cohen, 2011; Patrick & Tunnicliffe, 2013). Exhibits play a large role in these educational experiences and opportunities.

Socioscientific issues and exhibits

Traditionally used in the formal classroom, the Socioscientific Issues Framework (SSIF) is an instructional-based framework that utilizes concepts from the fields of developmental psychology, sociology, and philosophy as a way to describe the processes in which an instructional resource facilitates learning about science content that is embedded in socially relevant situations (Zeidler et al., 2009). The SSIF examines the epistemological growth of the learner and the potential for development of character as they engage with socioscientific-based instruction (Macalalag et al., 2019; Zeidler et al., 2009). The SSIF's main purpose is to create scientifically literate citizens who can use evidence-based scientific content knowledge to make morally conscientious decisions about real-world SSIs (Zeidler et al., 2005). It is important to distinguish between a SSI and SSIF, in that SSIs encompass presenting or discussing issues, but may not follow all of the defining characteristics of the SSIF. Through meaningful discussions, debates, and argumentative thinking, the SSIF is designed to aid those who engage with it in thinking about the complex science issues our societies face, and how those issues personally relate to them.

SSIs with an environmental focus are often relevant to and integrated into zoo and aquarium exhibits. Common SSIs found in ISI exhibits include pollution, invasive species, illegal wildlife trade, overharvesting of natural resources, destruction of habitat, climate change or an impact attributed with climate change (Idema, 2021 Chapter III & IV). However, these issues often appear as only a brief mention buried deep within exhibit interpretation or on stagnant signage, causing the SSI to seem more like an afterthought or a tangential connection to the exhibit message and science content conveyed (Idema, 2021 Chapter III & IV; Yun et al., 2020). While acknowledgement of a SSI is a step in the right direction, the SSI must be integrated in a meaningful way following the SSIF if the goal is to have visitors engage with SSIs at the levels needed to foster positive conservation actions (Zeidler et al., 2009)—supporting the mission of most ISIs. Instead of just introducing a SSI in an exhibit and expecting visitors to be able to navigate its complexities on their own, the SSIF is a tool designers can use to create SSI integrated exhibits supporting visitor exploration of science content, understanding the viewpoints of different stakeholders, confronting personal bias, as well as opportunities to formulate new perspectives.

Given that we already know SSIF instruction in the formal classroom is effective in engaging students in science learning grounded in real-world contexts (Eastwood et al., 2012; Herman, 2018; Kinslow et al., 2019; Sadler et al., 2016), we can expect that exhibits at ISIs, particularly zoos and aquariums, would be strengthened by using the SSIF. Informal science institutions may even be suited to better illustrate SSI impacts on nature than the formal classroom through their ability to provide greater opportunities for emotional experiences that enhance appreciation for species (Prevot &

Clayton, 2018). For example, an aquarium can create a permanent exhibit inviting visitors to explore the SSI of marine pollution through the eyes of a sea turtle. While such an interaction may technically be possible in a formal classroom, it is incredibly difficult to achieve at this scale and would likely be cost prohibitive. Furthermore, adapting the SSIF as a tool for ISI exhibit design can help create a shared language around SSI instruction grounded in empirical research and theory. Currently, there are many different terms for SSIs (e.g., critical issues-based science, hot button topics, hot science, issues-based science, sociocultural science, science in contexts) making it difficult to find appropriate literature to support ISI practitioners plan and design exhibits and programming (Yun et al., 2020). The SSIF has the potential to ensure ISIs are able to navigate the complexities of SSIs and use SSI as a way to open dialogue about difficult topics.

The Socioscientific Issues Framework

The SSIF has successfully been used in the formal science classroom to engage students in science learning (Sadler, 2011), while increasing their science understanding through the development of skills like questioning, argumentation, empathy, and moral reasoning (Sadler & Zeidler, 2005; Zeidler et al., 2009). The SSIF can be thought of as a series of concentric circles. At its core, the SSIF is composed of three main parts centered around a particular SSI – *Design Elements*, *Learner Experiences*, and *Teacher Attributes* – which are influenced by social constructs and key players found within the *Classroom Environment* and *Peripheral Influences* (i.e., the school/district, local and regional communities, and state/national policies) (Presley et al., 2013). Next, we discuss the characteristics for each piece of the SSIF in more depth.

Design Elements

Four essential features make up the *design elements* component. The first is the need to identify a compelling SSI rooted in the institution's science curriculum to build instruction around it (Presley et al., 2013). Second, the SSI needs to be presented at the beginning of instruction as opposed to an ending thought that follows the lesson. Presenting the SSI up front provides a grounded, real-world context for the learner to think about as they explore the different aspects and key players involved in the issue (Presley et al., 2013). Third, the lesson should provide scaffolding opportunities (e.g., Shabani, et al., 2010) that promote and lead to higher order practices (Anderson et al., 2001) such as argumentation, reasoning, and decision making (Presley et al., 2013). Finally, the lesson will ideally provide the learner with a culminating experience that helps the learner to synthesize and integrate new knowledge they acquired about the SSI with prior knowledge and experiences (Presley et al., 2013). Design elements set up critical guidelines for presenting SSI-based lessons that support learner experiences.

Learner Experiences

Learner experiences are a crucial part of the SSIF as they describe the involvement, interactions, and exposure learners experience as they engage with SSI-based instruction. Within the SSIF, learners need to be provided with opportunities to engage in higher order practices that involve but are not limited to reasoning and argumentation, as well as decision making (Presley et al., 2013). Learners should also be presented with opportunities where they can confront scientific ideas, theories, and misconceptions related to the SSI being studied. As part of their experience, learners have opportunities to collect and analyze scientific data pertinent to the issue and explore the different social dimensions associated with it (Presley et al., 2013). Additional recommended *learner experiences* include engaging learners with ethical aspects surrounding the issue studied, as well as consideration towards appropriate nature of science themes (Presley et al., 2013). Learner experiences call to attention needed cognitive pieces within SSI interactions crucial for supporting higher-level processing.

Teacher Attributes

In addition to *design elements* and *learner experiences*, there are important characteristics a teacher should exhibit to help ensure that their SSI lesson is effective. First, the teacher must be familiar with the SSI being presented. This familiarity needs to include a background knowledge of relevant science content and an awareness of the social dimensions (e.g., political, ethical, economic) connected to the issue (Presley et al., 2013; Zeidler et al., 2009). Second, teachers are also expected to act as both a facilitator and a learner, placing themselves in the position of a knowledge contributor on the issue as opposed to the sole authority. Third, teachers should be flexible and to some degree be comfortable with improvisation when handling the possible uncertainties that arise from using SSI-based instruction in the classroom. Because of the open-ended nature of SSIs, classroom discourse will not always follow a predictable pattern. Therefore, teachers who are adept at capitalizing on the opportunities of uncertainty are more effective at SSI-based instruction (Herman et al., 2018; Presley et al., 2013; Zeidler et al., 2011). Teacher attributes form the ideal baseline for how to help educators act as model learners in SSI-based instruction that is important for helping to set the tone for collective learning.

Classroom Environment

To create an effective SSI *classroom environment*, teachers need to start by setting high expectations for learner participation. Without learner participation, there is little chance that thought-provoking, higher order learner experiences will occur (Presley et al., 2013). High learner participation is more likely to happen if the learner views the classroom environment as a safe place to share and discuss their ideas about the SSI being studied (Presley et al., 2013). Hand-in-hand with the need to feel safe sharing in the classroom is the importance of respect. SSIs are often controversial (Zeidler et al., 2005), and the discussions that occur through engagement with SSIs can be difficult due to their polarizing nature. Therefore, both teachers and learners must respect each other and the differing perspectives that discussing a SSI can bring (Presley et al., 2013). There are many ways teachers may approach creating a safe classroom space that cultivates mutual respect (e.g., Harless, 2018; Robinson & Kakela, 2010). To help ensure classroom environments have high learner participation and that learners feel safe sharing, teachers can provide ample opportunities for collaboration amongst learners. Collaboration serves as a way for learners to build trust amongst each other and significantly influences student buy-in for participation (Presley et al., 2013). The learning environment is a critical consideration for SSI instruction as it influences the emotional connections to the content and can indirectly engage or disengage the learners.

Peripheral Influences

Entities beyond the classroom environment, *peripheral influences*, can also influence SSI instruction. Influences such as administrative personnel, school board, surrounding community members, regional, state, and/or national policies can dictate the who, what, when, where, and how often SSI are used in the classroom (Herman et al., 2018; Presley et al., 2013; Zeidler et al., 2011). Developing strategies that provide support and encourage teachers as they create and/or incorporate existing SSI curricula into their classroom environments is essential for successful SSI-based instruction (Presley et al., 2013). Access to quality existing curricula as well as supporting materials is also necessary for successful SSI-based instruction. Many teachers do not have the time, experience with, and/or confidence in creating their own SSI-curriculum (Bossér et al., 2015), therefore the SSIF encourages schools and districts to provide their educators with existing high-quality curricula that are flexible, support, and encourage SSI instruction in the classroom (Presley et al., 2013).

The different communities (e.g., churches, scout groups, neighborhoods, organizations, ISIs, and regional government) that are a part of and encompass a school district often influence what is taught in the classroom. When community members believe a SSI is not appropriate for the classroom, they can pressure teachers and administrators to remove the lesson or avoid the topic in the classroom (Presley et al., 2013). To help alleviate community pressure, teachers and administrators should familiarize themselves with local issues and viewpoints, to address community concerns, should they arise. Arranging meetings with parents and community members to explain the need for teaching a SSI creates transparency providing peace of mind, while avoiding the spread of misinformation (Presley et al., 2013).

State and national policy often govern science curriculum taught in the classroom. Current science education reforms reflect a movement centered around student evaluation, teacher accountability, and a standardized science curriculum (e.g., Next Generation Science Standards [NGSS]). The likelihood that SSI-based instruction will be affected by these movements is almost certain as teachers may be disinclined to incorporate an SSI-based lesson if they think it strays too far from the curriculum objectives outlined in their teaching evaluations (Presley et al., 2013). As a result, it is imperative that teachers and curriculum developers work together to create SSI content and lessons that are usable in the classroom and align with state and national standards (Presley et al., 2013).

Adapting the SSI Framework for ISI exhibit design

The SSIF is a useful lens for exploring teaching and learning practices in science, technology, engineering, and math (STEM) (Chowdhury et al., 2020; Herman et al., 2018; Presley et al., 2013; Sadler, 2011; Yun et al., 2020; Zeidler et al., 2009) given the cross disciplinary nature of STEM content and societal impacts of the content. Given that so much of STEM learning takes place out of formal classroom environments (Falk & Dierking, 2010), it would make sense to apply the SSIF to STEM learning in these informal educational environments. However, the language used to describe the original SSIF components is not fully inclusive of the various types of learning environments typically found in ISIs. For example, because the original SSIF is classroom-based, much of the literature focuses on the role of the teacher as they facilitate learning about SSI in a formal learning environment (Presley et al., 2013). However, in ISIs educators are often not present, therefore, it is up to an exhibit to fulfill the learning environment role for visitors. To make the SSIF more inclusive of informal learning environments, resources, and experiences, we have updated the language (Figure 1) of the core characteristic known as teacher attributes to instructional resource attributes, changed classroom environment to education environment, and provided updated descriptions for how SSIF components may be applied to exhibit design in ISIs. We also include exhibit and interpretation design principles (Tilden & Craig, 2009; Veverka, 2011) to address exhibit needs in design elements that are not found in formal classroom learning.

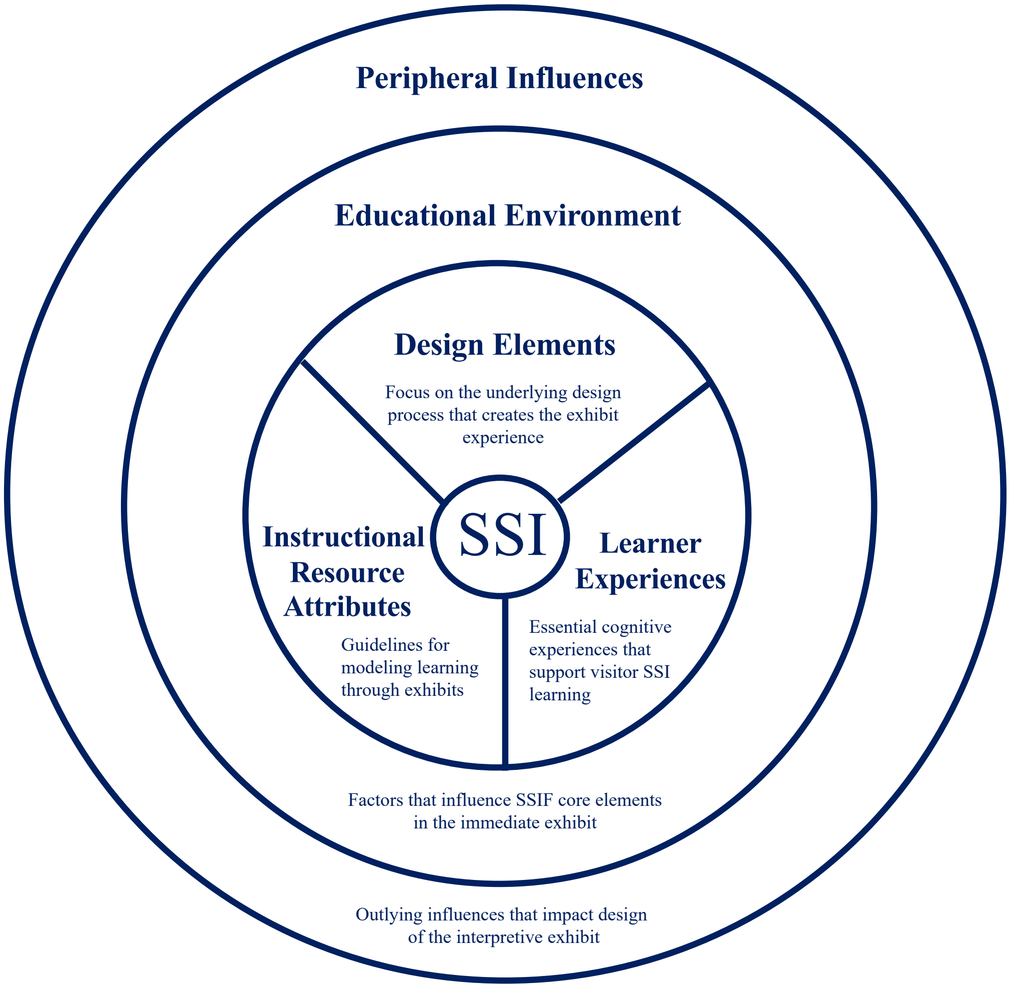

Figure 1. The Socioscientific Issues Framework core aspects for exhibit design. In the SSIF for exhibit design, teacher attributes becomes instructional resource attributes, the classroom environment becomes the educational environment, and characteristics of these aspects reflect how an exhibit can take on the role of instructor when an educator is not present. Adapted from “A Framework for Socio-scientific Issues Based Education,” by M. L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26-32.

Design Elements in ISI exhibits. In this revisited SSIF, design elements still provide critical guidelines for presenting SSI-based education messaging to support learner experiences. However, in exhibit-based ISI contexts, these elements are more focused on the underlying design process that led to creation of the exhibit experience.

SSI-based instruction, whether facilitated through an exhibit, program, or curriculum, features a relevant social issue connected to science. Without a foundational educational message built around a SSI, instruction is not classified as SSI-based; but instead the instruction merely includes a SSI example (Presley et al., 2013; Yun et al., 2020; Zeidler & Nichols, 2009). Distinguishing between the two types of instructional structures is important as they each serve a different educational role and can have different impacts on learner engagement. Developing an entire exhibit using the SSIF has more potential for visitor engagement over one that briefly mentions a SSI in context with other science information (Everett & Barrett, 2009; Serrell, 2020; Veverka, 2011; Yun et al., 2020).

The content and the messaging should align with the institution's mission and goals, as well as state and/or national education standards. Much like an SSI-based classroom lesson (Herman et al., 2018; Presley et al., 2013), the SSIF suggests that visitors are introduced to the SSI early and have it integrated throughout the exhibit message. Such integration of the SSI would make the intention of the exhibit's purpose clear for the visitor. For example, aquarium exhibits that mention climate change often present the issue in the form of one or two sentences on a sign describing how climate change impacts a particular species such as coral or penguins (Idema, 2021 Chapter III). This issue is treated almost as an afterthought because the information tends to be buried within husbandry information, fun facts about the species, and Convention on International Trade in Endangered Species (CITES) status (Serrell, 2015; Yun et al., 2020). In exhibits that use video screens as signage, climate change is often the last screen that appears for 30 seconds or less in a five-minute video/slideshow (Idema, 2021

Chapter III). Given the average amount of time spent at an exhibit (just under 4 minutes; Price et al., 2018) varies dramatically from visitor to visitor pending their interest, group type, and motivation (Bell et al., 2009; Falk et al., 2007; Serrell, 2015), many visitors may be missing out on climate change information as it flashes by on a screen. Instead, a climate change exhibit may be more effective if it incorporates interpretation principles (Tilden & Craig, 2009) to ensure its message is grounded in relevant, real-world contexts that introduces, informs, and helps shape visitor thinking about the different socio-scientific dimensions tied to the issue (Clayton & Myers, 2015; Presley et al., 2013; Yun et al., 2020). Exhibit messaging should also move beyond the presentation of science facts (Tilden & Craig, 2009) to content that has scientific concepts localized and made relevant for the visitor (Melber, 2007; Skydsgaard et al., 2016; Yun et al., 2020). Hence, the implementation of the SSIF is a logical fit for such ISI settings.

Just as scaffolding opportunities that lead to higher order thinking must be provided for SSI-based instruction in the formal classroom (Anderson et al., 2001; Herman et al., 2018; Presley et al., 2013; Sadler, 2011; Zeidler et al., 2009), so too should these opportunities be a part of SSI-based exhibit design. Scaffolding for SSI-based exhibits can come in many forms (e.g., Hints [Zurek et al, 2014]; Prompts [Siegel, 2007]; Overarching thematic questions [Boche & Henning, 2015]). For example, an interactive exhibit could stimulate visitor thinking by embedding prompts in signage to help adults encourage dialogue and debate between their visitor group and/or other visitors (Krange et al., 2019). Ideally, scaffolding will ultimately help visitors analyze different perspectives associated with the SSI as they work towards forming their own ideas about the issue (Presley et al., 2013; Yun et al., 2020). Ultimately, the visitor's exhibit experience should culminate in opportunities for reflection, practice, and the desire to take action.

One element missing from the original SSIF is the consideration of cognitive load of the SSI lesson. Interpretive exhibits vary in their cognitive load–the amount of physical and psychological time and energy an exhibit requires a visitor to expend as they interact with the exhibit and elements (Veverka, 2011). Regardless of motivation for a visit, learners enter an ISI with a set cognitive level of 100%. As they move through the ISI, this level reduces as the learner expends cognitive energy interacting with the information and components found within exhibits (Veverka, 2011). Visitor interest in an exhibit begins to drop the more they are saturated with information and stimuli (Veverka, 2011). Lower cognitive load exhibits are more passive in nature and may be glossed over by visitors without them retaining any content. Higher cognitive load exhibits are extremely interactive, requiring the visitor to expend more mental and physical energy which causes the visitor to reach mental fatigue faster. Interacting with multiple high cognitive load exhibits in a row can end with the visitor leaving prematurely (Veverka, 2011). A SSIF exhibit has the potential to be more cognitively taxing for learners because of the cross and interdisciplinary nature of the contexts. Underloading or overloading a lesson or ISI exhibit could potentially interfere with the learner experience and hinder any learning outcomes.

Learner Experiences in ISI exhibits. In any SSI-based instruction, the learner needs to engage in essential experiences related to the SSI presented, allowing them to engage in higher order thinking and practice, confront prior ideas, collect and analyze related scientific data, and navigate the complex sociocultural dynamics of the issue

(Presley et al., 2013; Yun et al., 2020). Engaging visitors in higher order thinking and practice through an exhibit can be achieved through games or role play, or through the use of prompts to foster dialogue or provoke thinking (Idema & Patrick, 2019; Krange et al., 2019; Silseth, 2012; Skydsgaard et al., 2016; Tilden & Craig, 2009). For example, a SSI-based exhibit focused on sustainable fishing could assign visitors with different roles (such as fisherman, restaurant owner, biologist, etc.) as they enter the exhibit. By having visitors play out how different stakeholders may act in a given scenario, they are provided with a way to engage with the content using a novel perspective. In the formal classroom, learners collect and analyze scientific data as part of their experience (Presley et al., 2013), however this may not be feasible in every SSIF exhibit. Instead, ISIs can provide visitors with takeaways such as packets (Marty, 2020), mobile applications (Delen & Krajcik, 2017; Soller et al., 2014) and/or QR codes that provide information and access to community science and conservation projects they can participate in. Participating in community science and conservation projects can help solidify knowledge gained from interacting with the exhibit, extending the lesson and visitor motivations for action (Ballantyne et al., 2011). With few exceptions, SSIF learner experiences are comparable in any learning environment, formal or informal.

Instructional Resource Attributes in ISI exhibits. Teacher attributes serve as a baseline guide for shaping how educators can serve as model learners in the original SSIF. However, in ISI settings, teachers are not a common player and instead interpretive exhibits often serve as the primary facilitator of science learning for visitors (outside of their own visitor groups) (Patrick & Tunnicliffe, 2013). As such, in this modified SSIF, we need to update how we view and describe *teachers* in order to be more inclusive of the available instructional resources in both formal and informal learning environments. *Instructional resource attributes* in this modified SSIF share many of the same descriptions as the original teacher attributes previously described.

During the planning phase of a SSIF designed exhibit, designers need to be familiar with the SSI that will be presented along with related relevant science content knowledge and the social dimensions tied to the issue (Presley et al., 2013; Zeidler et al., 2009). In ISI settings, the context surrounding the SSI may be more creatively expressed or integrated than a teacher might have the opportunity to elaborate upon in a formal classroom setting. While in-person teachers or interpreters have the luxury of acting as a facilitator and a learner in SSIF, this step can be a challenge when considering the role of an ISI exhibit. In order for an exhibit to avoid serving as a sole authority on an issue, exhibits must be designed in a manner that allows learners to interact and engage with the content and access prior ideas brought with them. Thus, exhibits should not rely on text heavy signage, but rather present foundational information required to understand scientific concepts involved with the SSI and leading into interactive components, such as the scaffolded activities described prior. ISIs can also leverage family units or learner groups that visit exhibits and find ways to encourage parents or advanced peers to help scaffold dialogue. Offering material that is more familiar to adults helps them ask more conceptual questions to their accompanying children (Melber, 2007). The third component is the most challenging adaptation to shift from a teacher to an exhibit. Again, in-person teachers and interpreters have the luxury of being flexible and integrating improvisation into their instruction, however exhibits are a more static feature in ISIs (Yun et al., 2020). Still, exhibits can maintain a level of flexibility through their ability to be regularly and easily updated and revised by designers. As such, new SSIF exhibits should be constructed with regular revision in mind, through direct, electronic, or supplemental resource updates. This revision is beyond regular maintenance, but rather an ability to update content, alter interactive activities and prompts, and transform dialogue topics in order to leverage current events, prior visitor interactions if possible, and changes in how we consider the SSI. We note that flexibility may come with associated costs that need to be considered by ISIs, either through higher upfront costs to support updateable technology or back-end costs to fund exhibit revisions.

Educational Environments. Expanding the SSIF to both include informal *educational environments* also expand the types of audiences considered as learners. While in a classroom setting, most students are required to attend and participate. Additionally, the teacher will be more informed as to the likely prior knowledge of their students given standardized learning objectives within the K-12 curricula. However, in ISIs, learners may represent one of five types of audiences: explorers, facilitators, professional/hobbyists, experience seekers, or rechargers (Falk et al., 2007) and come with larger variance in their prior knowledge. A way to reach all visitors regardless of their varying prior knowledge is to localize the SSI (Yun et al., 2020; Zeidler, et al., 2009) and draw explicit connections to help make the content relatable (Pedretti, 2004; Tilden & Craig, 2009). Given the variety of visitors to any given ISI, it can also be difficult to identify an appropriate level of expectation for learners. In our modified SSIF, we suggest that exhibits offer multiple levels of objectives to better attend to the needs of the learners, in terms of both types of audience and age range. It is still appropriate to push visitors to apply higher order thinking skills as an expectation. Teachers also have more control in formal classrooms vs informal education settings to create safe spaces and mutual respect. Being explicit about cultural appropriateness in how SSIs are presented is one way that ISIs can create these spaces. Encompassing cultural diversity in exhibits, through examples or stories, and designing exhibits in a manner that allows visitors to develop their own educated opinions without judgement, are other ways to show respect for visitors.

Peripheral Influences. Consistent with the original SSIF used in formal settings, *peripheral influences* such as administration and surrounding communities often influence SSI instruction in ISIs (e.g., Reyes, 2020). For example, Administration contributes to SSIF-based exhibit design success by facilitating access to relevant resources supporting exhibit development. Surrounding communities influence programming and exhibits in ISIs much the same way as they can impact classroom curriculum (Maynard, 2018; Patrick & Caplow, 2018). Unlike in formal settings, ISIs are influenced by funders, whether private contributions, grants, and/or visitors' entrance and program fees. If there is no community support for an SSI, then inclusion of such an issue within an exhibit may negatively impact revenue generating potential of the ISI through visitor protest or funding rejections (e.g., Koster & Schubel, 2007). Thus, there is a need to promote community support and willingness to engage in exploring perspectives to relieve pressures surrounding polarizing SSIs (Maynard, 2018; Presley et al., 2013). Exhibit designers and ISI administration can prepare themselves for possible pushback from communities by familiarizing themselves with local issues and the differing viewpoints (Presley et al., 2013). ISIs could even involve different businesses and organizations within communities in the planning process (Christensen et al., 2016;

Pirani, 2011) giving community members a voice in how SSIs impact them. By explicitly connecting a SSIF exhibit to local communities, ISIs increase the likelihood for community buy-in and deepen the relevance of SSIs for visitors. Additionally, ISIs could consider hosting previews of an SSIF exhibit to address potential community concerns (Yun et al., 2020).

ISIs are indirectly influenced by the same standards as used in formal educational environments given that most ISIs offer field trip programs for neighboring school districts as part of formal-informal educational partnerships. As such, ISIs are still bound to standards-driven considerations when developing educational materials, including exhibits. Ownership of the ISI can also influence focus on SSI within exhibits. While some ISIs are state or federally managed, many ISIs are privately owned through non-profit foundations or corporations, with a few belonging to publicly traded companies. Thus, ISIs are not as restricted by government policies in the same ways as formal education. Instead, ISI's tend to be more governed by accrediting boards (e.g., American Alliance of Museums [AAM], Association of Zoos and Aquariums [AZA], European Association of Zoos and Aquaria [EAZA], etc.) that require them to meet and maintain industry standards for education (AZA, n.d.).

Schools have Individual Educational Plans to support students with accessibility issues, but ISIs do not often have such formal structures in place and must consider accessibility needs (i.e., blind, deaf, hearing impaired, autism spectrum, physical access), in all exhibit and programming design. SSIF exhibits may involve adaptive tools that can be requested upon entering an ISI to assist visitors' experiences. Designers may also choose to highlight individuals in SSIs that represent members of different genders, and/or come from a mix of cultures, races, and ethnicities (Dawson, 2014). There is power behind seeing diverse role models engaging in STEM activities.

Application in the Literature

Previous implementation of SSIF in informal settings is understudied (Yun et al., 2020) and lacking in empirical research (Burek, 2012). While prior research has found ISIs may use a SSI to begin to communicate about science and conservation, they do not all utilize the SSIF to build instruction (Yun et al., 2020). There is a need for more aquariums and science centers to use SSIF programming and exhibits to improve scientific relevance (Koster & Schubel, 2007; Yun et al., 2020) and create a more scientifically literate society (Yun et al., 2020).

Much of existing research (e.g., Bandelli & Konijn, 2015; Pedretti, 2004; Skydsgaard et al., 2016) examines characteristics of design elements found in the SSIF through exhibits and programs. Museums can foster scientific citizenship through activities allowing the public to engage with scientists, participate in debate and dialogue forums, and special programming targeted for adult visitors (Bandelli & Konijn, 2015). SSI exhibits can also challenge visitors in intellectual and emotional ways by personalizing and increasing the relevancy of exhibit messaging (Pedretti, 2004). Furthermore, there is evidence that SSI exhibits can stimulate dialogue and debate amongst visitors (Pedretti, 2004; Pedretti, 2007). Implementing four exhibit design principles (curiosity, challenge, narratives, and participation) support SSI facilitation of visitor reflection and discussion (Presley et al., 2013; Skydsgaard et al., 2016). Curiosity can support the SSIF goal of creating compelling messages promoting discussion and reflection. When visitors are curious about a subject, they are more likely to seek out additional, relevant content to further their exploration of the content. Challenge is a way to create opportunities for visitors to reflect on their reactions and previously held ideas about the science information they encountered. Narratives involve using stories to make science contextualized, relatable, and relevant. Participation through elements such as manipulatives (Price et al., 2018), like touch screens and physical artifacts, can facilitate increased visitor engagement at an exhibit.

The other elements of the SSIF discussed in previous research include instructional resource attributes (Cameron, 2012), and the educational environment (Christensen et al., 2016; Esson & Moss, 2013) in ISI exhibits and programs. Museums are viewed as places that communicate science from differing perspectives, do research, and provide visitors with information on actionables and resources aiding behavior change (Cameron, 2012). As such, museum exhibits that integrate scientific information with real-world connections help visitors understand broader notions about SSIs like what being healthy means (Christensen et al., 2016). Even if ISI exhibits include "disturbing" illustrations and content as part of temporary exhibits, visitors tolerated the messaging and expressed comfort with reflecting upon and indirectly debating these issues with other visitors using message boards and post-it notes (Esson & Moss, 2013). While the aforementioned research explored elements of the SSIF, none looked at the SSIF in ISI exhibits from a holistic approach.

Thus far, studies investigating the SSIF in a holistic manner have used a place-based approach to informal learning but have not explored the SSIF in ISI exhibit settings. Currently, holistic investigations of the SSIF offer implications suggesting that engagement with SSIF instruction in informal environments may lead to increases in compassion toward people and nature (Herman, 2018; Herman et al., 2018), contextualized nature of science understanding (Herman et al., 2019), development of critical thinking and problem solving skills (Burek, 2012; Ervin & Sadler, 2008), science content knowledge (Burek, 2012; Kinslow et al., 2019), and a willingness to take action (Herman et al., 2018). If these are qualities that ISIs want visitors to build as a result of engaging with their exhibits and programming, then ISIs should consider utilizing the SSIF when designing their exhibits.

Exploring the SSIF in aquarium exhibits

As one of the places people go to get science information outside of a formal science classroom, aquariums are an important point of study (Bell et al., 2009). While limited research has explored the SSIF in ISI (e.g., Yun et al., 2009), even fewer studies focus on a holistic look at SSIF in aquarium settings. Through a series of three sub-studies, we explored how a SSI is communicated through an aquarium exhibit (Idema, 2021, Chapter III & IV; Reyes, 2020). To aid in our exploration, we used the outlined parts of the updated SSIF, to create a checklist for identifying what elements of the SSIF are already integrated in existing exhibits (Idema, 2021 Chapter III & IV; Reyes, 2020).

In person exhibits about climate change

We identified the primary features of the SSIF for each of the three core characteristics (*design elements*, *learner experiences*, and *instructional resource attributes*) and used this list as a guide to analyze 420 climate change exhibits from 50 aquariums across nine countries [Argentina (n = 1), the Bahamas (n = 1), Canada (n = 1), Greece (n = 1), Ireland (n = 1), Italy (n = 1), Japan (n = 1), the United Kingdom (U.K.) (n = 5), and the United States (U.S.)] (n = 38)]. (Idema, 2021 Chapter III). Of the 420 exhibits observed, only 3 exhibits featured climate change messaging throughout the exhibit, while 30 mention climate change or a human induced impact associated with climate change at least once. Based on the described list of characteristics, no exhibits used all the characteristics in ways to warrant being classified as representing the SSIF instructional approach suggesting a disconnect between the SSIF and practice in ISIs. The most common characteristic we found was the ability to ground the SSI in related science content under instructional resource attributes. Aquariums tended to include text heavy factual science information. While including relevant science information in climate change exhibits is important, if signage is too text heavy, visitor engagement declines (Bitgood, 1989; Serrell, 2015). Scaffold opportunities promoting higher order thinking and cognitive load planning were absent from the observed exhibits (Idema, 2021 Chapter III). Most noticeable was how few exhibits (n = 3) (from U.S. aquariums) attempted to ground the climate change message in localized and relevant contexts. These three exhibits also offered learner experiences through exploration of different social dimensions tied to climate change. While using different perspectives to convey the impacts of climate change on people within a community can be a powerful tool for engaging visitors in SSI learning (Presley et al., 2013), this tool becomes more powerful when used with the other learner experiences characteristics of the SSIF (Herman et al., 2018). We noted that only one of these exhibits also included an additional learner experience of collecting and analyzing data on the effects of ocean acidification (Idema, 2021 Chapter III). All exhibits showed evidence of background knowledge about climate change and related science content garnered from instructional resource attributes. However, we found an overall lack of interactive components. By incorporating interactive components over text heavy signage, ISIs can increase visitor engagement through opportunities to physically manipulate elements of the exhibit as they learn more about the SSI (Allen & Minion, 2020; Price et al., 2008; Roe et al., 2014). As we consider restructuring climate change exhibits, we need to ensure that characteristics to support successful SSI-based learning are not overlooked.

Virtual exhibits about climate change

The Covid-19 global pandemic presented ISIs with a myriad of unprecedented challenges including a need to make their content virtual for visitors sheltering in place (Graeber, 2020). Virtual exhibits are a combination of themed content, messaging, and species arranged on an online platform for public viewing. Content-wise, virtual exhibits are like in-person exhibits with photographs, live streams, and/or videos of species taking place of viewing organisms in-person. These virtual exhibits can be made available through ISIs' websites and offer visitors a way to freely access and engage with ISI content around the clock (Graeber, 2020; Song et al., 2004). Utilizing virtual exhibits allows ISIs to reach broad audiences with content that can be updated frequently and more cost effectively than in-person counterparts (Decker, 2015; Semczyszyn, 2013; Song et al., 2004). Unfortunately, research on virtual exhibits is limited (Foo, 2008; Kim, 2018). We explored climate change messaging using a SSIF lens in 256 virtual exhibits from aquariums across the United States (n=26) and Canada (n=1) (Idema, 2021 Chapter IV). We found that only 21 virtual exhibits across both countries mentioned climate change, or a human induced impact associated with climate change.

Similar to in-person exhibits, none of the observed virtual exhibits used all of the expected SSIF characteristics but they did share many of the same common core characteristics. For example, six virtual exhibits grounded the climate change message in local and relevant contexts. Design elements are critical as people may feel removed from climate change and its impacts because it can be difficult to see the immediate effects (Clayton et al., 2014) and they do not know how their everyday life may be impacted by climate change (Moser, 2010). In contrast, within the virtual dimension, we found that two virtual exhibits integrated scaffolding and five virtual exhibits explicitly attended to cognitive load balance (Idema, 2021 Chapter IV). The ideal exhibit grabs visitor attention as well as provokes thinking and interest in the featured topic through creative, unique ways (Beck & Cable, 2002; Tilden & Craig, 2009; Veverka, 2011). Virtual exhibits that incorporate the SSIF in their design exemplifies ideal exhibits by prompting open dialogue and encouraging the development of moral and ethical reasoning that leads to better environmental decision making (Sadler et al., 2007). However, we found that only seven of the observed virtual exhibits supported ideal learner experiences and included opportunities for visitors to engage in higher order practices, confront prior ideas, theories, and misconceptions, explore different social dimensions tied to climate change, collect and analyze data, learn about ethical/moral issues tied to the SSI, and/or consider nature of science themes connected to the SSI (Idema, 2021 Chapter IV). Learning from an online platform may also be difficult if information and visuals are stagnant (Song et al., 2004). Therefore, virtual exhibits need to incorporate interactive components such as games, videos, links to citizen science opportunities, or virtual pets (Dillahunt et al., 2008). However, we found a lack of interactive components (i.e., games, interactive maps, activities, etc.) in virtual exhibits (Idema, 2021 Chapter IV). Still, the most common instructional resource attributes found in all climate change exhibits reflected a familiarity with the SSI and the science content used as well as their potential to have content frequently updated to include current events.

Interpretations of a socioscientific issue exhibit

Reyes (2020) explored how families interacted with an SSI exhibit focused on water sustainability. Staff responsible for exhibit design were interviewed and eye-tracking was used to capture family interactions with the exhibit in real time. Reyes (2020) found that the theme of water sustainability was present throughout the exhibit via signage, videos, interactive touch screens and tanks with native and endemic species. According to the staff participant, the intent behind the exhibit's design was to make it interactive and accessible for all visitors through the use of touch screens and other digital displays as they "attract people's eyes more so than paper information sheets" (Reyes, 2020). By incorporating different design elements, the exhibit attempted to balance cognitive loads (Veverka, 2011) but still relied upon text heavy signage. Too much text can inhibit visitor engagement (Serrell, 2015) even if it is included in interactive ways (Veverka, 2011).

Building on the work of Reyes (2020) we found the water sustainability exhibit did not include scaffolding opportunities to foster higher order thinking and practice (Reyes et al., in progress). Learner experiences in the SSIF are largely influenced by scaffolding opportunities in the exhibit design elements and need to be supported through higher order practice. When these opportunities are missing, engaging visitors in higher order thinking and practice becomes more of a challenge (Patrick, 2014). However, the exhibit did provide visitors with some opportunities to explore different social dimensions through short videos about a native species life cycle and the different ways humans use water from the local aquifers and rivers (Reyes et al., in progress). The exhibit also presented visitors with moral and ethical aspects tied to water sustainability through videos and signage. However, the staff explicitly opted to focus the exhibit on a water sustainability message instead of climate change to present a less controversial issue less likely to upset visitors (Reyes et al., in progress). ISIs do not want to alienate the visitors and entities that fund their programs. However, the SSIF is purposely designed to facilitate controversial messages by encouraging visitors to explore different social dimensions tied to the SSI and promote institutional and community support.

We found that participants spent an average of four minutes interacting with the exhibit (Reyes et al., in progress). Adult participants mainly focused on digital signage. In contrast, child participants focused their attention on the live animals in the exhibit. Both groups focused on physical signage the least. While the majority of family participants identified a theme that closely aligned with the exhibit's intended message, none identified the exhibit's intended message in its entirety–to help visitors understand that the conservation of water is important because the overuse of water and nonpoint pollution within the watershed can harm local endangered aquatic species (Reyes et al., in progress). We found that participant interpretations aligned with their engagement focus. Adult responses were more reflective of information found in the videos and interactive touch screens while child responses talked about the need to protect aquatic species and their habitat or actions they could take to protect species (Reyes et al., in progress). Participants' experiences and exhibit message interpretations are reflective of the idea that visitors enter an exhibit with varying levels of prior knowledge, motivation, and interest (Bell et al., 2009; Falk et al., 2007). As such, ISIs may want to consider integrating multiple learning objectives into SSIF exhibits to address the needs of the different visitor groups engaging with their exhibits to ensure intended SSI takeaways.

Importance to the research

The SSIF is a tool that ISIs could use to design and evaluate exhibits. ISI staff could use the SSIF to identify missing SSIF characteristics in existing exhibits and develop solutions addressing those characteristics making exhibits more effective. In this capacity, the SSIF can aid ISIs in recognizing exhibit strengths and opportunities for improvement.

Trends in the SSIF usage reveal a lack of scaffolding, presentation of SSI in local and relevant contexts, and the inclusion of text heavy signage (e.g., Idema, 2021 Chapter III & IV; Reyes 2020). Scaffolding is essential as it fosters higher-order thinking and practice that leads to a better understanding of science (Sadler et al., 2016), ethical and moral reasoning (Sadler et al., 2007), and behavior change (Burek & Zeidler, 2015). In the formal science classroom, scaffolding opportunities are led by an educator (Presley et al., 2013). However, in ISIs an informal educator is not always present. During these times, the exhibit takes on the role of educator and a lack of scaffolding can hinder opportunities for deeper learning with SSIs (Krange et al., 2019; Presley et al., 2013). In this respect, ISIs can benefit from theory driven best practices used in formal education to improve effective exhibit design.

Exhibits are used in ISIs to introduce an SSI (Idema, 2021 Chapter III; Reyes, 2020) however, failing to expand on this introduction is a concern. SSIF exhibits address why an SSI is complex and introduce visitors to varying social dimensions tied to the SSI. Furthermore, there is a need to present SSIs in localized and relevant ways to visitors (Clayton & Myers, 2015). For example, coral reefs and polar habitats are important within the context of climate change, but most visitors have limited interactions with these ecosystems beyond a zoo/aquarium visit. Connections needed to ignite conservation action are challenging if visitors feel removed from the SSI (Clayton et al., 2014; Moser, 2010). Using native and endemic species as well as engaging visitors in learning about local social dimensions affiliated with the SSI may increase the personal relevance of the issue, and ultimately help visitors understand impacts of their actions.

Some research argues that a vast majority of visitors do not read exhibit signage (Churchman, 1985; Screven, 1992; Serrell, 2015; Shiner & Elwood, 1975), while others say that at least 95% of visitors read at least some signage (Barriault & Pearson, 2010; Davis & Thompson, 2011). Either way, ISIs cannot place too great a dependence on exhibit signage to engage visitors in SSI learning as not all visitors use physical signage in the same way (Roe et al., 2014). While interactive signage may hold visitor attention longer (Davis & Thompson, 2011; Holland et al., 2015; Roe et al., 2014) cognitive fatigue can occur if there is too much text (Veverka, 2011). SSIF exhibits have the potential to be mentally taxing due to the amount of cognitive energy that is expended (Shaby et al., 2017). Due to the high amounts of cognitive energy used in SSI-based learning, not every exhibit in an ISI needs to be an SSIF exhibit.

In the formal classroom, the SSIF has effectively engaged students in dialogue while helping them develop critical thinking and reasoning skills (Sadler et al., 2007; Zeidler et al., 2009). ISIs frequently work in tandem with school districts to ensure their program curriculum meets the standards schools need to justify field trips to said institutions (Patrick & Tunnicliffe, 2013). Because the SSIF employs provisions for meeting industry and educational standards at state/national levels, future uses for the SSIF could also assist with ISI curriculum design. This chapter introduces the SSIF for exhibit design and provides a foundation for examining SSIs in ISIs. As ISIs continue their quest to create more scientifically literate citizens, the SSIF serves as a vessel for generating exhibits, programming, teaching practices, and research that takes us there.

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III. COMMUNICATING CLIMATE CHANGE: EXPLORING THE USE OF A SOCIOSCIENTIFIC ISSUE THROUGH AQUARIUM EXHIBITS

Jenn L. Idema & Kristy L. Daniel

Introduction

Over 40% of the world's population lives within 63 miles of an ocean (United Nations, 2017). Across the globe, fish and other marine life contribute to the diet of nearly 3.2 billion people, with many of these being some of the world's poorest populations (The World Bank, 2018). With growing threats like climate change, pollution, and overfishing, human impact has intensified pressures on the world's marine resources (Clayton & Myers, 2015). Known as socioscientific issues (SSI), these anthropocentric pressures are complex and difficult to find solutions for due to the many different social dimensions connected with them (Sadler & Zeidler, 2005). Addressing SSIs increases the need for a more scientifically literate society. However, creating a science literate society is challenging when the average person spends less than five percent of their life in a formal science classroom (Falk & Dierking, 2010). Informal Science Institutions (ISI) such as zoos and aquariums, are places people visit where they can learn science information in formats they feel are approachable and non-threatening, allowing them to engage with science at levels they feel comfortable with (Bell et al., 2009). With more than 700 million people worldwide visiting annually, zoos and aquariums play an important role in educating their visitors about environmental issues through their ability to connect visitors with the natural world (Godinez & Fernandez, 2019). Zoos and aquariums can direct the experiences of visitors through artifacts, people, places, and species, creating unique learning environments that allow visitors to explore topics that interest them (Packer & Ballantyne, 2010). In ISIs, visitor engagement is typically voluntary and driven by free choice, allowing visitors to explore science content, form connections, and develop their own way of understanding through control over their learning environment (Packer & Ballantyne, 2010). Historically, public perception of zoos and aquariums has largely been that they are primarily places of entertainment, where visitors can go for a safe, fun day out, while possibly learning something in the process (Bell et al., 2009; Falk & Dierking, 2007). If the zoos and aquariums of today are to be considered more than just fun places to view animals, and instead be seen as places for conservation and learning (Carr & Cohen, 2011; Patrick & Tunnicliffe, 2013; Roe et al., 2014), then greater attention needs to be placed on the SSIs impacting the natural world. The challenge for aquariums, zoos, and other ISIs lies in designing meaningful opportunities for visitor engagement while conveying the often difficult messaging that surrounds SSIs (Esson & Moss, 2013).

Communicating Climate Change in Zoos and Aquariums

Climate change can be a polarizing SSI for people to discuss (Chin et al., 2020), and many people feel distanced from the SSI because its immediate effects are often difficult to see (Clayton & Myers, 2015). However, around the globe, communities continue to experience the impacts of climate change (Herman, 2018). ISIs such as zoos and aquariums, attempt to inform and engage visitors through exhibits that localize environmental issues such as climate change, in an effort to bring visitors and these issues closer together. In a survey of over 7000 zoo and aquarium visitors, Clayton et al. (2014) found a correlation between visitors' connection to the animals exhibited and their attitudes and behavior in relation to climate change. Additionally, Luebke et al. (2012)

found that zoo and aquarium visitors are more likely to believe in and care about the impacts of climate change, however these visitors believe there are barriers to taking action towards climate change. These findings suggest that zoos and aquariums have the potential to not only generate interest in the impacts of climate change, but support visitor action by providing information on ways visitors can engage in behaviors that mitigate climate change impacts (Clayton et al., 2014; Luebke et al., 2012; Moser, 2010).

The Role of Exhibits

Majority of zoo and aquarium visitors arrive with some type of learning agenda (Roe & McConney, 2015). Exhibits play a large role in the educational experiences visitors have as a result of their visit. Through their naturalistic design, the exhibits of today send a message to visitors that habitat conservation is integral for species survival (Hutchins & Smith, 2003). Exhibits further strengthen conservation messages through interpretive signage and interactive, hand-on elements that can be manipulated to enhance learning about an issue linked with the species housed within the exhibit (Bruce & Bryant, 2008; Serrell, 2015; Shani & Pizam, 2010). Engagement with an exhibit helps visitors generate personal meaning, creating connections between the information and species presented (Bacher et al., 2007; Beck & Cable, 2002) and through these connections, invoking a desire to protect nature (Godinez & Fernandez, 2019; Yilmaz et al., 2017). Exhibits act as mirrors, reflecting back to visitors our societies' ideas about the natural world through their design and messaging (Patrick & Tunnicliffe, 2013). While vastly different in design from the glass tanks and barred cages of their predecessors (Patrick & Tunnicliffe, 2013) the exhibits of today must continue to evolve to meet the demand for a more science literate society (Yun et al., 2020).

Theoretical Framework

The socioscientific issues framework (SSIF) is an instructional-based framework that draws from the fields of psychology, sociology, and philosophy to describe the processes in which an educator facilitates learning of science content that is embedded in relevant social contexts (Zeidler et al., 2009). Predominantly used in the formal classroom (e.g., Sadler, 2011; Sadler & Zeidler, 2005; Saunders & Rennie, 2011; Zeidler et al., 2005; Zeidler et al., 2009), the purpose of the SSIF is to create more scientifically literate citizens through SSI-based instruction that engages students in developing skills such as questioning, argumentation, moral reasoning, and empathy to increase their scientific understanding (Zeidler et al., 2005). Engagement with SSIF-based instruction contributes to science literacy (Chowdhury et al., 2020) and can lead to better environmental decision making (Sadler et al., 2007) and conservation action (Burek & Zeidler, 2014). Because these are qualities zoos and aquariums want visitors to take away as a result from their visit (Ballantyne et al., 2021), SSI-based instruction aligns well with the mission of these institutions (Patrick & Caplow, 2018). SSIF is largely understudied in informal settings (Yun et al., 2020). As such, we updated the language presented within the original SSIF to better reflect informal science education environments. Figure 2 illustrates the process in which an aquarium exhibit (instructional resource) draws upon pedagogical content knowledge, multi-disciplinary experiences, and subject matter knowledge to facilitate visitor engagement with the SSI of climate change (Zeidler et al., 2009). Through engagement with science content set in local and relevant social contexts, the visitor can potentially develop and use subject matter knowledge, intellectual reasoning, decision making, character and reflective judgement, argumentation, moral reasoning, and life experiences that lead to more environmental conscious decision making.

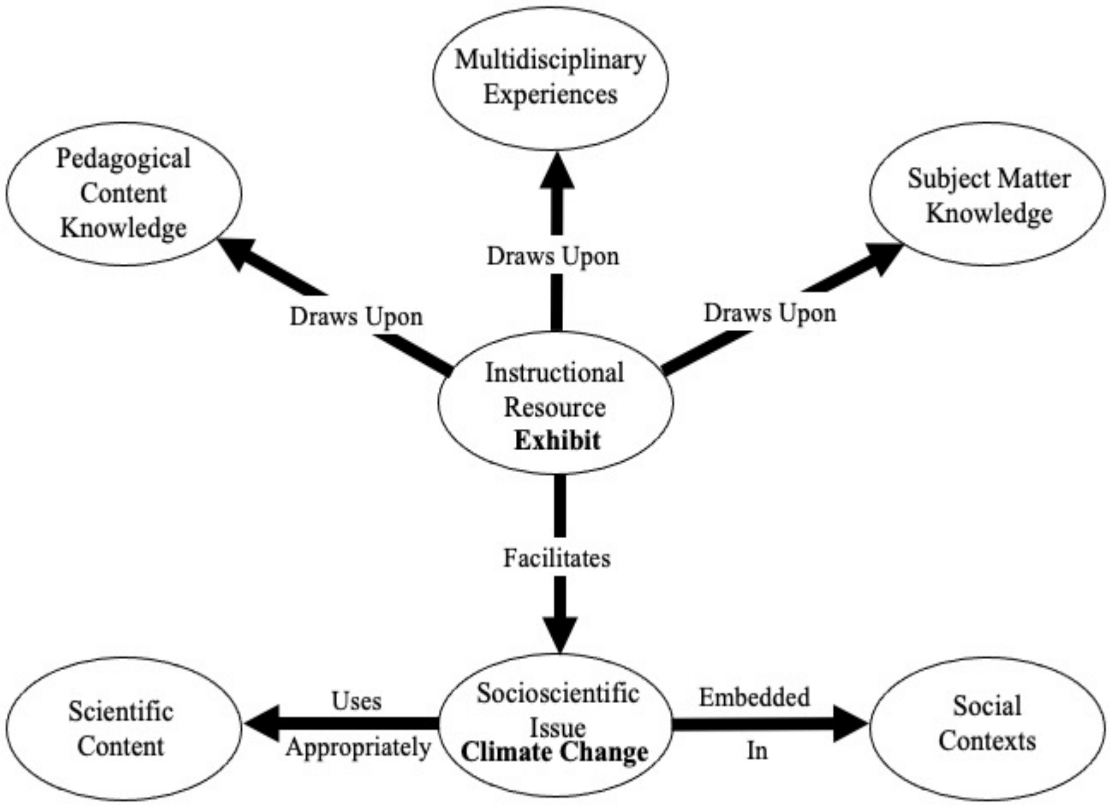

Figure 2. Process of creating a socioscientific issues framework exhibit. We adapt the SSIF (Zeidler et al., 2009) to make it inclusive of learning environments beyond the formal science classroom. In our version, the role of teacher is fulfilled by an ISI exhibit. This figure illustrates how the SSIF can be used for designing an SSIF-based exhibit. Adapted from "Advancing Reflective Judgement through Socioscientific Issues," by D. L. Zeidler, T. D. Sadler, S. Applebaum, & B. E. Callahan, 2009, *Journal of Research in Science Teaching, 46*, 74-101.

Presley et al. (2013) created a model for SSI-based education that captures key elements for effective SSI instruction and learning. However, this model was intended for formal education environments. Within ISIs, the traditional role of an educator is often replaced by interpreters or exhibits (Idema, 2021 Chapter II). As such, Idema (2021 Chapter II) adapted the language in Presley et al.'s (2013) SSI-based education model to be more inclusive of the various types of instructional resources and learning environments found in informal settings, as well as added additional characteristics that should be taken into consideration when designing a SSIF exhibit. The updated SSIF consists of three core aspects – *design elements*, *learner experiences*, and *instructional resource attributes* (Idema, 2021 Chapter II). *Design elements* focus on the underlying design process that leads to the creation of the exhibit experience. *Learner experiences* encompass the cognitive experiences needed to support visitor interactions with SSI. *Instructional resource attributes* serve as a set of guidelines for modeling learning through exhibits. Structured around a SSI, each of the core aspects and their characteristics are also shaped by their surrounding *educational environments* and other *peripheral influences* (i.e., ISI administration, funders, school districts, local and regional communities, state/national policies, industry standards) (Idema, 2021 Chapter II; Presley et al., 2013). The *educational environment* includes factors that can influence the core elements of the SSIF in the immediate exhibit environment. *Peripheral influences* are the surrounding administration, communities, funders, and governing bodies that influence exhibit design within an ISI.

Research Questions

The purpose of our study is to explore how an ISI such as an aquarium supports visitor learning about SSI through exhibits about climate change. The following research questions guided our study:

1. How do aquariums present climate change to visitors through their exhibits?
    a) What SSIF characteristics are present in existing aquarium exhibits about climate change?

b) How do aquariums localize a climate change message for visitors through their exhibits?

c) How do aquariums make a climate change message relevant for visitors through their exhibits?

2. What trends exist within interpretive exhibit design for presenting climate change impacts on marine/aquatic ecosystems?

Methodology

Using a descriptive qualitative approach (Patton, 2015) we collected data between March 2017 – March 2020 from a convenience sample (Farrokhi & Mahmoudi-Hamidabad, 2012) of 50 accredited facilities across 9 different countries [Argentina (n = 1), the Bahamas (n = 1), Canada (n = 1), Greece (n = 1), Ireland (n = 1), Italy (n = 1), Japan (n = 1), the United Kingdom (U.K.) (n = 5), and the United States (U.S.)] (n = 38)]. Collecting data from accredited facilities allowed us to ensure certain standards were met regarding conservation and education priorities as part of the facilities' accreditation process requires them to meet rigorous criteria regarding animal care and management, involvement in conservation and research programs, education programming through exhibits and interpretation staff, safety policies and procedures, security, physical facilities, guest services, and quality of staff (AZA, n.d.).

Data Collection

We used an observational protocol to collect basic information about the aquarium (i.e., location, aquarium type, number of exhibits observed) and document aquarium exhibits that featured the SSI of climate change. We used the names of each exhibit and the exhibit's boundaries outlined on aquarium's facility map to determine the boundaries for our exhibit observations. Initial observations at two local aquariums found no exhibits with the words “climate change” included in their messaging. However, exhibits did mention human induced impacts typically associated with climate change (i.e., rising sea temperatures, coral bleaching, melting sea ice, extreme weather, and/or habitat destruction, species reproduction, and species behavior changes as a result of climate change). Consequently, we altered the initial protocol to include messaging that referenced human-induced impacts associated with climate change. Members of the research team trained in the observational protocol observed and documented exhibits through photographic and video evidence. As part of the protocol, we documented how many exhibits were in the facility and of those, how many exhibits were about climate change/human-induced impacts or contained at least one reference to climate change/human-induced impacts. If no climate change exhibits were identified, we documented the number of exhibits in the facility and any other SSI topics present. If we did identify a climate change/human-induced impact message in an exhibit, we documented the entire exhibit through still photographs and/or video. The team member collecting the data noted the types of species present throughout the exhibit as well as the amount of physical signage, and types of interactive components and manipulatives present. We de-identified all aquariums and exhibits, using pseudonyms, to maintain confidentiality and followed approved IRB procedures (#6594, Appendix A).

Data Analysis

We conducted a conventional content analysis to analyze the components of each exhibit allowing us to examine exhibits while avoiding preconceived categorizations of content (Hsieh & Shannon, 2005). This method of analysis allowed natural patterns and themes to emerge. Using photographs and captured still screens from video evidence taken of exhibits we holistically coded (Saldaña, 2016) each as being either an exhibit about 1) *climate change/human-induced impact associated with climate change*, an exhibit that 2) *references climate change/human-induced impact associated with climate change at least once*, or contains 3) *no mention of climate change/human-induced impact associated with climate change*. Using the SSIF as a lens for understanding how exhibits use SSI to engage visitors, we devised a checklist of 19 characteristics as described in Idema (2021 Chapter II) that makeup the three core aspects (i.e. *design elements*, *learner experiences*, *instructional resource attributes*) for exhibit design (Table 1).

Table 1. SSIF exhibit design checklist.

SSIF Core Aspects and their characteristics	Characteristic Present?	Description of Characteristic
Design Elements - focus on the underlying design process that leads to the creation of the exhibit experience		
Includes a social issue connected to science		
The SSI is featured throughout the exhibit		
Content and messaging aligns with the ISI's mission, goals, and industry standards		
Incorporates interpretation principles		
Grounds the message in real-world contexts that are localized		
Grounds the message in real-world contexts that are relevant to visitors		
Provides scaffolding opportunities that foster higher-order thinking and practice		
Balances cognitive loads within the exhibit		
Learner Experiences – essential cognitive experiences that support visitor learning about the SSI		
Actively engages the visitor in higher order practices		
Provides opportunities for confronting ideas, theories, and misconceptions tied to the SSI		
Provides visitors with access to opportunities to collect and analyze data tied to the SSI		
Provides opportunities for visitors to explore different social dimensions tied to the SSI		
Engages visitors in learning about the ethical/moral aspects of the SSI		
Encourages visitors to consider nature of science themes tied to the SSI		
Instructional Resource Attributes – guidelines for modeling learning through exhibits		
Exhibit design reflects a familiarity with the SSI being considered		
Exhibit design reflects a familiarity with related science content		
Exhibit design reflect a familiarity with the social dimensions tied to the SSI		
Uses interactive components that contain science content over text heavy physical and/or virtual signage		
Ability to have interactive components updated to leverage current events tied to the SSI		

Note. The SSIF checklist builds on the work of Presley et al. (2013) by updating the language used to describe the role of an instructional resource, gives consideration to principles for exhibit design, and reflects a focus on how the SSIF can be used for ISI exhibits. Adapted from "A Framework for Socio-scientific Issues Based Education," by M.

L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26-32.

Focusing solely on the first two exhibit classifications, we used magnitude coding (Saldaña, 2016) to determine the extent to which the core characteristics from the SSIF were present, absent, or unclear within the exhibit. Then we used frequency counts to determine how many SSIF core characteristics were present in each exhibit. As part of the SSIF characteristics checklist, we deductively coded exhibit content as either containing a message that was localized, relevant, both localized and relevant, or neither. For the purpose of our study, we defined an exhibit as localized if the theme, message, and species featured are representative of the native and/or endemic species, and/or the local communities surrounding the aquarium's location. For example, if an aquarium located on the southeastern coast of the US included an exhibit on coral reefs native to the area and the exhibit mentioned how those reefs are being impacted by rising sea temperatures as a result of climate change it was marked as localized. Additionally, we defined an exhibit message as relevant if it contained information on how climate change or human-induced impacts associated with climate change might affect visitors. A relevant message could also contain information on steps visitors could make to help mitigate the effects of climate change. For example, one exhibit mentioned how rising sea temperatures and ocean acidification have caused local oyster beds to die off. The message continued to talk about how oyster die off changed the availability of oysters on local restaurant menus and in neighborhood grocery stores. The exhibit then mentioned actions visitors could take to help reduce their carbon footprint, such as riding a bike over driving a car, conserving energy by powering down computers at the end of a workday.

As such, the exhibit was marked as both localized, as it talked about oyster beds local to the aquarium area, and relevant, because it discussed how visitors were being impacted and what they could do to help. Additionally, we used a deductive approach to code for the whether or not the exhibit message aligned with the institution's mission/goals outlined on their webpage.

Finally, we used descriptive statistics to discern any trends across exhibits (Vogt, 2005). We maintained trustworthiness of our data through the use of interrater agreement (Tinsley & Weiss, 2000). Two members of the research team independently coded exhibit data. Analytical discrepancies were discussed until reaching 100% consensus and all researchers agreed upon final coding.

Results

Of the 420 exhibits observed, only 3 (all from aquariums in the U.S.) were classified as an exhibit about *climate change/human induced impact associated with climate change*, while 30 (6 exhibits from aquariums in the U.K. and 24 exhibits from aquariums across the U.S.) contained a message that *referenced climate change/human-induced impact associated with climate change at least once*. Figure 3 illustrates the breakdown of which countries and states had exhibits with climate change/impact associated with climate change (CC) messaging and which ones did not. Other SSIs documented in aquarium exhibits (Figure 4) included mentions of marine pollution (n = 61), sustainable fishing (n = 52), invasive species (n = 47), and wildlife trade (n = 32).

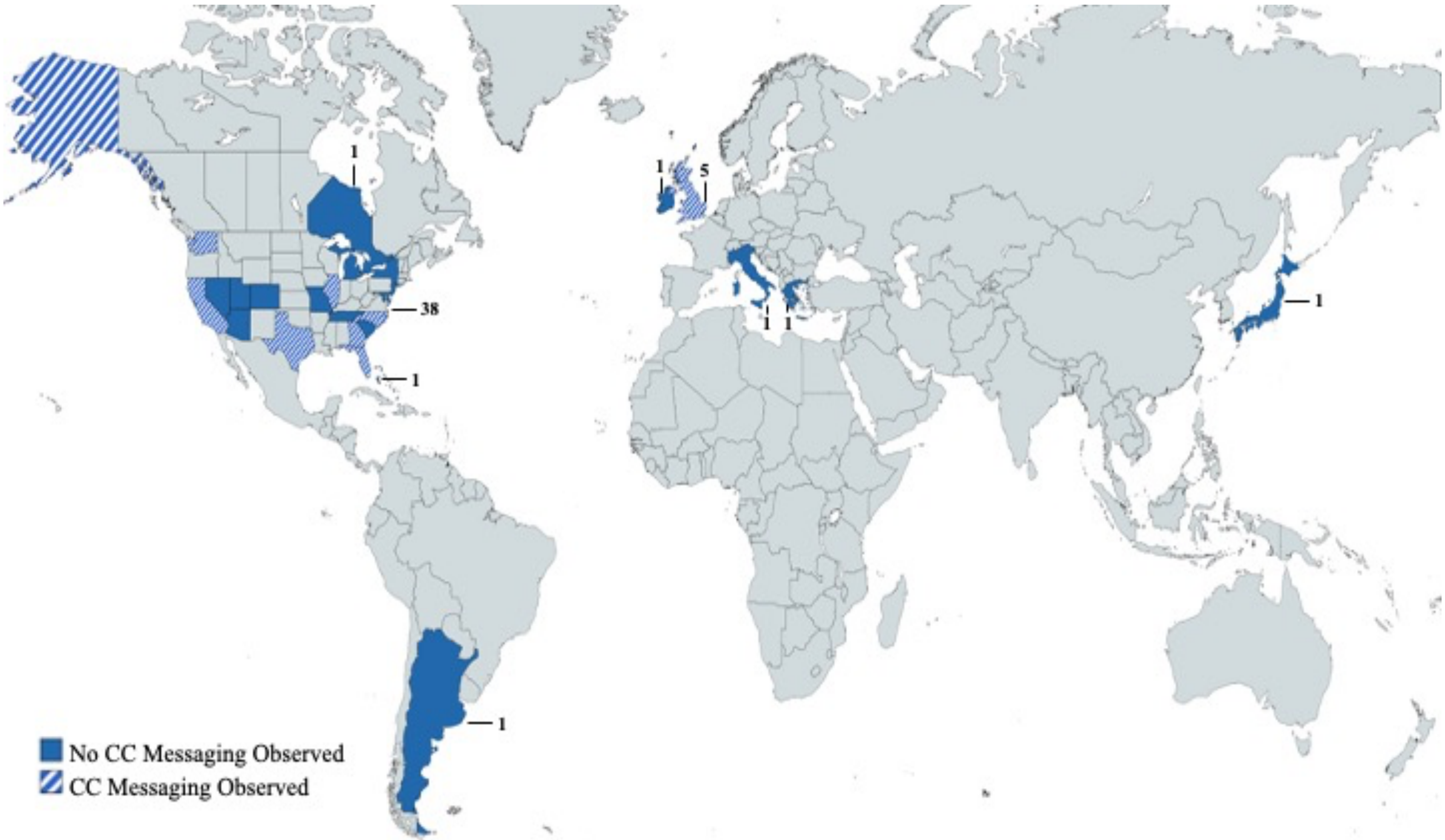

Figure 3. Aquarium observations of in-person exhibits by country. Illustration of the number of aquariums from each country where data was collected as well as which countries had exhibits with climate change/impact associated with climate change (CC) messaging.

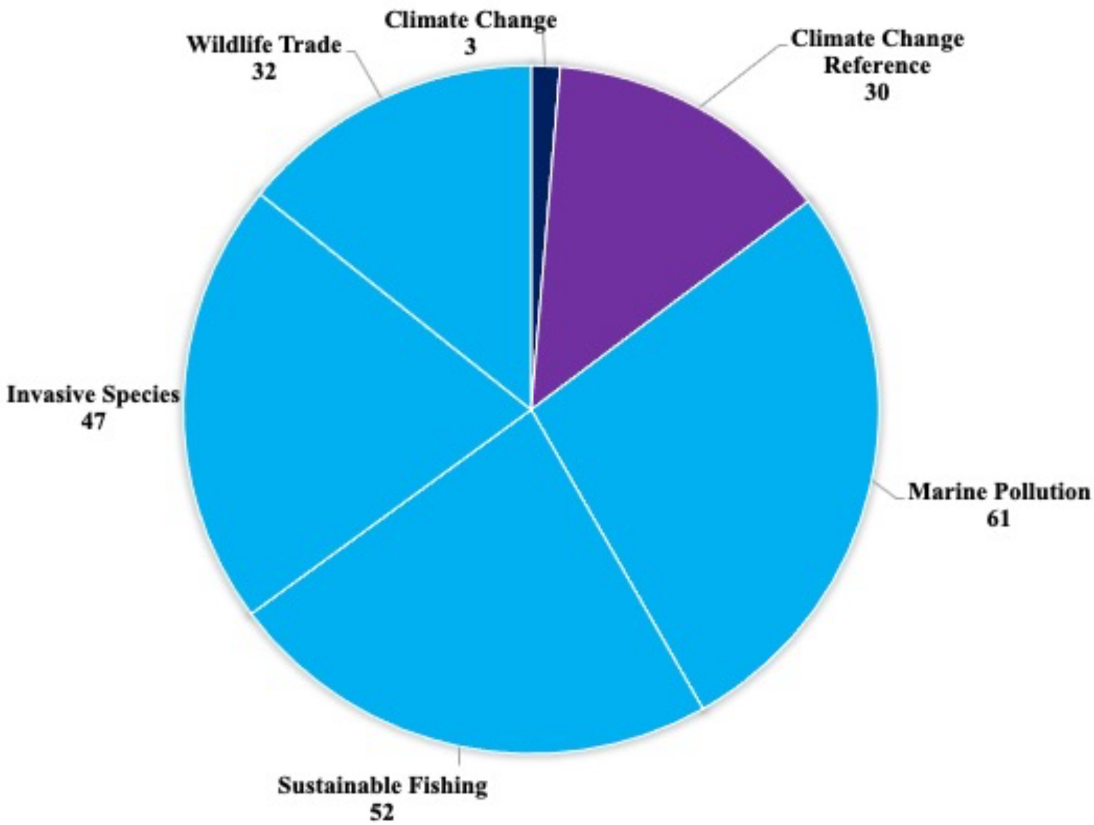

Figure 4. Socioscientific issues observed in in-person aquarium exhibits. Number of in-person exhibits observed is broken down by SSI message.

Aquarium ownership was classified into four types – Private For-Profit (n = 20), Non-Profit (n = 18), Publicly Traded (n = 6), and Government/Research Institute Run (n = 6) Private for-profit run facilities are typically owned by a corporation or individual and aim to earn a profit for its founders and/or management group (Majaski, 2021). Non-profit run facilities are organizations that do not earn any profits for the organization. Instead, money earned through visitor fees and donations from patrons help fund the facilities' objectives and goals (Sullivan, 2018). Publicly traded facilities are those owned by public shareholders who have claims to portions of the company's assets and profits (Majaski, 2021). Government/research institute run facilities are those facilities that depend on and receive money from a municipality, state, or federal funding to keep their doors open. These facilities can also be managed by a research institution such as a university (Sullivan, 2018). Figure 5 depicts aquarium observed by ownership type.

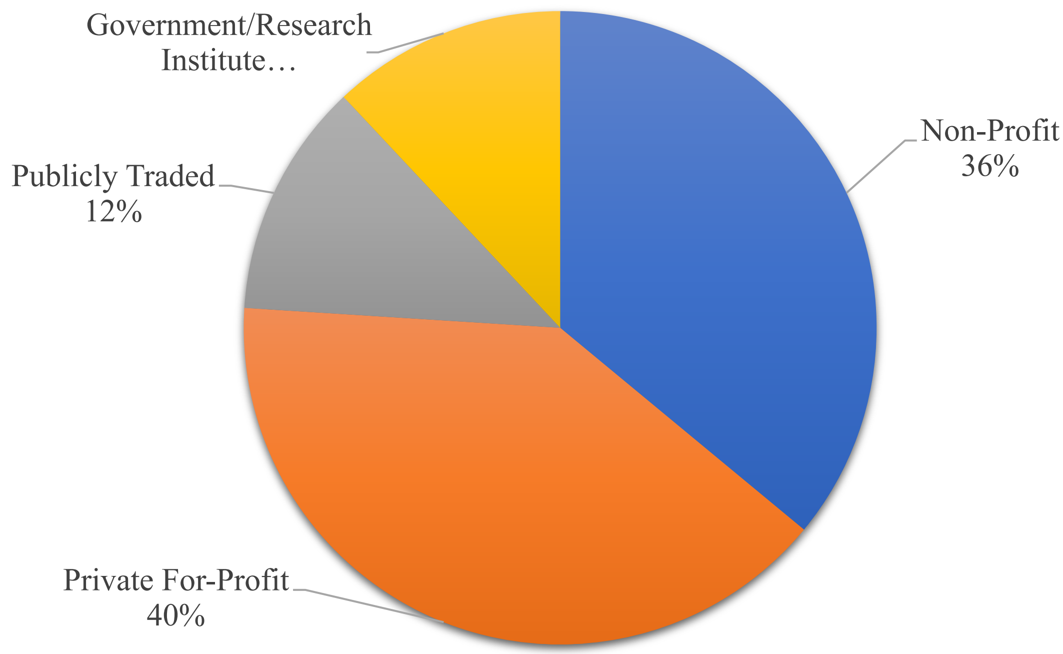

Figure 5. Aquariums observed by ownership type (n = 50)

With regard to the relationship of ownership type and the inclusion of a climate change/impact associated with climate change exhibit we found two non-profit aquariums and one government/research institute run aquarium contained an exhibit about climate change/impact associated with climate change. For those exhibits that contained a reference to climate change/impact associated with climate change, we found non-profits to contain a reference most often (n = 12), followed by those aquariums managed by government/research institute entities (n = 9). However, exhibits with a climate change/impact associated with climate change message could still be found in publicly traded (n = 4) and private for-profit aquariums (n = 5). Figure 6 illustrates the breakdown of climate change/impacts associated with climate change messaging by aquarium ownership type.

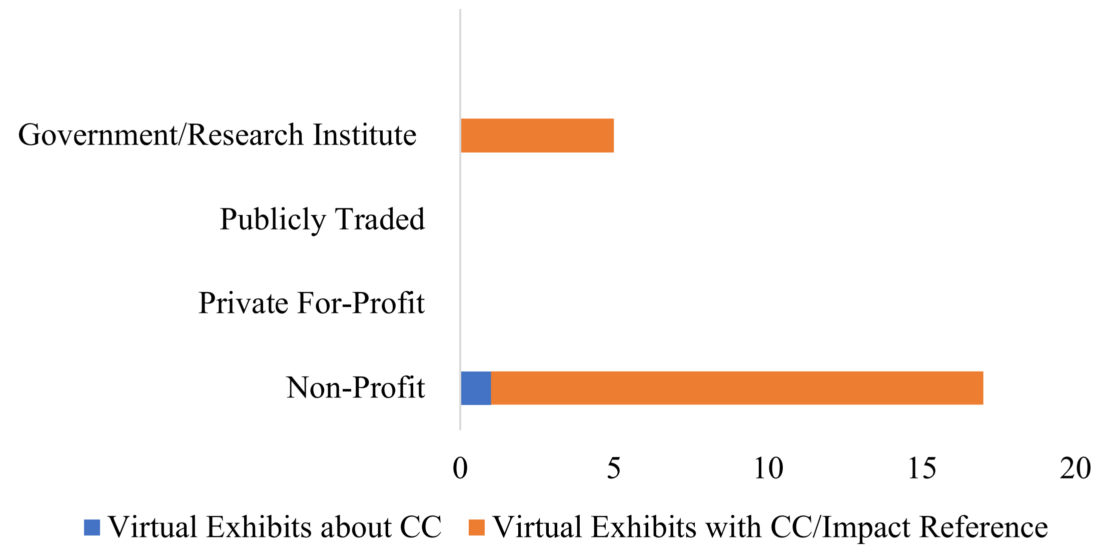

Figure 6. Exhibits with climate change/impact messaging by aquarium ownership type. The number of exhibits about climate change (CC) and exhibits with a CC/impact associated reference are shown for each aquarium ownership type observed.

SSIF Characteristics

Of the 33 exhibits that fell within one of the first two exhibit classifications, we found that none used all the SSIF characteristics. All exhibits (n = 33) included a social issue connected to science, incorporated interpretation principles, and contained content and messaging that aligned with their ISI's mission/goals under the core aspect of design elements. Additionally, all exhibits showed characteristics of instructional resource attributes by expressing some form of familiarity with the selected SSI through their mention of climate change/human-impact associated with climate change within the exhibit and by grounding the SSI in relatable science content, reflecting a familiarity with the science content tied to the SSI. However, this is where commonalities in SSIF core characteristics for exhibit design found across all 33 exhibits ends. Instead, exhibits fell into one of three groups (Figure 7) – exhibits that contained between six or less characteristics (*low characteristic inclusion*), exhibits that contained between seven to nine characteristics (*moderate characteristic inclusion*), and exhibits that contained 10 or more characteristics (*high characteristic inclusion*).

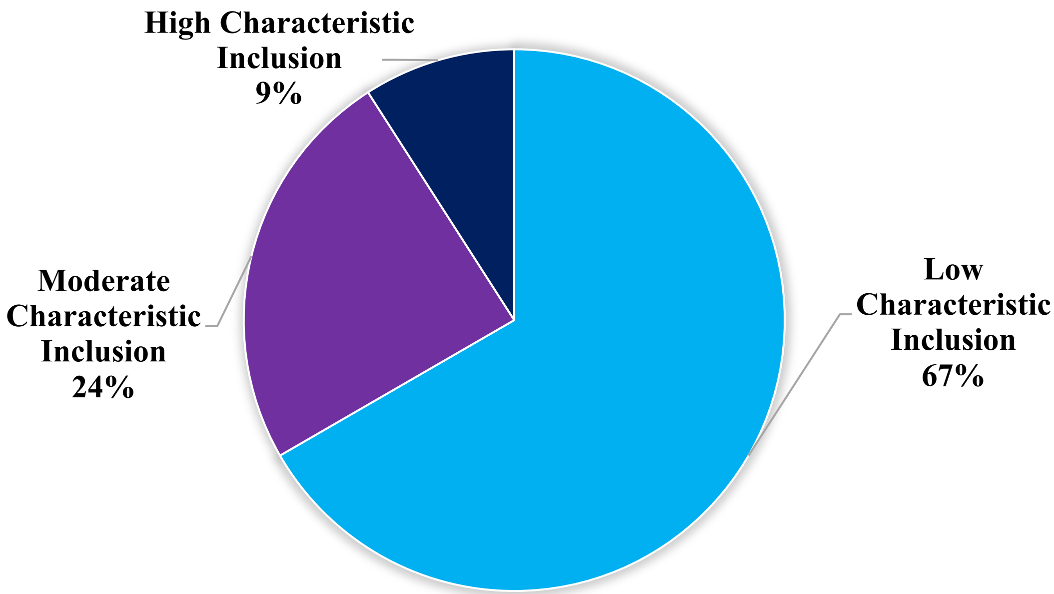

Figure 7. SSIF characteristic inclusion groups for in-person exhibits (n = 33).

To better illustrate what SSIF core characteristics were found in exhibits (Table 2), we introduce our findings in the form of a representative exhibit profile for each group. Each representative exhibit profile features an exhibit that was randomly chosen from those exhibits in the inclusion group that contained the maximum number of core characteristics for the group. Each inclusion group profile describes the most typically included core characteristics in the group and includes an exhibit description representative of these characteristics.

Table 2. SSIF characteristics present in climate change/impact messaging in in-person exhibits.

SSIF Core Aspects and their characteristics	Low	Moderate	High
Design Elements - focus on the underlying design process that leads to the creation of the exhibit experience	n (%)	n (%)	n (%)
Includes a social issue connected to science	22 (100)	8 (100)	3 (100)
The SSI is featured throughout the exhibit	0	0	3 (100)
Content and messaging align with the ISI's mission, goals, and industry standards	22 (100)	8 (100)	3 (100)
Incorporates interpretation principles	22 (100)	8 (100)	3 (100)
Grounds the message in real-world contexts that are localized	5 (23)	3 (38)	3 (100)
Grounds the message in real-world contexts that are relevant to visitors	5 (23)	3 (38)	3 (100)
Provides scaffolding opportunities that foster higher order thinking and practice	0	0	1 (33)
Balances cognitive loads within the exhibit	0	0	1 (33)
Learner Experiences – essential cognitive experiences that support visitor learning about the SSI			
Actively engages the visitor in higher order practices	0	0	1 (33)
Provides opportunities for confronting ideas, theories, and misconceptions tied to the SSI	0	0	2 (67)
Provides visitors with access to opportunities to collect and analyze data tied to the SSI	0	0	1 (33)
Provides opportunities for visitors to explore different social dimensions tied to the SSI	0	1 (13)	1 (33)
Engages visitors in learning about the ethical/moral aspects of the SSI	0	0	1 (33)
Encourages visitors to consider nature of science themes tied to the SSI	0	0	2 (67)
Instructional Resource Attributes – guidelines for modeling learning through exhibits			
Exhibit design reflects a familiarity with the SSI being considered	22 (100)	8 (100)	3 (100)
Exhibit design reflects a familiarity with related science content	22 (100)	8 (100)	3 (100)
Exhibit design reflects a familiarity with the social dimensions tied to the SSI	0	1 (13)	1 (33)
Uses interactive components that contain science content over text heavy physical and/or virtual signage	0	4 (50)	1 (33)
Ability to have interactive components updated to leverage current events tied to the SSI	0	8 (100)	1 (33)

Note. Adapted from “A Framework for Socio-scientific Issues Based Education,” by M. L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26-32.

Low Characteristic Inclusion – Meet the Penguins. All of the exhibits classified as low SSIF characteristic inclusion (n = 22 exhibits) contained a reference to climate change or a human-impact associated with climate change at least once, although none featured this message throughout the exhibit. The major differences in this group involved the core aspect of design elements. Only five exhibits attempted to ground their SSI messages in real-world contexts that were localized, and only five of the exhibits attempted to ground their message in real-world contexts that were relevant. Unfortunately, none of the exhibits in the low characteristic inclusion group offered any type of climate change messaging that was both localized and relevant for visitors.

We chose an exhibit about penguins to represent the low characteristic inclusion group to describe what an exhibit with the maximum number of characteristics in this inclusion group might look like. The exhibit contained all five shared characteristics, plus the additional characteristic of grounding the message in real world contexts relevant to visitors. Entering the exhibit, there is a large enclosure that spans the length of the building, behind a clear, thick, floor-to-ceiling, acrylic wall. The enclosure is a naturalistic sub-Antarctic habitat that facilitates penguin-in-the-wild behavior such as swimming, diving and porpoising, leaping out of the water, and nesting and rearing young amid artificial rock ledges and ice shelves. Within the large enclosure are several different penguin species. Visitors pass through the exhibit via a slow-moving walkway. Spanning the top length of the enclosure are back-lit banner signs that introduce each species in the exhibit, along with a picture of the species, and distinguishing facts about the species and the enclosure. It is lunchtime on a sunny midsummer day, but the inside of the exhibit is dimly lit with outlines of the birds visible. According to one of the overhead signs, “The lighting simulates what you find in their sub-Antarctic habitats,” but no further explanation about the lighting is provided. Along the opposite wall of the enclosure are a series of five, large backlit signs about each of the species housed in the exhibit. Each of these signs contains between two to four different photos of the species, the common and scientific name for the species, a general fact about the species, a husbandry fact about the species, and a conservation fact that gives visitors actions they can do to help protect penguins. These conservation facts are:

> You can help: Support conservation efforts through organizations such as [aquarium sponsored conservation organization].
>
> You can help: Conserve water. A family of 4 can save up to 1000 gallons of water each month by taking showers less than 5 minutes long.
>
> You can help: Support environmentally responsible companies when purchasing seafood products.
>
> You can help: Don’t trash where you splash. Trash will find its way to the ocean. When possible, recycle and reuse.
>
> You can help: Recycling efforts can prevent thousands of pounds of greenhouse gases from entering the atmosphere each year.

There are a total of 20 signs spread throughout the exhibit. The vast majority of exhibit signage found contains a mix of two to five, short sentences about penguin hatching and care of young, physical characteristics, diet and eating habits, and habitat and distribution, along with graphics of penguins. This exhibit was labeled as Category 2 because it mentioned the need to prevent greenhouse gasses from entering the atmosphere. Additionally, this penguin exhibit was marked as being relevant because it provided visitors with conservation actions they could do to help protect penguins and their environment. Noticeably missing from the exhibit is the inclusion of interactive components and manipulatives over text heavy signage under SSIF core aspect of instructional resource attributes.

Moderate Characteristic Inclusion – Reef Rendezvous. Of the eight moderate SSIF characteristic inclusion exhibits, we only classified one exhibit as Category 1 and the other seven as Category 2. We noticed differences across these exhibits in all three SSIF core aspects (Table 2). Under design elements, only one of the exhibits featured a climate change and/or a human impact associated with climate change message. Similar to the low characteristic inclusion group, three exhibits grounded their SSI messages in real-world contexts that were localized and three of the exhibits grounded their message in real-world contexts that were relevant for visitors. And like the low characteristic inclusion exhibits, none of the moderate characteristic inclusion exhibits included any type of climate change messaging presented in both localized and relevant contexts for visitors. With regard to learner experiences characteristics, one exhibit provided visitors with opportunities to explore different social dimensions tied to the SSI and as such, also demonstrated a familiarity with social dimensions tied to climate change—an instructional resource attributes characteristic. Additionally, four of the moderate characteristic inclusion exhibits utilized interactive components that contained science content. However, the interactive components (i.e., touchscreens and/or QR codes) contained text-heavy science information. While not all of the exhibits contained interactive components, they each did include some form of technology (e.g., a revolving screen and/or video clip) that had the ability to be updated in order to tie in current events related to climate change issues. Therefore, we classified all of the moderate characteristic inclusion exhibits as having the ability to update interactive components in order to leverage current events tied to the SSI.

We chose an exhibit about coral reefs to represent the moderate characteristic inclusion group to describe what an exhibit with the maximum number of characteristics in this inclusion group might look like. The exhibit contained nine of the SSIF core characteristics. In addition to six shared characteristics across the moderate inclusion group (Table 2) the coral reef exhibit contained a message ground in real world contexts relevant to visitors, provided opportunities to explore different social dimensions tied to the SSI and the exhibit design reflecting a familiarity with these social dimensions, This exhibit is spread across two floors of the aquarium with a sloping walkway lined with smaller 50-to-200-gallon tanks that allow visitors to explore multiple perspectives of a naturalistic barrier reef habitat. The largest tank in the exhibit is a quarter of a million gallons and contains a large wall of artificial coral, where visitors can view over 200 different species of fish, stingrays, and sharks swimming amongst the reefs. The first floor of the exhibit contains the largest view of the barrier reef habitat. The viewing area spans from floor to ceiling. Along the walls next to the large viewing area and along the walkway lined with smaller tanks are small signs that contain pictures of the exhibit species along with their common and scientific names, and a fact about the species. A wall-mounted monitor with revolving signage provides visitors with information about what healthy coral reefs need (i.e., clean moving, salt water, water temperatures between 73°F and 84°F, and sunlight), how fast corals grow, and short video clips that illustrate for visitors how divers attach aquarium grown coral to existing reefs for reef restoration.

Along the wall where the sloping walkway ends are two large signs. The first sign contains an enlarged close-up image of a coral polyp along with a labeled infographic that explains the symbiotic relationship between coral polyps and zooxanthellae. Mounted on the sign are two, three-dimensional artificial examples of coral that visitors can touch. The second sign contains an enlarged image of a coral reef as a background and is divided into thirds. In two of the sections there are two images of coral reefs along with multiple paragraphs of small text. The first paragraph mentions the value of coral reefs ecologically, "Thousands of marine fish and invertebrate species use them as vital breeding, spawning, nursery, and feeding grounds". The second paragraph mentions the value of coral reefs economically for a tourist economy, "Beautiful reefs also attract tourists, whose cash supports local economies." The third paragraph contains a human induced impact associated with climate change, "Carbon dioxide from burning fossil fuels affects the ocean. Warmer water, rising sea levels and changing chemistry endanger coral reefs and the coastlines they protect." The next section of this sign talks about climate change impacts on coral reefs. The first paragraph mentions that, "pollution, overfishing and warming ocean waters from climate change threaten these reefs. Today people are teaming up to reverse destructive trends. Coast and reef restoration, education, sustainable fishing, and marine reserves are all part of the solution." The second paragraph gives visitors actions they can do to help coral species, "You can help to save corals. Avoid buying coral or shell souvenirs. Fight warming ocean waters by reducing fossil fuel use, bike instead of drive, unplug electronics not in use, or turn up the AC thermostat." The third paragraph mentions coral bleaching, "Corals stressed by water that's too warm release their colorful partner algae, causing coral bleaching. If it's too warm for too long, the corals die." The third section of the sign contains an image of a male president of a small island nation in the South Pacific that depends on fishing as the nation's major source of income and food. Additionally, he "pushed developed nations globally to fight climate change for the future of his country and around the world." In all, there are 30 signs within the exhibit, and these are the only signs within the exhibit that directly mention climate change or a human impact associated with climate change.

The SSIF core characteristics of note represented in Reef Rendezvous include climate change messaging set in real-world contexts that are relevant to visitors under design elements characteristics. Similar to the first exhibit profiled, signage in Reef Rendezvous includes a list of conservation actions visitors can do to help protect coral species. The exhibit also provides examples of different social dimensions connected to climate change that visitors can explore through signage mentioning the economic value of reefs for tourism and impacts of climate change on people from an island nation. The exhibit also contains instructional resource attributes characteristics through its interactive components. Visitors can touch and interact with two coral manipulatives. Additionally, there is revolving signage with video clips offering the ability to be updated frequently, leveraging current events tied to climate change.

High Characteristic Inclusion – Shark Tank. Three exhibits had high characteristic inclusion. All three of the exhibits contained the same number of SSIF core characteristics (n = 12), but they were not always the same ones (Table 2). Unlike the previous two characteristic inclusion groups, all of the exhibits in high characteristic inclusion ground their climate change/human impact associated with climate change messaging in contexts that were both localized and relevant for visitors (design elements). These were the only characteristics the three exhibits shared in addition to the characteristics that were shared across all of the characteristic inclusion groups.

We chose a Shark Tank exhibit to represent the high characteristic inclusion group to describe what an exhibit with the maximum number of characteristics in this inclusion group might look like. The exhibit contained 12 of the SSIF core characteristics. In addition to eight shared characteristics across the high inclusion group (Table 2) the Shark Tank exhibit balanced cognitive loads within the exhibit, provided visitors with opportunities to confront ideas and misconceptions, encouraged visitors to consider the nature of science themes tied to the SSI, used interactive components and manipulatives over text-heavy signage, and had the ability for its interactive components to be updated to feature current events tied to the SSI.

Shark Tank is an exhibit about a hard bottom reef habitat local to the area. The exhibit contains a 1500-gallon tank filled with different reef fish and shark species with rocky outcrops to simulate what Shark Tank looks like in the wild. Around the acrylic viewing areas are four wall-mounted monitors. Three of these monitors contain revolving species identification information (i.e., a photo of the animal, 10-second video clip of the species moving, and common and scientific name of the species). The fourth wall-mounted monitor shows a three-minute video about megalodons - how it was once an ancient sea home to megalodons and is now a hardbottom reef. The video goes on to discuss the size of megalodons and how fossilized shark teeth can be found all around local hardbottom reefs. The video then switches gears to present science content and misconceptions about climate change, as well as how sharks in the wild are affected by warming sea temperatures. The video begins with narrated text while showing a split screen of healthy reefs versus reefs that are stressed. The narrator explains, “Changes in ocean temperature, damage to hardbottom habitat, and poor water quality could affect everything living on the reefs.” The video continues with defining what global warming is and how it relates to climate change.

An infographic explaining greenhouse gas effects is shown while the narrated text continues, “Ocean temperatures are rising because people and livestock generate billions of tons of carbon dioxide and other greenhouse gasses every day. Excess heat usually radiates from Earth out into space. Heat trapping gasses like CO_2 prevent heat from leaving the atmosphere causing the planet to warm.” The next screen talks about a common misconception regarding climate change and global warming. “Some people get confused about global warming.” The screen shows a cartoon man, with a question bubble that says if the Earth is warming then why was winter so cold this year? The narrated text continues, “If we don’t do something to help stop global warming, our normal weather patterns like cold temperatures in the winter and hot temperatures in the summer are going to become more extreme.” The next screen shows aquarium visitors cars traveling along a busy highway, refinery towers with billowing smoke flowing out of them, a local shrimp boat, and a man fishing on the local beach. The narrated text gives visitors actions they can do across a series of screens to help mitigate the impacts of global warming, “Help preserve these habitats by preventing pollution and reducing fossil fuel use. Help protect reef habitat by supporting well managed fisheries and Marine Protected Areas. Turn off the lights when you leave the room. Power down computers at the end of each workday. Bike ride rather than use a car or play video games.” Across from this video monitor is a size accurate replica of megalodon jaws. The jaws are positioned so that visitors can take photos standing inside the mouth of a megalodon. The sign in front of the jaws includes a megalodon tooth manipulative that visitors are encouraged to, “Please touch!” The sign also includes a QR code for visitors to use to learn more about megalodons and post their photos with the jaws on the aquarium’s social media pages. Additionally, the sign mentions that sharks are currently, “in need of protections because without them, ocean ecosystems would become unbalanced.” To the left of the megalodon jaws is a smaller sign over a donation box that encourages visitors to make a “Meg-A Donation,” to support the aquarium.

While Shark Tank’s climate change messaging is not featured throughout the exhibit, the messaging that is included is grounded in both localized (i.e., features a local habitat with native species) and relevant (i.e., gives visitors actions visitors can do to help mitigate climate change impacts) contexts. The exhibit does not provide visitors with opportunities for scaffolding that leads to higher order practice. However, it does make attempts to balance cognitive loads through the inclusion of appropriate science content across signage that is not text heavy, short videos about Shark Tank habitat, manipulatives and QR codes that engage the visitor in learning about Shark Tank beyond their aquarium visit, and a tank full of brightly colored fishes and sharks visible from a large viewing area. The exhibit only has two learner experiences characteristics. Shark Tank provides visitors with opportunities to confront ideas, theories, and misconceptions about climate change through the infographic about the differences between global warming and climate change. The infographic that tells visitors about the greenhouse gas effect encourages them to consider this nature of science theme tied to climate change. The inclusion of things visitors can touch (e.g., megalodon teeth and jaws), QR codes that extend the science lesson beyond the aquarium visit, and the use of video clips and revolving signage reflect the characteristic of using interactive components that contain science content over text heavy physical signage under instructional resource attributes. The QR codes, videos, and revolving signage also have the ability to be updated to include current events related to climate change impacts.

Identifying Trends Across Exhibits

Looking at trends across the 33 exhibits, we found that coral reefs (n = 17) were the most commonly featured organisms in relation to the SSI. Only three exhibits talked about climate change in relation to humans. The most common way aquariums communicated the SSI was through physical signage that contained pictures and text information, found across all exhibits. The second most common communication element (n = 19) was wall-mounted video screens containing revolving information. Table 3 shows the overview of exhibits by organisms featured, message theme, climate change/impacts, and common communication elements used in the exhibits for conveying information to visitors.

Table 3. Trends in climate change/impact messaging in in-person aquarium exhibits.

# Exhibits	Primary Organisms Featured*	Message Themes	Climate Change/Impacts	Communication Elements
16	Reef building corals	Habitat impacts Behavior impacts	Ocean acidification Bleaching Rising sea temperatures	Physical signage, wall-mounted monitors with revolving signage, videos, touch tanks
6	Polar species Penguins Polar bears Cetaceans Seals/Sea lions	Habitat impacts Behavior impacts	Warming temperatures cause changes to habitat Melting sea ice Species behavior changes, Prey availability	Physical signage, wall-mounted revolving screens, interactive holograms
6	Other			
	Elasmobranch	Behavior impacts	Warming temperatures change migration routes	Physical signage, wall-mounted monitors with revolving signage, videos, touch tanks
	Sea Otters		Prey availability	
	Invertebrates	Habitat impacts	Rising sea temperatures cause habitat changes	
	Sea birds Dolphins			
3	Humans	Accelerating impacts	Human contributions, impact communities	Physical signage, wall-mounted monitors with revolving signage, hands-on manipulatives, QR codes
2	Unspecified species/Animals in general	General impacts	Climate change impacts animals	Physical signage
33	Total			

Note. Signs can mention more than one organism.

None of the 33 exhibits used all of the characteristics in a manner that would warrant them being classified representative of a holistic SSIF instructional approach. All three characteristic inclusion groups addressed some characteristics in the core aspects of design elements and instructional resource attributes, but few exhibits (n = 4) addressed characteristics under the core aspect of learner experiences (Table 2).

We found that all climate change/impact associated with climate change exhibits included a relevant social issue connected to science. We also found that over half of the exhibits (57.6%) attempted to make the SSI localized only (n = 8), relevant only (n = 8), or both localized and relevant (n = 3) for visitors.

Of the 33 exhibits that fell within one of the first two exhibit classifications, we found that the most common instructional resource attribute was the ability to ground the SSI in related science content. Exhibit designers showed background knowledge of climate change and science content related to the SSI by including factual science information. However, with the exception of two exhibits, this information was presented in a text-heavy manner. When pictures and/or manipulatives were used to help illustrate the impacts of climate change, the pictures or infographics were small and text blocks were larger than the included images. Scaffold opportunities that promote higher order thinking and cognitive load planning were also absent from a majority (97.0%) of the exhibits.

Study Limitations

We collected exhibit data over a three-year period. Given the length of time used for data collection, exhibits could sometimes be updated after data was collected. To help ensure reliability of our observations over time, when possible, a member of the research team would revisit the site annually and document any exhibit changes that could affect the data. When a site revisit was not possible, we used aquariums' websites to compare their current listed exhibit information with data that was collected. In the event that an exhibit was updated or in the process of going through updating, and new observations could not be collected, data from that exhibit was omitted from analysis. Only four of the exhibits we observed were updated during the data collection period. One of these exhibits originally contained a climate change reference in August of 2018, but a year later was closed for updates. As of June 2021, the exhibit update is not complete. Therefore, the exhibit was omitted from analysis. The other three exhibits did not feature the SSI of climate change nor did they reference climate change/impact before and after their exhibit updates. As such, their update did not impact our data analysis.

The use of convenience samples can sometimes lead to bias as collected samples may not be representative of the population of interest (Farrokhi & Mahmoudi-Hamidabad, 2012). To help address potential bias, we only collected data from AZA, BIAZA, EAZA, and WAZA accredited facilities to ensure standards were met regarding conservation and education priorities. Using accredited facilities allowed us to make general comparisons regarding SSI messaging across aquarium exhibits.

Exhibits often mentioned an impact associated with climate change rather than specifically using the term climate change. There was some concern regarding interteam reliability on exhibit observation procedures. To ensure consistency across research team observational data we provided each team member with a list of terms associated with climate change to look for in aquarium exhibits. Also, given that we collected data from nine different countries, English was not the common language written or spoken in four of these countries. When possible, we worked with an interpreter fluent in the native language to identify if an exhibit contained a climate change impact message. When an interpreter was not available (n = 2 aquariums), we used a photo-based translator app via a smartphone to interpret the language (Italian, Spanish). While these types of apps are not 100% accurate, their accuracy on average approaches 80%, with higher translation accuracy in European languages, allowing for a basic understanding of an exhibit message's theme and broad context (Groves & Mundt, 2015).

Discussion

Amongst the aquarium exhibits surveyed (n = 420), only 33 contained any mention of climate change and/or its impacts. Prior studies about delivering difficult messages and engaging in climate change dialogue suggest visitors are willing to reflect thoughtfully on content and even engage other visitors in dialogue (Esson & Moss, 2010; Luebke et al., 2015). Thus, the lack of messaging about climate change and its impacts on marine/aquatic ecosystems in exhibits is concerning.

Our findings reflect a disconnect between theory supporting known best practice and implementation in practice. To address the disconnect, ISIs could consider restructuring climate change exhibits to include prompts for engaging visitors in dialogue about differing community member perspectives, incorporating science information that would allow visitors to confront prior ideas and/or misconceptions about climate change, and exploring the moral and ethical aspects tied to climate change. Using different perspectives to convey the impacts of climate change on people within a community can be a powerful tool for engaging visitors in SSI learning (Presley et al., 2013), however that tool becomes more powerful when used with the other learner experiences characteristics of the SSIF (Herman et al., 2018). While including relevant science information in climate change exhibits is important, if signage is too text heavy, visitor engagement declines (Bitgood, 1989; Serrell, 2015). By incorporating interactive components over text-heavy signage, ISIs are likely to increase visitor engagement by allowing visitors to participate in physically manipulating elements of the exhibit as they learn more about the SSI (Davis & Thompson, 2011; Holland et al., 2015; Roe et al., 2014). As we embark on the potential restructuring of SSI exhibits with a focus on climate change, assurances should be given that characteristics making SSI-based learning successful are not overlooked.

Additionally, the lack of local connections within SSI exhibits could limit visitor perceptions about climate change as well as their willingness to take action (Clayton & Myers, 2015; Luebke et al., 2015; Moser, 2010). We found that trends in aquarium exhibit communication focused on environmental issues like marine pollution, sustainable fishing, invasive species, and the illegal wildlife trade rather than on climate change. While these issues are no less important, perhaps a reason aquariums choose to engage visitors through exhibit design in these SSI environmental issues is because they are more visible and less controversial in nature (Reyes, 2020). Ownership type, which is a peripheral influence characteristic (Idema, 2021 Chapter II), could also play a role in an in an ISI's decision toward whether or not include the SSI of climate change in its exhibits. We found non-profit and government/research institute run aquariums included climate change/impact associated with climate change messaging in their exhibits most often than for-profit and publicly traded aquariums. The reason for this finding can likely be attributed to the mission and purpose of the aquarium (Patrick & Caplow, 2018). Regardless, exhibits cannot rely solely on easy issues and charismatic species to appeal to visitors, nor depend solely upon signage to carry SSI messages across to visitors.

However, by understanding how ISIs communicate SSIs to visitors we can develop insights into how we can begin engaging visitors in effective conservation learning that leads to action. If ISIs are to continue moving forward with exhibit design that engages people in conservation dialogues and behaviors, then they have to first be willing to incorporate major SSIs into their exhibits. Using the SSIF to restructure current climate change/impact exhibits or in the design of new exhibits could help ISIs like aquariums move beyond introducing the SSI and instead allow them to engage visitors in learning about the complexities that surround climate change.

Implications for Practice

SSIF-based instruction in formal classrooms is an effective way to support contextual learning about science (Sadler & Dawson, 2012), promote nature of science understanding (Eastwood et al., 2012), develop higher order thinking (Saunders & Rennie, 2011; Zeidler et al., 2009) and increase moral/ethical empathy (Burek & Zeidler, 2014; Herman et al., 2018). These are qualities important for creating scientifically literate citizens who make environmentally conscious decisions and are more inclined to engage in pro-environmental actions (Herman et al., 2018; Sadler et al., 2007). Incorporating the SSIF into the places people visit to learn science outside of the classroom (i.e., ISIs) has the potential to more effectively contribute to a science literate society.

Our findings call attention to strengths in active ISI communication practices as well as opportunities to further enhance messaging. The SSIF for exhibit design (Idema, 2021 Chapter II) can be used as a tool ISIs can use for identifying strengths and opportunities in existing exhibits, allowing them to make adjustments to core elements to turn low characteristic inclusion into a higher category. Additionally, the SSIF could be used to design new exhibits about SSI.

Existing literature on SSIF use in informal environments is limited (Burek & Zeidler, 2014; Yun et al., 2020). Our project draws connections between existing work about engaging students in SSI-based learning in the formal classroom with potential applications for engaging ISI visitors in SSI-based learning outside of the classroom. Our study provides insight into how existing exhibits in aquariums communicate the SSI of climate change as well as identifies what aspects of the SSIF can be found in those exhibits, contributing to this gap in the literature. The next steps in our research are to explore how the SSIF may be used in other types of visitor experiences found in aquariums, such as virtual exhibits and in-person programming. Once we improve our understanding of how SSIs are communicated in informal settings, we can better identify which SSIF characteristics make SSI-based instruction most effective (Presley et al., 2013). Then, we can shift our focus to the visitor experience, exploring how theory driven practice from the formal science classroom impacts visitor engagement in informal science learning spaces.

Conclusion

It is not our intention to alienate or attack zoos and aquariums for their choices with regard to offering climate change related exhibits. We recognize this is a complex issue and while ISIs may want to present the issue to visitors, they may not choose or be able to for a variety of reasons. For example, there may be risks (e.g., alienating visitors/funders, politics) associated with committing climate change information to exhibit signage (Moser, 2010) and aquariums may instead choose to communicate climate change in other formats such as informal educator-led programming. We focused on exhibits because this is one of the largest ways ISIs communicate science information to the public (Patrick & Tunnicliffe, 2013; Serrell, 2015). Our intention is to bring to the surface the need for communicating climate change and other SSIs in contexts local and relevant for visitors. Doing so can increase community participation in actions that help mitigate known climate change impacts (Walsh & Tsurasaki, 2014).

As the environmental issues of today continue to grow, so too does the need for a more scientifically literate society. As one of the most popular places people go to get science information outside of a formal classroom (Bell et al., 2009), ISIs, such as zoos and aquariums, are important places of study. The zoos and aquariums of today present themselves as centers for conservation and learning (Patrick & Capslow, 2018) and some argue that these claims are backed by little empirical evidence to justify these claims (Carr & Cohen, 2011). Our findings contribute to the gap in SSIF use in ISIs as well as help provide evidence supporting why zoos and aquariums matter as educational providers.

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IV. CLIMATE CHANGE IN A VIRTUAL WORLD: EXPLORING SOCIOSCIENTIFIC ISSUE COMMUNICATION IN ONLINE AQUARIUM EXHIBITS

Jenn L. Idema, Dominique Ocampo, Kristy L. Daniel, & Michelle E. Forsythe

Introduction

Climate change is a complex, arduous, and often divisive socioscientific issue (SSI) to discuss. Many feel far removed from climate change because the immediate effects of greenhouse gas emissions caused by the burning of fossil fuels or the conversion of forests into farmland are difficult to see (Moser, 2010; Clayton et al., 2014). Consequently, people fail to understand how their actions and the actions of the communities in which they live impact aquatic and marine ecosystems regardless of their distance from an ocean (Clayton & Myers, 2015). Aquariums play an important role in the science literacy of their surrounding communities. With the average American spending less than five percent of their life learning about science in a formal classroom (Falk & Dierking, 2010), aquariums provide their visitors with avenues for learning about science and the natural world in formats that are engaging and easy to comprehend (Bell et al., 2009; Patrick & Tunnicliffe, 2013; Semczyszyn, 2013). One way aquariums promote learning is through their exhibits. Exhibits serve as a form of communication between the visitor and artifacts, species, and/or resources presented by the institution, and through engagement, help visitors generate personal meaning for these things (Bacher et al., 2007; Beck & Cable, 2002). Ideally, exhibits should: grab the visitor's attention, provoking interest in the subject; allow the visitor to make connections between content featured and their life; present information in unique, creative ways and viewpoints; relate to other stories being told within the facility and use theming design (e.g. color, visuals, fonts, logos, layout, music, etc.) to help create and establish unity; have a learning objective with specific, desired outcomes; and align with the mission and purpose of the facility in which it is a part (Beck & Cable, 2002; Tilden & Craig, 2009; Veverka, 2011).

Exhibits can also be used as a platform for engaging visitors in learning about controversial SSI such as climate change (Clayton et al., 2014; Esson & Moss, 2013; Zeidler & Nichols, 2009). While mainly used in the formal classroom to engage students in discussion and debate (Zeidler & Nichols, 2009), the socioscientific issues framework (SSIF) can serve as a way for aquariums to engage visitors in learning about climate change (Idema, 2021 Chapter II). Incorporating the SSIF into exhibits can provide visitors with opportunities to connect with climate change and its impacts in a minimally or non-controversial way, that might make them more receptive to the message and encourage them to make more environmentally conscious decisions (Ballantyne, 2016; Clayton & Myers, 2015; Esson & Moss, 2013).

The Need for Accessing Science Information in Virtual Spaces

The Covid-19 global pandemic presented ISIs with a myriad of unprecedented challenges. With so many institutions shut down and the general public sheltering in place and or in isolation, a growing demand for access to science information through online virtual experiences arose almost overnight (Graeber, 2020). The virtual exhibits found on ISI websites provide an avenue for addressing this challenge through the ability to provide visitors with engaging around the clock access to science information for little to no cost, in the convenience of their own home, in unique and entertaining ways

(Graeber, 2020; Song et al., 2004). Virtual exhibits create an even greater potential for visitor learning about SSIs through the ability to reach a broader audience via content that can be changed and updated more frequently and cost effectively than their in-person counterparts (Decker, 2015). We acknowledge that virtual exhibits are not the only way ISIs engage with visitors online; however, they are becoming a more common way visitors access science content outside of visiting an ISI in-person (Graeber, 2020). Because research on virtual exhibits is limited (e.g., Foo, 2008; Kim, 2018), and even more limited are studies investigating the use of the SSIF in ISIs (e.g., Idema, 2021 Chapter III & III; Yun et al., 2020) the purpose of our study is to explore how climate change/human-induced impacts associated with climate change are communicated through virtual aquarium exhibits. We used the following research questions to drive our study:

1) How are climate change/climate change impacts presented in virtual exhibits offered by aquariums?
    a. How is climate change/climate change impacts content in virtual exhibits localized for visitors?
    b. How is climate change/climate change impacts content in virtual exhibits made relevant for visitors?
2) What SSIF core characteristics (design elements, learner experiences, instructional resource attributes) can be found in virtual climate change/climate change impact exhibits?
3) What are the trends in climate change/climate change impact messaging in virtual exhibits across aquariums?

Using the Socioscientific Issues Framework in Virtual Exhibits

For the purpose of our study, we define virtual exhibits as a combination of themed content, messaging, and organisms arranged on an online platform, typically an ISI website, for public viewing. Content-wise, virtual exhibits are similar to in-person exhibits. We equate still pictures, livestreams of webcams, and/or videos of species to being representative of viewing different marine and aquatic species in-person. Virtual exhibits can be composed of multiple pages much like an in-person exhibit can have multiple tanks housing a variety of species (Benbow, 1997). Headlines and other text are comparable to in-person exhibit signage (Figure 8). While not as physically tactile as in-person manipulatives and touch tanks (Veverka, 2011), interactive maps and games can provide visitors with opportunities for active-learning (Arvanitis et al., 2009; Sylaiou et al., 2017) about organisms when people click on interactive elements like migratory routes of tagged animals or match animals based on adaptations to their habitats.

Figure 8. Elements of a virtual exhibit. Any information that could identify the aquarium used in the example of a virtual exhibit elements has been blinded.

Our study was guided by an updated SSIF for exhibit design (Idema, 2021 Chapter II), and combines insights from past models (e.g., Presley et al., 2013; Zeidler et al., 2009) to explore how an instructional resource, such as a virtual aquarium exhibit, facilitates SSI-based learning through relevant science content embedded in socially relevant contexts (Idema, 2021 Chapter II & III). The SSIF aims to offer an instructional approach that facilitates the development of scientifically literate citizens who can use their knowledge of evidence-based science to make morally and ethically conscientious decisions about the SSIs of today's world (Zeidler et al., 2005). The SSIF focuses on the development of intellectual reasoning, decision making, argumentation, moral reasoning, and reflective judgment skills by engaging in science learning using real-world contexts (Zeidler et al., 2009). Through design elements creating exhibit experiences, cognitive elements supporting learner experiences, and instructional resource attributes modeling learning, the updated SSIF captures key elements and experiences that make SSI-based instruction successful in formal classrooms (Presley et al., 2013; Zeidler et al., 2009) and adapts them for use in ISI exhibits (Idema, 2021 Chapter II).

Virtual exhibits can look different from their in-person counterparts regarding how they balance cognitive loads (design elements) (Fahy, 2008), provide visitors with access to collect and analyze data connected to the SSI (learner experiences) (Goforth et al., 2014) and incorporate technology to augment SSI learning (instructional resource attribute) (Arvanitis et al., 2009; Sylaiou et al., 2017). As such, we broaden the definitions of these SSIF core aspect characteristics to be more inclusive of virtual exhibit spaces.

Methodology

Using a descriptive qualitative research design approach, our study examined 256 exhibits from Association of Zoos and Aquariums (AZA) accredited aquarium websites across two countries, the U.S. (n = 26) and Canada (n = 1). A convenience sample (Farrokhi & Mahmoudi-Hamidabad, 2012) of 27 aquariums was selected from the AZA's 2020 list of accredited aquariums found on their website. In order to achieve and maintain accreditation these institutions must meet rigorous industry standards in animal care and management, involvement in conservation and research programs, education programming through exhibits and interpretation staff, safety policies and procedures, security, physical facilities, guest services, and quality of staff (AZA, n.d.). Thus, collecting observations from only AZA accredited institutions allowed us to make general comparisons across aquariums. We collected data on virtual aquarium exhibits from May of 2020 through June of 2021. All aquariums and their virtual exhibits were de-identified and assigned a pseudonym to maintain confidentiality and followed approved IRB procedures (#6594, Appendix A).

Data Collection

Using a similar approach as Idema (2021, Chapter III), we collected basic information about aquariums (i.e., location, aquarium type, number of virtual exhibits observed) and used the updated SSIF for exhibit design (Idema, 2021 Chapter II) to document climate change communication in virtual aquarium exhibits. Based on prior research (Clayton et al., 2014; Idema, 2021 Chapter III) human-induced impacts typically associated with climate change (i.e., rising sea temperatures, coral bleaching, melting sea ice, extreme weather, and/or habitat destruction, species reproduction, and species behavior changes as a result of climate change) were included in our definition of virtual climate change messaging. Members of the research team trained in the observation protocol observed and documented how many virtual exhibits were on an aquarium's website and of those, how many virtual exhibits were about climate change/human-induced impacts or contained at least one reference to climate change/human-induced impacts. If we were unable to identify any virtual exhibits as climate change exhibits at an aquarium, we documented the number of virtual exhibits on the ISI's website and any other SSI topics present. If we did identify a climate change/human-induced impact message in a virtual exhibit, we reviewed the entire virtual exhibit, including any links to other webpages. We noted the types of organisms presented throughout the virtual exhibit, as well as virtual signage and types of interactive components used to communicate climate change/impacts associated with climate change. All aquariums and virtual exhibits were de-identified and given pseudonyms to maintain confidentiality as outlined in approved IRB procedures (#6594, Appendix A).

Data Analysis

We conducted a conventional content analysis to analyze the components of each virtual exhibit which allowed us to see any natural patterns and themes emerge from the data while avoiding preconceived categorization of content (Hsieh & Shannon, 2005). Then we holistically coded (Saldaña, 2016) each virtual exhibit as either an exhibit about 1) *climate change/human-induced impact associated with climate change*, an exhibit that 2) *referenced climate change/human-induced impact associated with climate change at least once*, or 3) *contained no mention of climate change/human-induced impact associated with climate change*. Focusing solely on the first two virtual exhibit classifications, we applied the SSIF exhibit design checklist (Idema, 2021 Chapter II & III) as a lens for examining how aquariums used virtual exhibits to engage visitor in learning about climate change. The checklist includes 19 characteristics of the core aspects of design elements, learner experiences, and instructional resource attributes that influence SSI-based instruction (Idema, 2021 Chapter II & III). Under design elements, we explored whether or not a virtual exhibit about and/or contained a reference to climate change/impact associated with climate change:

1) Incorporated a social issue connected to science,

2) Featured the SSI throughout the virtual exhibit,

3) Content and messaging aligned with the ISI's mission/goals and/or industry standards,

4) Incorporated interpretation principles used for exhibit design,

5) Ground the message in real-world contexts in ways that are localized,

6) Ground the message in real-world contexts in ways that are relevant for visitors,

7) Provides opportunities for scaffolding that foster higher-order thinking and practice in visitors, and

8) Balances cognitive loads within the exhibit (Idema, 2021 Chapter II & III).

With regards to learner experiences characteristics that are essential experiences for supporting visitor learning about SSI we examined whether or not the virtual exhibit can:

1) Actively engage visitors in higher order practices,

2) Provide visitors with opportunities to confront prior ideas, theories, and misconception they might have and/or are historically tied to the SSI,

3) Connects visitors with opportunities to collect and analyze data related to the SSI (i.e., community/citizen science opportunities),

4) Provides opportunities for visitors to explore different social dimensions connected to the SSI,

5) Engages visitors in learning about the ethical/moral connected with the SSI, and

6) Encourages visitors to consider nature of science themes tied to the SSI (Idema, 2021 Chapter II & III).

Known as teacher attributes in the original SSIF (Presley et al., 2013), we updated the language of this core aspect to instructional resource attributes as exhibits can take on the role of educator in ISIs when an informal educator cannot be present (Idema, 2021 Chapter II & III). Under instructional resource attributes we explored whether or not a virtual exhibit's design:

1) Reflects a familiarity with the SSI being considered,
2) Reflects a familiarity with science content related to the SSI,
3) Reflects a familiarity with different social dimensions connected to the SSI
4) Uses interactive components connected to science content over text-heavy virtual signage, and
5) Has the ability to have interactive components updated to be reflective of current events connected with the SSI (Idema, 2021 Chapter II & III).

Next, we applied magnitude codes (Saldaña, 2016) to determine the extent to which each core characteristics was present, absent, or unclear. For example, we classified each virtual climate change SSI exhibit's central message as either *localized*, containing a message that was *relevant*, containing a message that was *both localized and relevant*, or *containing neither*. We defined a virtual exhibit as *localized* if it contained a theme, message, and/or species native to the area near or around the aquarium. An example of a localized virtual exhibit is from an aquarium located on the southeastern coast of the U.S. that included a virtual exhibit on native coral reefs. The virtual exhibit used still photos and video footage of coral expelling their symbiotic algae partners to introduce visitors to the topic of coral bleaching. Additional text and video narration explains to visitors that coral bleaching is caused by rising sea temperatures that are occurring as a result of climate change. We classified this exhibit as being localized because it discussed a climate change impact on native species that could be found in the waters near the aquarium. We defined *relevant* as a virtual exhibit message containing information on how climate change or an impact associated with climate change (e.g., rising sea temperatures, coral bleaching, melting sea ice, extreme weather, changes in species behavior) might affect visitors. A relevant message might also contain information on, or list actions visitors could take part in to help mitigate climate change impacts. For example, one virtual exhibit used text and pictures to explain to visitors how rising sea temperatures have created dead zones of low water oxygen levels and habitat loss for blue crabs, a species native to the area where the aquarium is located. Low water oxygen levels and habitat loss, combined with being a favorite dish for humans, have led to serious declines in blue crab populations. This aquarium supplemented the localized messaging by providing links to current research being done on blue crabs, detailing a citizen science project offering a way for visitors to directly participate in this issue, and notating additional actions for visitors such as help clean up local waters to positively impact blue crab populations. We classified this virtual exhibit as both *localized* (because it discussed how local species were being impacted by rising sea temperatures) and *relevant* (because it discussed how visitors were being impacted—blue crab availability in restaurants and grocery stores). This exhibit was made even further relevant by offering opportunities for visitors to become engaged and directly support the issue (i.e., providing access to the citizen science project and actions to clean up local waters). Note that a virtual climate change SSI exhibit could be classified as *localized*, *relevant*, *both localized and relevant*, or *neither localized or relevant*. Using the institution's mission and goals outlined on aquarium webpages, we applied a deductive approach to code messaging alignment. We then used frequency counts to determine the number of SSIF core characteristics addressed in each virtual exhibit.

A deductive approach was used to apply descriptive codes (Saldaña, 2016) to the data for capturing emergent trends in focal organisms, messaging type, and communication components used (i.e., links to research, audio clips, video clips, live webcams, text, games, etc.) to communicate the climate change SSI. To maintain trustworthiness, we used inter-rater reliability with two of our researchers independently coding all data. Any discrepancies in coding were reviewed and discussed between the research team members until 100% consensus was reached.

Results

Of the 256 virtual exhibits, we classified only one exhibit from an aquarium in the U.S. as a virtual exhibit about *climate change/human-induced impact associated with climate change* and 20 virtual exhibits (19 from the U.S. and 1 from Canada) as containing a message that *referenced climate change/human-induced impact associated with climate change at least once* (Figure 9).

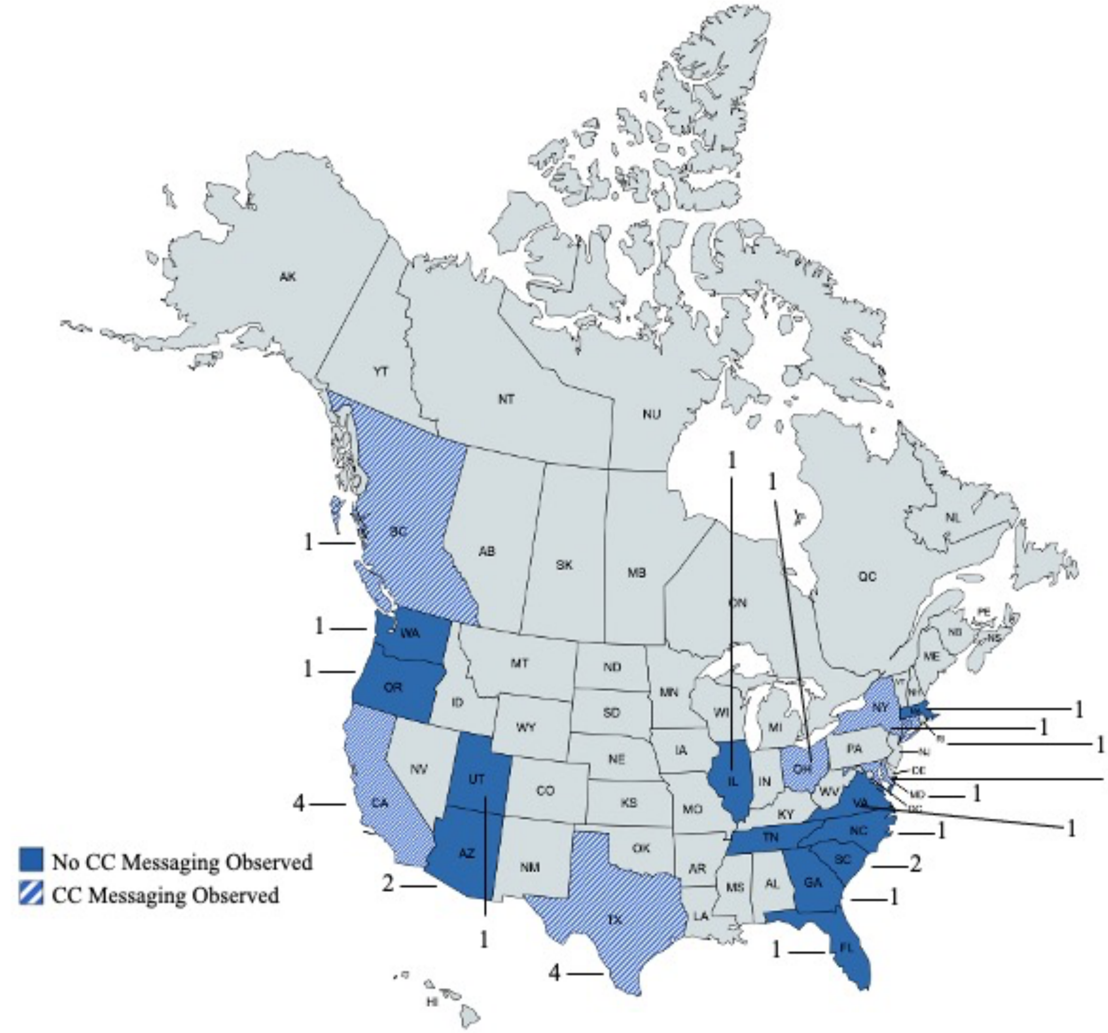

Figure 9. Aquarium observations by country/state. Illustration of the number of aquariums from the U.S. and Canada where data was collected, as well as where aquariums with virtual exhibits about climate change (CC)/impact messaging were located.

Other SSIs documented in virtual aquarium exhibits (Figure 10) included information about marine pollution (n =36), sustainable fishing (n = 29), human development (n = 17), invasive species (n = 13), and wildlife trade (n = 10). Moving forward with the presentation of our findings, we focus solely on the 21 virtual exhibits that contain a climate change/impact associated with climate message. We found four different aquarium types. Non-Profit run (n=19) facilities are managed by an organization or foundation that does not earn profits for the organization founders and rely on visitor

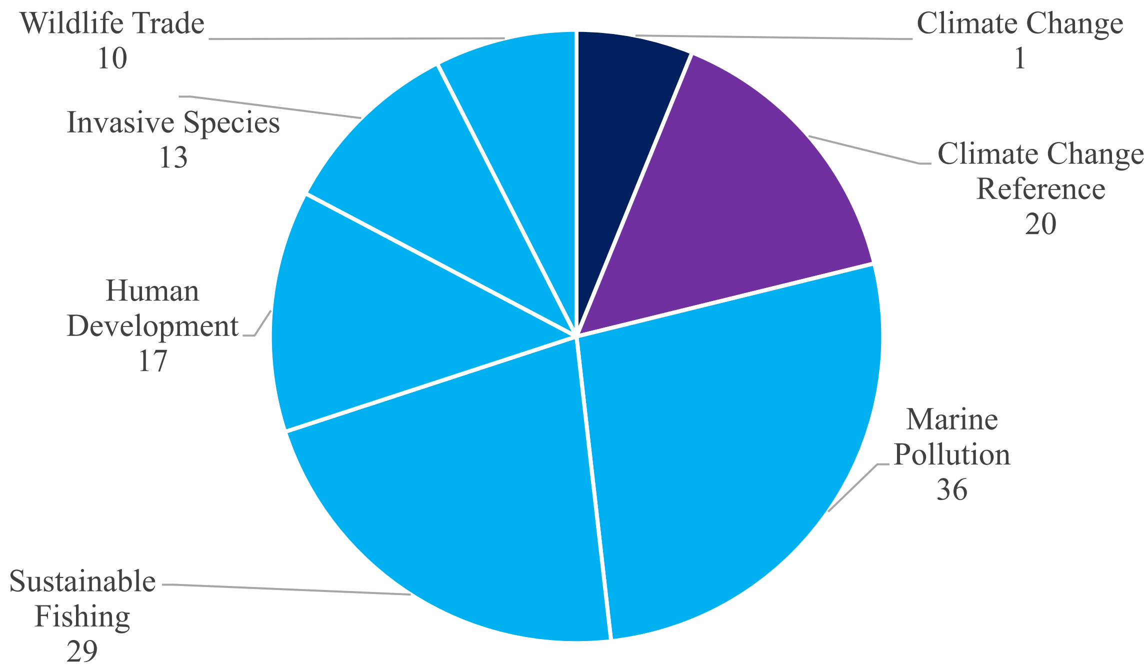

Figure 10. SSI messaging topics observed in virtual aquarium exhibits.

fees, donations, and grants to help fund the facility's objectives and goals (Sullivan, 2018). Similar to non-profit institutions, government/research institution run (n = 5) facilities do not earn profits. However, instead of being run by an organization, these institutions depend on municipality, state, or federal funding along with visitor fees and donations to operate (Sullivan, 2018). Government/research institutions can sometimes be managed universities as well. Private For-Profit (n = 2) institutions are usually owned by an individual or corporation with the aim of earning a profit for its founder(s) and/or management group (Majaski, 2021). Publicly Traded (n = 1) institutions are owned by public shareholders. These shareholders are entitled to portions of the company's assets and profits (Majaski, 2021). Figure 11 depicts aquariums we observed by their ownership type. Regarding the relationship between aquarium type and virtual exhibits about climate change/impact associated with climate change we found that the one virtual climate change exhibit belonged to a non-profit organization in California.

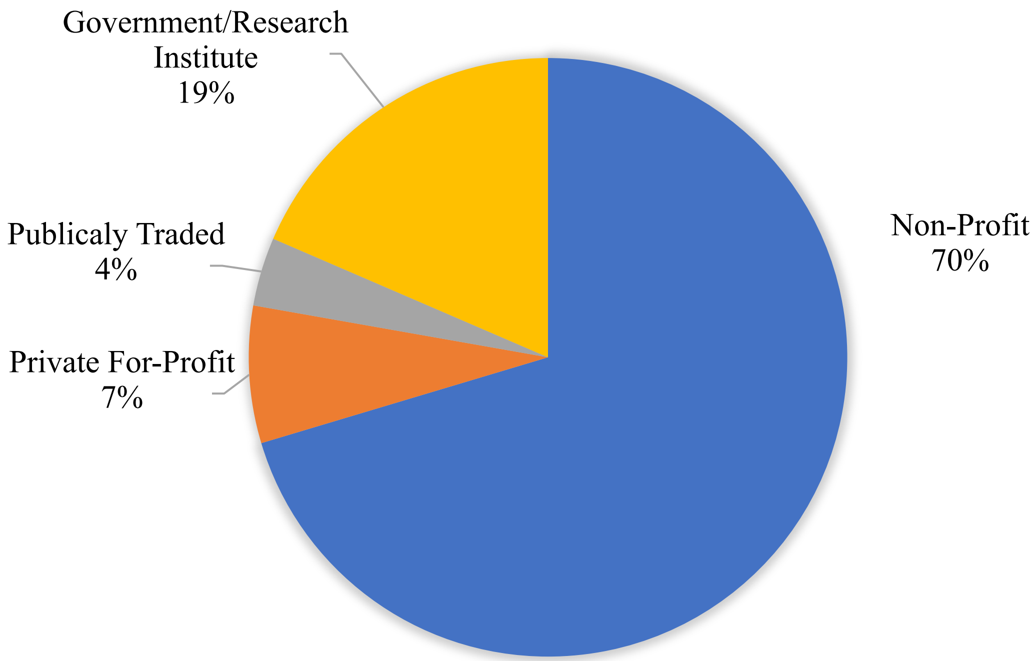

Figure 11. Aquariums observed by ownership type for virtual exhibits (n = 27).

Virtual exhibits that contained a reference to climate change/impact associated with climate change were largely found in non-profit aquariums (n = 16). The remaining virtual exhibits with a reference to climate change/impact associated with climate change were found in government/research institute run aquariums (n = 5). No climate change reference messaging was found in virtual exhibits from publicly traded and private for-profit aquariums. Figure 12 illustrates these virtual exhibits with climate change messaging by aquarium type.

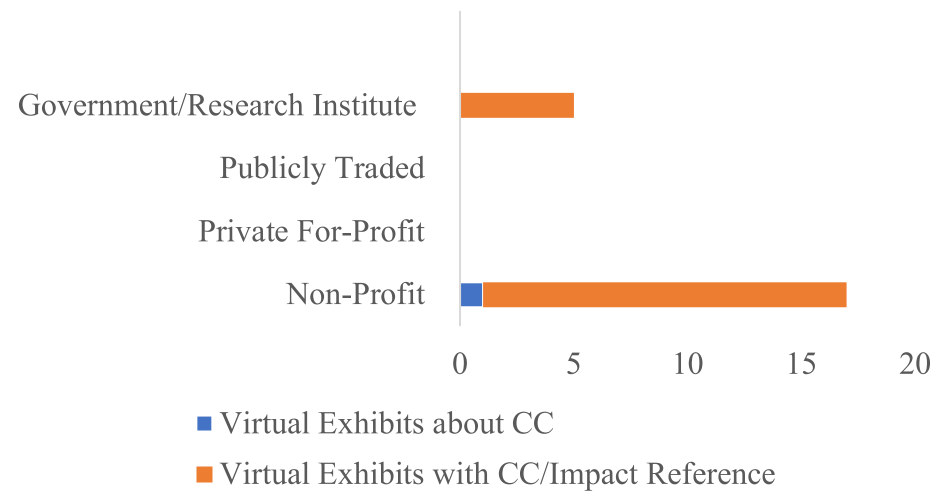

Figure 12. Virtual exhibits with climate change/impact messaging by aquarium type.

SSIF Characteristic Inclusion

Applying the SSIF characteristics checklist (Idema, 2021 Chapter II & III) to virtual exhibits classified as climate change/impact associated with climate change and those exhibits that referenced climate change/impact associated with climate change at least once (n = 21), we found that none of the exhibits used all the characteristics in a way that warrants classification as an SSIF instructional approach for exhibit design (Idema, 2021 Chapter II). All of the virtual exhibits (n = 21) included a social issue connected to science, incorporated interpretation principles and contained content and messaging that aligned with their ISI's mission/goals under the core aspect of design elements. Additionally, all exhibits expressed the instructional resource attributes characteristic of familiarity with the SSI through their mention of climate change/human impact associated with climate change within the virtual exhibit. All 21 virtual exhibits ground the SSI in relatable science content, reflecting a familiarity with the science content surrounding climate change and human induced impacts associated with climate change. Because of the online nature of virtual exhibits, all exhibits were marked as having the ability to be updated to leverage current events about climate change impacts. These were the only characteristics that virtual climate change/ impacts associated with climate change exhibits shared. We further classified virtual exhibits into three groups (Figure 13) – virtual exhibits that contained six or less characteristics (*low characteristic inclusion)*, virtual exhibits that contained between 7 and 11 characteristics (*moderate characteristic inclusion)*, and virtual exhibits that contained between 12 and 15 characteristics (*high characteristic inclusion)*.

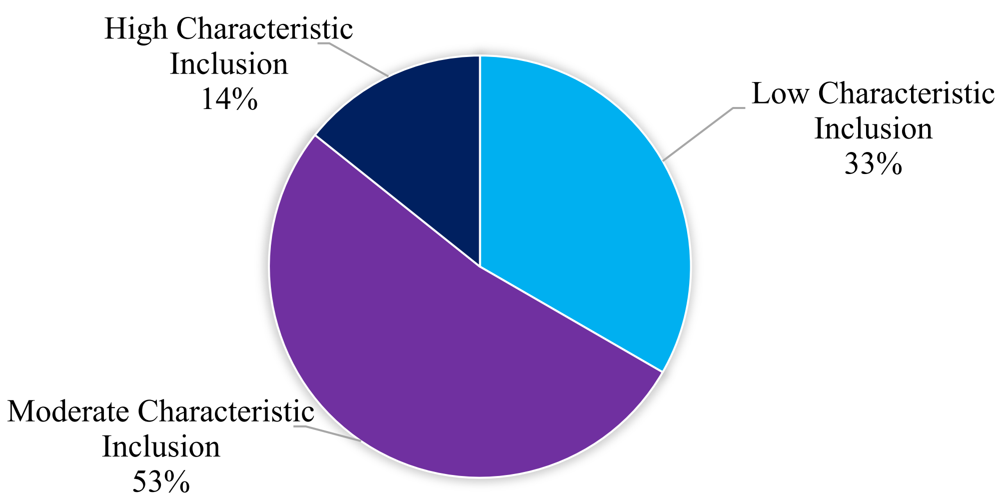

Figure 13. SSIF characteristic inclusion groups for virtual exhibits (n=21).

To illustrate the SSIF characteristics found in each group (Table 4), we capture our findings in a virtual exhibit profile for each characteristic inclusion group. Each virtual exhibit profile features an exhibit that was randomly chosen from the virtual exhibits in the inclusion group that contained the maximum number of core characteristics for the group. Each inclusion group profile describes the most typically included core characteristics for the group and includes a virtual exhibit description of these characteristics.

Table 4. SSIF core characteristics present in virtual exhibits about climate change/impacts.

SSIF Core Aspects and their characteristics	Low	Moderate	High
Design Elements - focus on the underlying design process that leads to the creation of the exhibit experience	n (%)	n (%)	n (%)
Includes a social issue connected to science	7 (100)	11(100)	3 (100)
The SSI is featured throughout the exhibit	0	0	1 (34)
Content and messaging aligns with the ISI's mission, goals, and industry standards	7 (100)	11(100)	3 (100)
Incorporates interpretation principles	7 (100)	11(100)	3 (100)
Grounds the message in real-world contexts that are localized	0	3 (27)	2 (67)
Grounds the message in real-world contexts that are relevant to visitors	0	3 (27)	3 (100)
Provides scaffolding opportunities that foster higher-order thinking and practice	0	0	2 (67)
Balances cognitive loads within the exhibit	0	2 (18)	3 (100)
Learner Experiences – essential cognitive experiences that support visitor learning about the SSI			
Actively engages the visitor in higher order practices	0	0	2 (67)
Provides opportunities for confronting ideas, theories, and misconceptions tied to the SSI	0	0	1 (34)
Provides visitors with access to opportunities to collect and analyze data tied to the SSI	0	1 (9)	2 (67)
Provides opportunities for visitors to explore different social dimensions tied to the SSI	0	4 (37)	1 (34)
Engages visitors in learning about the ethical/moral aspects of the SSI	0	0	2 (67)
Encourages visitors to consider nature of science themes tied to the SSI	0	0	0
Instructional Resource Attributes – guidelines for modeling learning through exhibits			
Exhibit design reflects a familiarity with the SSI being considered	7 (100)	11 (100)	3 (100)
Exhibit design reflects a familiarity with related science content	7 (100)	11 (100)	3 (100)
Exhibit design reflect a familiarity with the social dimensions tied to the SSI	0	5 (45)	1 (34)
Uses interactive components that contain science content over text heavy physical and/or virtual signage	0	11 (100)	3 (100)
Ability to have interactive components updated to leverage current events tied to the SSI	7 (100)	11 (100)	3 (100)

Note. Adapted from "A Framework for Socio-scientific Issues Based Education," by M. L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26-32.

Low Characteristic Inclusion – Saving Seals and Sea Lions. Virtual exhibits with low characteristic inclusion (n = 7 virtual exhibits) contained up to six SSIF core aspect characteristics (Table 4). No further design elements characteristics and instructional resource attributes were found in these virtual exhibits beyond those shared by all 21 of the exhibits. Additionally, none of the low characteristic inclusion virtual exhibits contained any learner experiences characteristics. None of the virtual exhibits in the low characteristic inclusion group included any climate change messaging that was localized, relevant, or both localized and relevant for visitors.

We chose a virtual exhibit about seals and sea lions represent the virtual climate change/impact exhibits in the low characteristic inclusion group. Opening the virtual exhibit page, visitors are greeted with information about the five different pinniped species at the aquarium. The initial exhibit webpage has a large picture of a sea lion that takes up half of the page. Heavy text gives visitors adaptation differences between seals and sea lions. Scrolling down the page, there is information on husbandry, natural habitat, range in the wild, IUCN status, and threats in the wild. The information is followed by a picture of one of the aquarium animals. Tabs can be clicked on for each of the five different pinniped species with the same type of information found on them. The only reference to climate change is the entire virtual exhibit is found on the spotted seal page under threats, "Climate change and habitat loss" are listed. Each species' page has an additional link to a pdf file containing more in-depth information about species' size, status, appearance, range/distribution, habitat, prey, predators, mating behaviors, threats, and fun facts. This exhibit was classified as a Category 2 because of its reference to climate change as a threat to spotted seals. There are no interactive components in the virtual exhibit beyond text, still photos, a pdf file with more still photos and heavy text.

Moderate Characteristic Inclusion – World of Jellies. Virtual exhibits in moderate characteristic inclusion contained between seven and eleven SSIF core aspect characteristics (Table 4). We classified all virtual moderate characteristic inclusion exhibits (n = 11) as Category 2. Like the low characteristic inclusion virtual exhibits, moderate characteristic inclusion virtual exhibits did not share any further design elements characteristics and instructional resource attributes beyond those shared by all 21 exhibits. However, three of the virtual exhibits with moderate characteristic inclusion did contain content and messaging that was grounded in contexts that were both localized and relevant for visitors under the SSIF core aspect of design elements. We found exhibits in this group used interactive components more frequently (n = 7) than the low characteristic inclusion group, although not all exhibits in the group addressed this instructional resource attributes characteristic.

An example of a moderate characteristic inclusion virtual exhibit is an exhibit about jellies. The virtual exhibit's main page uses a large picture of a sea nettle along with the invitation for visitors to explore the intriguing world of sea jellies and learn more about their importance for ocean ecosystems. Scrolling down the page, visitors can click on pictures of different types of jellies to explore what is a sea jelly, the importance of jellies, a sea jelly gallery, jelly husbandry, jelly conservation, jelly reproduction, and a webcam link for viewing a local species of jellies. Each link takes visitors to a separate webpage with brightly colored still photos of different jelly species juxtaposed with heavy texted information. Clicking on the *Importance of Jellies* link, provides visitors with information on different social and cultural dimensions related to jelly populations. Per the virtual exhibit, jellies are important because they are a part of sea creatures and human diets, contain biochemicals that show promise in treating various human diseases, and have advanced the study of proteins in cell and molecular biology research. A reference to climate change is found when visitors click on the link to a jelly conservation page. Using one large picture of a smack of jellies along with a full page of text, the virtual exhibit explains the impact of human contributions to the creation of low oxygen waters that create dead zones and how that impacts jelly populations.

> Some jellies thrive in low-oxygen environments… A changing climate and warming ocean are likely to affect sea jellies. Those that thrive in warmer waters may increase in number, while those that live in cold-water habitats may diminish. Large jelly blooms can pose problems for ocean swimmers because of the danger of being stung by some species. They can also clog cooling water pumps at coastal power plants, causing regional power outages.

The page includes information on ocean pollution and gaps in scientific research on jellies. Visitors are also provided with an opportunity to collect scientific data on jellies through an additional link under the headline, "What Can You Do?" The link informs visitors about a citizen science project they can take part in that monitors jellies along local coastlines and provides scientists with valuable scientific data.

The SSIF core characteristics of note represented in the virtual jellies exhibit include messages grounded in contexts that are localized through its inclusion of messaging about native jelly species and relevant for visitors by informing them about swimming hazards and potential regional power outages caused by growing jelly populations (design elements). The virtual exhibit addresses learner experiences characteristics by providing visitors with an opportunity to explore different social dimensions tied to the SSI via information on countries of the world that use jellies as a source of food and how jellies are utilized in medical research. Visitors are also provided with another learner experience through the opportunity to collect and analyze data tied to the SSI via a citizen science project. The virtual exhibit reflects the instructional resource attributes of a familiarity with different social and cultural dimensions tied to the SSI by including information about how Asian countries and medical research can be impacted by a lack of jellies.

High Characteristic Inclusion – An Ocean of Expression. Three virtual exhibits had high characteristic inclusion. One virtual exhibit in this group was classified as a Category 1 while the others were classified as Category 2. These virtual exhibits contained between 12 to 15 SSIF core characteristics (Table 4). High characteristic inclusion exhibits attempted to balance cognitive loads within the exhibits through their inclusion of some combination of audio clips, videos, live webcams, interactive graphics and games visitors could click on, brightly colored photographs, links to citizen science opportunities, links to current scientific research, and organism information under design elements. Two of the virtual exhibits included a message that was both localized and relevant.

Unlike previous inclusion groups, high characteristic inclusion virtual exhibits were found to have the learner experiences characteristic of engaging visitors in learning about the ethical and moral aspects tied to climate change/human induced impact associated with climate change. This characteristic was frequently expressed as, “If we don’t start changing our behavior” or “It is our responsibility to protect our oceans for future generations” and often ended with actions visitors could do to help lessen human-induced impacts on climate change. Virtual exhibits that had high characteristic inclusion also shared the instructional resource attributes characteristic of uses interactive components that contain science content over text heavy signage. While these three virtual exhibits did use text to communicate science content, they integrated text into infographics to help explain concepts over the use of heavy text. Two of the exhibits also provided opportunities for scaffolding using prompts.

An Ocean of Expression is an example of virtual exhibits with high SSIF characteristic inclusion and is an exhibit about marine mammals found in Arctic waters. The virtual exhibit uses 15 characteristics out of a possible 19. Entering the virtual exhibit, visitors learn it is a collaborative project between the aquarium, an oceanographic institution, and a production company. The virtual exhibit invites visitors to click on a marine mammal infographic (belugas and narwhals, baleen whales, sperm whales, beaked whales, porpoises, dolphins, and/or pinnipeds) to explore their voices. Each of these infographics links to webpages with videos and audio clips of whales, along with additional links to information on species' diet, range, behavior, IUCN status, and fun facts. Below the marine mammal graphics is a self-changing banner that visitors can click on to find information and videos about the changing Arctic, unusual mortality events, updates on whale tracking, and how organisms are affected by changes in Arctic sea ice. At the top of the page are additional links to:

1) Species - visitors can choose to learn more about cetaceans or pinnipeds by exploring these links;
2) Exhibit - visitors can explore where current physical Ocean Expression exhibits can be found in six different aquariums across the United States;

3) Videos - visitors can watch different videos on marine mammal species, acoustic research, conservation efforts, and different issues in focus. Issues in focus include links to videos and information on changing Arctic habitats, unusual mortality events, whale entanglement, modern whaling, and subsistence hunting;
4) Education - visitors can engage in learning about marine mammals through printable activities. The virtual exhibit states all activities included in the exhibit align with National Science Education Standards and Ocean Literacy Principles. Also listed are links to additional resources including government agencies, non-profits, interactive maps of the Earth and educational standards and principles;
5) Games - visitors can play "call matching" by listening to marine mammal calls and matching them to corresponding species photos, or the memory game that has visitors match marine mammals with their adaptations and habitats at different levels of easy, medium, or hard; and
6) Blog - visitors can read blogs from different scientists conducting research on marine mammals around the world.

Climate change information on the exhibit comes from a variety of links. The first is a 1:25 minute video on marine mammals in the changing Arctic. The video explores how global increases in temperature cause rapid reductions in seasonal Arctic ice and as result, opens the region up for new human activities that will impact an already fragile environment. Visitors are posed the question via a banner headline, "How will Arctic marine mammals adapt to these increasing changes in their environment?" Clicking on a link, visitors can apply the knowledge gained from organism information throughout the virtual exhibit to play a game that matches an organism with its adaptations and habitat.

Further webpage links provide access to videos about unexpected marine mammal die-off events in the Gulf of Mexico, Southern California, and Florida, and what these events tell us about the health of our oceans. A menu of additional video links lead visitors to organism information, current acoustic research, and conservation efforts.

An Ocean of Expression includes multiple social issues connected to science in the form of videos about climate change impacts on the Arctic Ocean, fishing sustainability and whale entanglement, and modern whaling versus subsistence hunting. The virtual exhibit's content and messaging aligns with institutional/national standards and this is affirmed for visitors via the exhibit's declaration that "all activities included in the exhibit align with National Science Education Standards and Ocean Literacy Principles." While the exhibit does not put climate change/human impacts associated with climate change in localized contexts, it does make them relevant for visitors by explaining through the video on Arctic Ocean impacts how climate change is having a cascading effect on ocean food chains, including seafood humans eat. The virtual exhibit balances cognitive loads through minimalistic text combined with videos to convey the impacts of climate change on species, games visitors can play to learn more about marine mammal characteristics and adaptations, and acoustic sound clips visitors can help scientists classify through a citizen science project. The only design elements characteristics the virtual exhibit does not address is putting messaging in local contexts.

Regarding learner experiences characteristics, the virtual exhibit provides visitors with access to opportunities to collect and analyze data via links to a citizen science project that has visitors listening to different whale calls to help scientists better understand whale "languages." The virtual exhibit also provides visitors with opportunities to explore different social dimensions tied to climate change through a video about the Inupiaq people and the impact climate change has on their subsistence hunting. This video is in contrast with a video on modern whaling. The virtual exhibit also engages visitors in learning about the ethical/moral aspects of the SSI through statements like "It is our responsibility to protect our oceans for future generations" and videos about the impact climate change is having on Inupiaq peoples. Unlike virtual exhibits in previous characteristic inclusion groups, this virtual exhibit meets all five of instructional resource attributes characteristics. The exhibit's design reflects familiarity with climate change through the presentation of climate change impacts on marine mammal species as well as familiarity with related science content present. By including viewpoints from native peoples, scientists, and members of the modern whaling industry via short videos, the virtual exhibit reflects a familiarity with different social dimensions connected to rising sea temperatures and thinning Arctic ice. The exhibit uses multiple forms of interactive components via short videos, audio clips, and games to convey science content as opposed to heavy text, and as these elements are through an online platform, they can be easily updated to include updates in research and current events linked to climate change/human induced impacts associated with climate change.

Identifying Trends Across Virtual Exhibits

Trends across virtual exhibits revealed organisms of focus could be classified into two main groups – nonpolar and polar. Nonpolar organisms included mammals (humans, dolphins, and otters), fish (sharks and seahorses), birds (bald eagle), invertebrates (reef-building corals, jellies, crabs, and shellfish), and algae (kelp). Polar organisms included marine mammals (cetaceans, pinnipeds, and polar bears) and birds (penguins). Virtual exhibits mainly focused on how climate change/impacts associated with climate change impact marine habitats, Habitat impacts on polar organisms focused on how rising sea temperatures cause sea ice to thin, which influences polar organisms' ability to survive. In non-polar organisms, habitat impacts focused on water quality and how climate change impacts create low oxygen dead zones. Economic impacts messaging only applied to the non-polar group. This messaging talked about how climate change causes declines in species (such as crabs and shellfish) that are economically important for human communities as well as how the destruction of coral reefs could impact research in the medical field or alter the protection of coastal communities from storms. Table 5 shows the overview of virtual exhibits by organisms featured, message theme, climate change/impacts and common communication elements used in virtual exhibits to convey information to visitors.

Table 5. Trends in virtual climate change/impact exhibits.

# Exhibits	Primary Organism Featured*	Message Themes	Climate Change/Impacts	Communication Elements
	Non-Polar			
1	Humans	General impacts	Changes to climate	Still photos, text, links to current research, videos; interactive map
1	Dolphins	Habitat impacts	Loss of species habitat	Still photos, text, links to current research
1	Otters	Habitat impacts	Habitat loss, prey availability	Still photos, text
1	Sharks	Population impacts	Rising sea temperatures reduce species populations	Still photos, text
1	Sea horses	Population impacts	Rising sea temperatures impact on species population	Still photos, text
1	Bald Eagle	Habitat impacts	Rising sea temperatures impact habitat, prey availability	Clickable slide show
2	Reef building corals	Economic impacts	Climate change causes losses medical research, food, coastal development	Still photos, text, links to current research, videos
2	Jellies	Population impacts Economic impacts	Ocean temperature changes impact species populations; large blooms impact vacationers, clog cooling water pumps at coastal power plants causing regional power outages	Still photos, text, links to current research, links to citizen science projects, gifs, links to webcam
2	Shellfish	Habitat impacts Economic impacts Population impacts	Ocean acidification; habitat loss and low water oxygen levels impact species populations; impacts fishing industry (job loss)	Still photos, text; links to biologist pages, links to current research
1	Kelp	Habitat impacts	Rising sea temperatures impact habitats	Still photos, text; links to citizen science projects
	Polar			

2	Cetaceans	Habitat impacts	Rising sea temperatures impact habitats	Still photos, text; infographics, acoustic sound clips, videos, interactive map, interactive game
2	Pinnipeds	Habitat impacts	Rising sea temperatures impact habitats	Still photos, text
		Population impacts	Rising sea temperatures impact prey availability	
1	Polar bears	Habitat impacts	Rising sea temperatures impact	Still photos, text; links to interactive games
3	Penguins	Population impacts	Rising sea temperatures impact breeding	Still photos, text; webcam links; current science news links
		Habitat impacts	Rising sea temperatures impact prey availability	
21	Total			

None of the 21 virtual exhibits used all of the SSIF characteristics that would justify classification as representative of a holistic SSIF instructional approach. Across all three characteristic inclusion groups, some characteristics in the core aspects of design elements and instructional resource attributes were addressed. In the moderate and high characteristic inclusion groups, seven virtual exhibits addressed some learner experiences characteristics (Table 4).

All virtual climate change/impact associated with climate change exhibits included a social issue connected to science, but few attempted to make the SSI message relevant only (n=1) or both localized and relevant (n=5) for visitors. None of the virtual exhibits made the SSI localized only. Additionally, opportunities for scaffolding were absent from 90.48% of the virtual SSI exhibits and only 23.80% addressed cognitive load planning. Only seven of the observed virtual exhibits supported learner experiences and included opportunities that would allow visitors to engage in higher order practices, confront prior ideas, theories, and misconceptions, explore different social dimensions, collect and analyze data, learn about ethical/moral issues, and/or consider nature of science themes linked to climate change and its impacts.

All 21 of the virtual exhibits reflected familiarity with the SSI and presented relevant science content related to climate change. Despite their potential for interactive components, we found the most common form of communication virtual exhibits used to communicate science content was still photos and text. In 85.71% of the virtual exhibits, science content was text heavy, with long paragraphs of text and a few photos used to convey information. The information communicated through still photos and text was largely about exhibit organisms (n=19), although four exhibits used this method of communication to additionally describe the in-person version of the aquarium exhibit. Other common elements used to communicate information in virtual exhibits include videos/links to videos/livestreams (n=11), links to research either currently being done by scientists or citizen/community science projects visitors could participate in (n=10), and moving photos and slideshows with text (n=9). Additionally, some exhibits provided visitors with actions they could do by engaging with the exhibit (n=6) such as playing a game, clicking on an interactive map, or activities (i.e., science experiments, coloring sheets) that could be downloaded and/or printed.

Limitations of the Study

We collected virtual exhibit data over the course of one year. We were not able to collect data on when a virtual exhibit was created, nor were we able to document how frequently virtual exhibits were updated as the Covid-19 pandemic prevented us from collecting interviews with ISI staff that would provide answers to these questions. To help ensure reliability of our virtual exhibit observations over the year of data collection, a member of the research team would revisit each virtual exhibit every three months to check for exhibit updates and update the virtual exhibit observation accordingly to reflect the most current version of the exhibit. We found only one exhibit was updated during this time. Infrequent updates were likely due to a large number of ISI staff were either laid off or furloughed during the pandemic and a lack of funds from visitor fees that support virtual exhibit updates. This exhibit observation was updated with additional still photos and a link to a live webcam of a penguin exhibit. In the event that a virtual exhibit could no longer be found, we omitted the observation from our data analysis. Only two virtual exhibits were omitted from data analysis and neither of these exhibits contained a reference to climate change or its impacts.

During initial data collection we noticed a trend begin to arise regarding the structuring of virtual exhibits. Some aquariums used exhibits as a space to tell visitors what they would see if visiting the facility in-person. Other aquariums structured virtual exhibits as novel online experiences not available if visiting the institution in-person or used virtual exhibits to augment in-person exhibit experiences through extended lessons. There was some concern that exhibit structure might influence interteam reliability on exhibit observation procedures. To ensure consistency across research team observations we only entered virtual aquariums through links labeled *exhibits* or *virtual exhibits*.

Discussion

Our study explored socioscientific communication by examining the presentation of climate change messaging featured in virtual aquarium exhibits (n = 256).

Furthermore, we examined how virtual climate change messages were localized and/or made relevant to visitors. Less than 10% of virtual exhibits incorporated messages about climate change/impacts associated with climate change and fewer still (2%) ground those messages in contexts that were only relevant and/or both localized and relevant. Aquariums have the advantage of attracting visitors and providing a large platform for exposure to climate change (Moser, 2010; Clayton & Myers, 2015) through their virtual exhibits. Therefore, the lack of climate change/impacts associated with climate change messaging in virtual exhibits is concerning given that ISIs like aquariums are viewed as places people can trust to provide factual science information (Bell et al., 2009; Falk & Dierking, 2010; Semczyszyn, 2013), and in light of recent Covid-19 restrictions, there is greater dependency for access to ISIs virtually (Graeber, 2020). By not engaging visitors in learning about climate change in virtual exhibits, aquariums may be missing opportunities for connecting visitors with an SSI that is likely already impacting them (Herman, 2018). Additionally, embedding climate change/impacts associated with climate change messaging in contexts that are both local and relevant for visitors can help them better understand how their actions and the actions of their communities impact the environment (Ballantyne, 2016; Nisbet, 2009), yet few (n=6) virtual exhibits attempted to do this. Prior studies on the SSI suggest relevance is a key part in learning about climate change (Allen & Crowley, 2017) and fostering changes in attitudes that help increase participation in conservation actions (Herman et al., 2018; Sadler et al., 2007; Walsh & Tsurusaki, 2014). The omission of climate change/impacts associated with climate change messaging in virtual exhibits furthers a divide between the publics' feelings and the SSI (Clayton & Meyers, 2015).

Our findings reflect discrepancies between theory supported known best practices for science instruction and implementation of practice. As such, aquariums could benefit from restructuring their virtual exhibit format to include the SSIF characteristics that make SSI-based learning effective (Idema, 2021 Chapter II). Our findings revealed a reliance on text to engage visitors in learning about climate change/impacts associated with climate change. In the updated SSIF, text-heaviness is an instructional resource attributes characteristic that can hinder learning about SSI because it contributes to an imbalance in cognitive loads (Idema, 2021 Chapter II). People already struggle to relate to climate change/impacts associated with climate change due to its complexities (Clayton & Myers, 2015; Moser, 2010) and combined with an over-reliance on text, visitors may lose interest and exit the virtual exhibit before engagement can occur (Bitgood, 1989; Serrell, 2015; Veverka, 2011). Text-heavy content and balancing cognitive load can be addressed through the inclusion of purposeful interactive components (i.e., interactive maps, games) that reinforce science concepts discussed in the virtual exhibit (Idema, 2021 Chapter II). Only 33% of the virtual exhibits that included climate change/impact associated with climate change messaging utilized the instructional resource attributes characteristic of interactive components. Virtual exhibits as technology have the added benefit of incorporating interactive components more easily than their in-person counterparts, as well as the ability to be updated more frequently and cost effectively (Decker, 2015; Song et al., 2004) to leverage current events and research tied to climate change (Idema, 2021 Chapter II). By not including interactive components in the virtual exhibits with climate change messaging, aquariums may be further missing opportunities to engage visitors in learning about this SSI.

Implications for Practice

The Covid-19 pandemic hit society hard and unfortunately, ISIs were not spared from these impacts (Graeber, 2020). However, the pandemic did provide some validations for ISIs. The pandemic further highlighted the need for having a science literate society (Sinclair et al., 2020). As some of the largest places where science education happens outside of a formal classroom, ISIs are important contributors towards the science literacy of their communities (Bell et al., 2009; Falk & Dierking, 2010; Patrick & Tunnicliffe, 2013). In our current technology age, people have access to science information as easily as a swipe of a smartphone touch screen or the click of a mouse. Thus, there is also a need for supporting access to science from reliable and credible online sources such as what can be provided by ISIs (Gallotti et al., 2020; Godinez & Fernandez, 2019). As reliable sources for science information, ISI virtual exhibits can provide safe spaces for visitors to confront misconceptions, prior knowledge and explore ideas about climate change, and other controversial SSIs. The SSIF is a way to ensure the virtual places people visit have effective built-in strategies that can help navigate and build skills necessary to make decisions and engage actions needed to mitigate climate change impacts (Herman et al., 2018; Sadler et al., 2007). Designers are faced with creating virtual exhibits that can teach SSI content while also balancing cognitive loads in online spaces (Fahoy, 2008). Interactive components online look different than in physical environments and can offer unique experiences. Still, designers must be attentive to how content is communicated and focus on using less text and more user-friendly interactive elements. The included technology in virtual exhibits should augment and not hinder potential learning experiences. The SSIF for exhibit design provides a foundation for best practices to enhance current virtual exhibits and create new exhibits (Idema, 2021 Chapter II).

The global pandemic also illustrates opportunities to enhance visitor science learning through virtual exhibits (Graeber, 2020). People were looking for fun, socially distant, engaging ways to supplement formal classroom learning (Graeber, 2020). Virtual exhibits allowed aquariums to continue engagement with visitors throughout lockdown scenarios (Antoniou et al., 2013). Virtual exhibits also have the ability to reach broad audiences as platforms for science learning through little to no cost, round the clock access (Benbow, 1995; Benbow, 1997; Decker, 2015; Graeber, 2020; Song et al., 2004). Because virtual exhibits are generally free to access, they can provide opportunities for people who cannot afford the luxury of visiting an aquarium in person with access to science information. Herein, lies an opportunity for virtual exhibits to reach an audience they may not have been reaching in-person.

Conclusion

Without knowledge about SSIs such as climate change, there is limited engagement by individuals to reverse the destruction of habitats, rapid biodiversity losses, and exponential growth of invasive species (Ballantyne, 2016). Therefore, it is vital for aquariums and other ISIs to facilitate learning about SSIs in online communities by providing visitors with virtual exhibits that feature appropriate science content, embedded in local and relevant social contexts (Zeidler & Nichols, 2009).

As technology continues to advance, aquariums and other ISIs are presented with more opportunities for engaging visitors in learning about SSI in creative and unique ways. However, before more innovative ways to engage the public in SSI learning can be developed, we first have to understand how ISIs currently communicate and engage visitors with SSI in online communities. Literature on virtual exhibits is limited (Foo, 2008; Kim, 2018) and even more limited are studies that examine the use of socioscientific issues in virtual spaces (Idema, 2021 Chapter II; Yun et al., 2020). Existing research focuses on virtual exhibit design rather than the educational messaging communicated within the exhibit (Antoniou et al., 2013). This study contributes to the nascent literature on virtual exhibits through its exploration of a platform that has the potential to increase accessibility of science information to broader audiences.

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V. DISCUSSION

Key Takeaways and Implications

Chapter II serves as an introduction to the SSIF, calling attention to the lack of empirical research on the SSIF in informal settings (Burek, 2012; Yun et al., 2020). This chapter defines SSIF's fundamental features, identifies potential influences that impact SSI-based instruction, and adapts the framework for use in ISI exhibit design. By clearly defining the SSIF's characteristics and goals, Chapter II helps address the need for a common language around SSI education in ISI (Yun et al., 2020), and sets the scene for the next two chapters.

Chapter III explores climate change communication in existing in-person aquarium exhibits. In this study, I used the updated SSIF for exhibit design as a lens for gaining insight into how aquariums communicate the SSI of climate change, how they localize and make climate change messaging relevant for visitors and identify trends in messaging. The results of this study revealed a lack of climate change messaging in existing exhibits as well as a disconnect between the SSIF and practice in aquariums. While existing in-person climate change exhibits employed some of the SSIF characteristics, none did so holistically. Additionally, few in-person exhibits made any attempts to localize climate change messaging and/or make it relevant for visitors. This is concerning as the lack of local and relevant connections could hinder visitor perceptions about the SSI and impact their involvement in climate change actions (Clayton & Myers, 2015).

Chapter IV examines climate change messaging in existing online aquarium exhibits. This research happened as a result of the Covid-19 pandemic, which dramatically altered my original proposed research, in addition to changing the way aquariums and other ISIs engaged with the public (Graeber, 2020). The findings from this study revealed virtual exhibits with climate change messaging mirror their in-person counterparts. Few aquariums incorporate climate change messaging in virtual exhibits. While some exhibits use characteristics of the SSIF in their approach to climate change communication, none do so in a way that fully supports SSIF-based instruction. Lack of climate change knowledge limits the engagement of individuals in actions that help mitigate climate change impacts (Ballantyne, 2016). As such, it is important for aquariums and other ISIs to utilize SSI instructional-based approaches (Presley et al., 2013) in the spaces people frequent to learn about science in fun and engaging ways (Bell et al., 2009). By using the SSIF in their in-person and virtual exhibits, ISIs can provide visitors with the tools needed to navigate the complexities of SSIs.

My dissertation research provides insight for ISIs by calling attention to the need for more climate change communication in both in-person and virtual exhibits, while presenting them with suggestions that can make current exhibits more effective. By adapting the SSIF for use in exhibit design, my research also provides ISIs with direction for planning future exhibits.

In formal education, research suggests that professional development surrounding SSIF-based instruction can develop and maintain educator confidence in their science teaching abilities (Carson & Dawson, 2016; Gray & Bryce, 2006; Sadler, 2011; Tidemand & Nielsen, 2017). Here lies another opportunity for SSIF adaptation from the formal to the informal classroom. SSI are complex and often controversial (Zeidler & Nichols, 2009). Informal educators may not be comfortable or have the knowledge of best practices for engaging visitors in learning about SSI. Adapting the SSIF for informal science educator professional development could help them become more effective at engaging visitors in learning about local and relevant SSIs.

As society evolves, so too do the identities of the institutions that house and preserve what our cultures deem worth saving (Patrick & Tunnicliffe, 2013; Rabb, 1994; Yun et al., 2020). As ISIs look to the future of exhibit design and programming, the SSIF can serve as a vehicle that helps take them there.

A Preliminary Analysis of Overlapping Exhibits

An additional question arose as a result of my analysis of in-person and virtual exhibits – how does climate change/impact associated with climate change messaging compare across the same aquarium exhibit's in-person and virtual version? Data was collected from 14 of the same AZA accredited aquariums across the U.S. in-person and virtually. Of these aquariums, only one contained any exhibits that overlapped virtually and in-person (Figure 14). At this aquarium, two exhibits overlapped. Both of these exhibits came from a non-profit institution located in California (Sullivan, 2018). The first was an exhibit that referenced climate change impacts on coral reefs.

Applying the SSIF characteristic checklist (Idema, 2021 Chapter II – IV) to the exhibits, I found the coral reef exhibit shared many of the same SSIF characteristics across both types of exhibits. Under *design elements*, both types of exhibits included a social issue connected to science, with their content and messaging aligning with the aquarium's mission/goals, and industry standards, and incorporated exhibit design principles (Tilden & Craig, 2009; Veverka, 2011). However, only the virtual exhibit ground its message in context that were relevant for visitors by discussing the potential

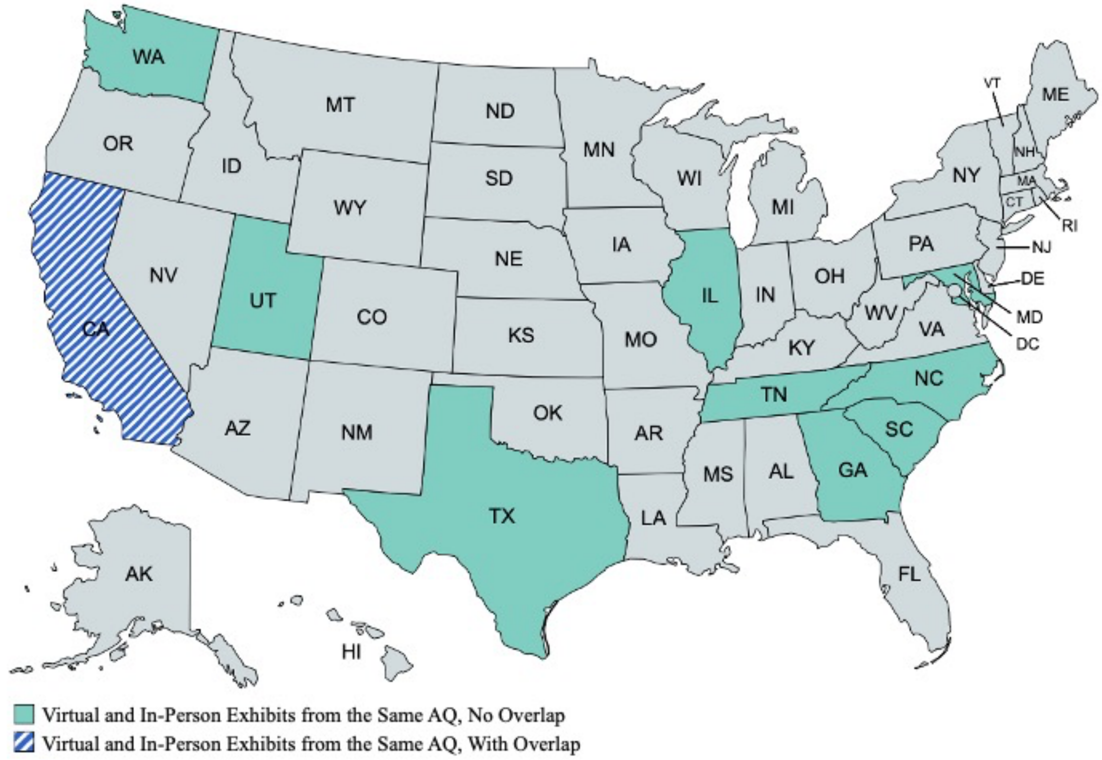

Figure 14. Aquariums by location. Illustration of state locations of aquariums where observations of both in-person and virtual exhibits were conducted.

for medical breakthroughs derived from studying coral reefs. The virtual exhibit encouraged visitors to "take action" to help save coral reefs. Both versions of the exhibit shared the *learner experience* characteristic of providing visitors with opportunities to explore different social dimensions connected to the SSI, but that is the only characteristic present that both types of exhibits shared. In-person, the coral reef exhibit provided visitors with opportunities to confront prior ideas, knowledge, and misconceptions about climate change's impact on coral reefs through use of physical signage that talked about common misconceptions about climate change. Virtually, the exhibit contained the learner experience characteristic of providing visitors with opportunities to learn about the ethical/moral connections to the SSI. Through still photos and text, the virtual coral exhibit informed visitors about the potential "life-saving medicines" that could help cure diseases and create new medicines for sick people. Looking at *instructional resource attributes*, both types of exhibits shared the characteristics of familiarity with the SSI being considered and familiarity with the science content connected to climate change. However, only the virtual exhibit's design reflected a familiarity with social dimensions tied to the issue and had the ability to have its components updated to leverage current events tied to climate change and its impacts.

The second exhibit that overlapped both in-person and virtually is an exhibit about human impacts such as consumption of natural resources and land development and their contributions to climate change. Both types of this exhibit shared the design element characteristics of including a social issue connected to science, featured the SSI of climate change throughout the exhibit, contained content and messaging that aligns with the aquarium's mission/goals and industry standards, as well as incorporated exhibit interpretation principles (Tilden & Craig, 2009; Veverka, 2011). Both types of exhibits attempted to balance cognitive loads within the exhibit. In-person, the human impact exhibit used interactive touch tables and manipulatives visitors could touch and move that simulated how human actions contribute to climate change. Virtually, this was done through interactive infographics visitors could click on, however, the information in this virtual exhibit was text-heavy with long paragraphs of information. The design elements the exhibits differed in was the attempt to ground its message in local and relevant contexts. Only the virtual human impact exhibit did this. Learner experience characteristics differed greatly between the two types of exhibits in that only virtual version of the human impact exhibit contained any of these characteristics. Regarding instructional resource attributes exhibits differed in their use of interactive components over text heavy signage. While the virtual exhibit did incorporate some interactive components (i.e., interactive infographics) the vast majority of the exhibit contained long paragraphs of information. Table 6 illustrates the SSIF characteristics found in virtual and in-person exhibits about the impacts of climate change on coral reefs and human impacts that contribute to climate change.

Table 6. A comparison of in-person and virtual aquarium exhibits that overlap.

SSIF Core Aspects and their characteristics	**In-Person Coral**	**Virtual Coral**	**In-Person Human Impact**	**Virtual Human Impact**
Design Elements - focus on the underlying design process that leads to the creation of the exhibit experience				
Includes a social issue connected to science	P	P	P	P
The SSI is featured throughout the exhibit	A	A	P	P
Content and messaging aligns with the ISI's mission, goals, and industry standards	P	P	P	P
Incorporates interpretation principles	P	P	P	P
Grounds the message in real-world contexts that are localized	A	A	A	P
Grounds the message in real-world contexts that are relevant to visitors	A	P	A	P
Provides scaffolding opportunities that foster higher-order thinking and practice	A	A	A	A
Balances cognitive loads within the exhibit	A	A	P	P
Learner Experiences – essential cognitive experiences that support visitor learning about the SSI				
Actively engages the visitor in higher order practices	A	A	A	P
Provides opportunities for confronting ideas, theories, and misconceptions tied to the SSI	P	A	A	P
Provides visitors with access to opportunities to collect and analyze data tied to the SSI	A	A	A	A
Provides opportunities for visitors to explore different social dimensions tied to the SSI	P	P	A	A
Engages visitors in learning about the ethical/moral aspects of the SSI	A	P	A	P
Encourages visitors to consider nature of science themes tied to SSI	A	A	A	A
Instructional Resource Attributes – guidelines for modeling learning through exhibits				
Exhibit design reflects a familiarity with the SSI being considered	P	P	P	P
Exhibit design reflects a familiarity with related science content	P	P	P	P
Exhibit design reflect a familiarity with the social dimensions tied to the SSI	A	P	A	A
Uses interactive components that contain science content over text heavy physical and/or virtual signage	A	A	A	P
Ability to have interactive components updated to leverage current events tied to the SSI	A	P	P	P
Total	7	10	8	14

Note. P = Characteristic is present. A = Characteristic is absent. The SSIF checklist is adapted from "A Framework for Socio-scientific Issues Based Education," by M. L. Presley, A. J. Sickel, N. Muslu, D. Merle-Johnson, S. B. Witzig, K. Izci, and T. D. Sadler, 2013, *Science Educator, 22*, 26-32.

In-Person verses Virtual Exhibits

Based on a preliminary analysis of overlapping exhibits and the work from Idema (2021, Chapters II-IV), I cannot in good faith make any claims that in-person exhibits are better than virtual exhibits or vice versa. For this aquarium, virtual exhibits had higher SSIF characteristic inclusion than in-person exhibits, but that does not necessarily mean t one type of exhibit is better than the other. Each exhibit type has its merit for the purpose that it serves. In-person exhibits can offer visitors opportunities to form emotional connections to animals and nature, as well as hands-on learning experiences (Ballantyne et al., 2011; Patrick & Tunnicliffe, 2013; Prevot & Clayton, 2018)) that can engage visitors in learning about SSI. In contrast, virtual exhibits can reach a have the ability to reach a broader audience around the clock, be updated easier, more frequently, and cost effectively than in-person exhibits (Decker, 2015; Song et al., 2004). Considerations must also be given to a virtual exhibit's purpose. The 13 other aquariums where the data was collected both virtually and in-person, virtual exhibits contained information about what visitors would see when they visited the aquarium in person, while the two exhibits that overlapped served as a way to augment a visitor's experience before or after they visit the exhibit in-person. Based on preliminary analysis, a virtual exhibit's purpose can influence SSIF-based instruction through exhibits. ISIs could benefit from applying lessons learned during the Covid-19 pandemic regarding access to reliable science information (Sinclair et al., 2020) and the need for opportunities to visit ISIs virtually (Graeber, 2020) and reassess the purpose of their virtual exhibits. Ultimately, ISIs should combine multiple types of exhibits, programming, and curricula to meet the wide array of visitor needs.

Next Steps in the Research

My current research plan is to continue exploring ways ISIs can address the gaps in SSI communication. First, I plan to explore the SSIF for exhibit design across different types of ISI. Current research focuses on the incorporation of SSIs in museums and science centers (Cameron, 2012; Christensen et al., 2016; Skydsgaard et al., 2016; Stuedahl et al., 2014) rather than the use of the SSIF in ISIs. What little research exists on exhibits that contain an SSI focuses more on exhibit's design elements with little attention given to exhibit messaging (Antoniou et al., 2013). I would like to apply the updated framework to climate change exhibits in museums other types of informal learning environments such as science festivals and science cafes to gain a more holistic understanding for how informal experiences can engage visitors in learning about this SSI through their exhibits.

Insights from this research could strengthen partnerships across institutions and provide best practices for SSI-learning by identifying strengths and opportunities to make existing and future exhibits more effective. Additionally, I would like to interview ISI administration and exhibit designers to identify potential barriers for communicating certain types of SSI (Reyes, 2020). Gaining a better understanding of where barriers for SSI communication exist could help ISI find new and more effective strategies for overcoming them.

The Covid-19 pandemic forced me to temporarily abandon my plans to study visitor engagement with in-person climate change exhibits. Post-pandemic, I hope to pick up where I left off, and explore visitor engagement with climate change exhibits to understand the visitor experience and what they take away from interacting with SSI messaging. Then I want to use my findings to further refine the SSIF for exhibit design to create ISI exhibits - both in-person and virtually - that can increase visitor knowledge and engage them in conservation action.

As discussed in Chapter II, the SSIF can be used as a tool for evaluating existing and future ISI exhibits. Another research goal of mine is to apply the findings from my dissertation research in combination with the findings from future study on visitor engagement with SSI exhibits and create an intervention plan. I would then implement this intervention to study how easily an existing exhibit that mentions a SSI can become a SSIF-based exhibit.

My ultimate research goal with the SSIF is to take the lessons I have learned from engaging in SSIF research in ISI and design an SSIF-based exhibit from the ground up. As part of this research goal, I aim to seek out partnerships with different types of ISIs, community members, practitioners from both formal and informal science education fields, researchers, and funders to create a cross-disciplinary learning experience that embraces the successes of formal SSI-based learning to enhance visitor engagement with SSI in informal settings. My hope is to secure enough funding to create and sustain the exhibit long-term, while making it available to the public for little to no cost. Myself, along with my community of researchers, could then study visitor engagement and refine the exhibit with the intent to create a model for exhibit design that ISIs around the world could use to create and engage visitors in learning about the complex issues our world faces today.

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APPENDIX SECTION

APPENDIX A

IRB Approval Letter

TEXAS STATE UNIVERSITY
SAN MARCOS
The rising STAR of Texas

In future correspondence please refer to 6594

June 28, 2019

Jennifer Idema
Texas State University
601 University Dr.
San Marcos, TX 78666

Dear Jennifer:

Your application titled, "Exploring the impacts of socio-scientific environmental issues through aquarium exhibits" was reviewed by the Texas State University IRB and approved. It was determined there are: (1) research procedures consistent with a sound research design and they did not expose the subjects to unnecessary risk. (2) benefits to subjects are considered along with the importance of the topic and that outcomes are reasonable; (3) selection of subjects are equitable; and (4) the purposes of the research and the research setting are amenable to subjects' welfare and produced desired outcomes; indications of coercion or prejudice are absent, and participation is clearly voluntary.

1. In addition, the IRB found you will orient participants as follows: (1) informed consent is required; (2) Provision is made for collecting, using and storing data in a manner that protects the safety and privacy of the subjects and the confidentiality of the data; (3) Appropriate safeguards are included to protect the rights and welfare of the subjects. (4) Compensation will not be provided for participation.

This project was approved at the Full Board Review Level until May 31, 2020

2. **Research should not be conducted at any site not approved by Texas State IRB.** Please note that the institution is not responsible for any actions regarding this protocol before approval. If you expand the project at a later date to use other instruments, please re-apply. Copies of your request for human subjects review, your application, and this approval, are maintained in the Office of Research Integrity and Compliance.

Report any changes to this approved protocol to this office. Notify the IRB of any unanticipated events, serious adverse events, and breach of confidentiality within 3 days.

Sincerely,

Monica Gonzales

Monica Gonzales
IRB Regulatory Manager
Office of Research Integrity and Compliance
Texas State University

CC: Dr. Kristy Daniel
Jennifer Idema
Victoria Reyes

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This letter is an electronic communication from Texas State University-San Marcos, a member of The Texas State University System.