AN ABSTRACT OF THE THESIS OF

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Title: The Deep Sea and Me: A Design-Based Research Study to Advance Public Literacy of the Deep Sea Using an Exhibit at a Public Marine Science Center

Abstract approved:

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Andrew R. Thurber

With growing populations and consumer demand, there has been a turn to the deep sea to meet our natural resource needs. The deep sea provides a range of benefits to humans—called ecosystem services—including carbon sequestration, fisheries, waste absorption and detoxification, and nutrient cycling, all of which are vital to life as we know it (Armstrong et al., 2012, Thurber et al., 2014). Barriers to effective management of deep-sea resources include (1) a lack of understanding by society of the benefits received from the deep sea and (2) how the public values it. To address this knowledge gap, this study utilized an iterative design-based research methodology to evaluate: (1) how to effectively use an exhibit at a science center to contribute to public literacy of the deep sea over the short and long-term and (2) how the public values deep-sea habitats. Three iterations of an exhibit entitled "The Deep Sea and Me" were evaluated and refined based on naturalistic observation, questionnaires, and interviews of visitors to ensure the exhibit's short and long-term success as a tool to communicate policy-relevant deep-sea science. Exhibits containing video and interactive components succeeded in communicating deep-sea information that was retained by visitors during their visit and one month later. Visitors tended to agree with protection-oriented statements towards the deep sea. This study provides insight into how to effectively communicate policy-relevant information about the deep sea to an audience that has little to no prior knowledge of the ecosystem, yet who will be increasingly responsible for making use decisions of this habitat.

The Deep Sea and Me: A Design-Based Research Study to Advance Public Literacy of the Deep Sea Using an Exhibit at a Public Marine Science Center

by
Katherine D. Darr

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Katherine D. Darr, Author

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CONTRIBUTION OF AUTHORS

Dr. Andrew Thurber, Dr. Shawn Rowe, and Jennifer East were involved with the design, methodology, and writing of Chapter 2 and Chapter 3.

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Chapter 1: INTRODUCTION

The deep sea is the Earth's largest ecosystem and provides diverse benefits to mankind, termed ecosystem services (Armstrong, Foley, Tinch, & van den Hove, 2012; Thurber et al., 2014; Jobstvogt, Hanley, Hynes, Kenter, & Witte, 2014). These include carbon sequestration, fisheries, pharmaceutically-valuable marine genetic resources, waste absorption and detoxification, and nutrient cycling, all of which are vital to life as we know it (Armstrong et al., 2012; Thurber et al., 2014). Barriers to effective management of deep-sea resources include a lack of (1) understanding by society of the benefits received from the oceans and (2) tools that can facilitate public involvement in deep-sea management. This study will provide insight into how to effectively communicate information about the deep sea to an audience that likely has little to no prior knowledge of the ecosystem, yet who will be increasingly responsible for making use decisions of this habitat in coming years.

A scientifically literate population enables citizens to actively contribute to informed policy and management decisions (Medved and Oatley, 2000; Steel, Lovrich, Lach, & Fomenko, 2005; Ehler, 2008; Pierce, Steel, & Warner, 2009). This is especially pertinent for Oregon's deep sea where there are many current and emergent uses. The purpose of this study was to develop and refine an exhibit that effectively communicates the importance of Oregon's deep-sea habitats and ecosystem services to visitors at a public science center over the short and long-term. In addition to contributing to the understanding of learning in informal settings, this study has important societal implications because many people are unfamiliar with the various deep-sea habitats and services that impact our daily lives through material benefits, such as fish, and nonmaterial benefits including scientific, cultural, and educational value (Thurber et al., 2014). Through the iterative development and evaluation of an exhibit at a public science center, we sought to answer the following questions: (1) how does an exhibit contribute to changes in visitor knowledge and perception of the deep sea over the short and long-term and (2) what elements of the exhibit contribute to visitor learning and engagement? Using a mixed methods approach to exhibit evaluation to reach our primary research objectives, we examined:

- If learning goals were met and retained
- What visitors learned about the deep sea
- How visitors perceived the role of the deep sea
- What learning behaviors visitors displayed
- How visitors perceived the exhibit

The Need for a Deep Sea Literate Public

A potential barrier to effective management of deep-sea resources is a lack of understanding by society of the benefits received from the deep sea. Many of the trade-offs between deep-sea ecosystem services have impacts on both natural and socioeconomic systems. Therefore, it is imperative for the public to understand the possible cumulative impacts and trade-offs of commercial exploits in the deep sea (Berkes, 2011). Understanding how the public values deep-sea ecosystem services is vital to establishing an informed, widely-supported, adaptive management strategy (Lester et al., 2010). Before the public can make meaningful contributions to management discourse, they must first understand what the various services are and how they are relevant to their lives (Steel, Lovrich, Lach, & Fomenko, 2005; Pierce, Steel, & Warner, 2009; Lewinsohn et al., 2015).

Knowledge is a prerequisite for citizens to participate in the policy process and contribute to management decisions (Steel et al. 2005; Pierce et al. 2009; Lewinsohn et al. 2015). Scientists can take steps to support public awareness of relevant deep-sea habitats and services to foster public knowledge and encourage involvement in the management of this ecosystem. All stakeholders deserve to receive high quality, accurate policy-relevant information and scientists can assist in fulfilling this need by sharing their work with public audiences (Baron, 2010). Deep-sea scientists should consider presenting their work in informal learning institutions, like museums and science centers, because most adult learning occurs in these settings (Falk & Dierking, 2010).

The Value of an Exhibit to Educate Oregon's Public

Informal learning institutions are important areas of science learning for adults and families (Medved & Oatley, 2000; Falk & Dierking, 2010). 95% of adult science learning occurs in these settings (Falk & Dierking, 2010). Many informal learning institutions have exhibits and displays explicitly aimed at improving scientific literacy of visitors (Medved & Oatley, 2000; Beaulieu et al., 2015; Martin, Durksen, Williamson, Kiss, & Ginns, 2016). Regarding the deep sea, Oceans Networks Canada and the Ocean Explorium have successfully used deep-sea video as a tool to engage the public with ocean literacy principles and improve their understanding of the deep sea (Hoeberechts et al., 2015; Beaulieu et al., 2015). Prior studies of science literacy in museums and science centers have primarily focused on whether or not visitors achieve learning outcomes immediately after interacting with an exhibit (Spiegel et al., 2012; Beaulieu et al., 2015;

Martin et al., 2016). There is a gap in knowledge regarding long-term retention of knowledge obtained from exhibit interaction. This study addresses that gap by assessing the retention of science knowledge and sustained interest in the deep sea one month following participants' visits.

Theoretical Framework

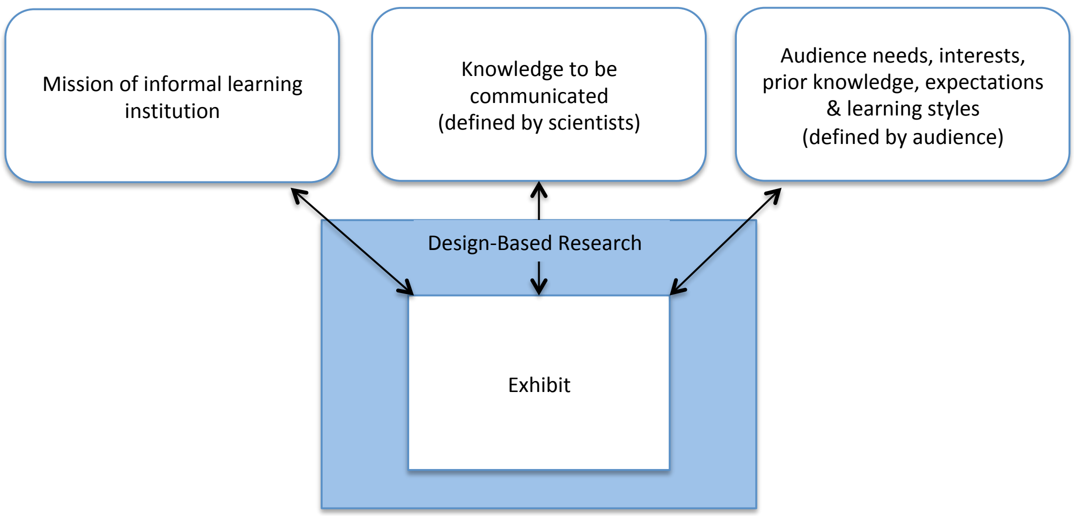

Figure 1: A collaborative transaction approach to science outreach program development in informal learning institutions between three communities of practice. (adapted from Kelly, 2004).

To facilitate successful collaboration between scientists, a science center, and the audience in the creation of an effective science outreach exhibit, we adapted a transaction approach to exhibit design to include design-based audience research (Figure 1) (Kelly, 2004; Seagram et al. 1993). The transaction approach supports a dialogue between information providers—scientists and a public science center in this case—and the audience to create an exhibit that meets the needs of all parties involved (Kelly, 2004; Seagram et al. 1993). Design-based research (DBR) involves multiple rounds of evaluation and refinement of a learning intervention, like an exhibit, to support greater in situ efficacy (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). A DBR-modified transaction approach enables the information providers to evaluate the success of the learning tool at different stages. Based on audience feedback collected from observations, interviews, and surveys, the tool is refined after each round of evaluation. Here, this approach ensured that scientists' outreach goals were met, museum goals were met, and audience expectations and needs were met.

Design experiments have been described as "test beds for innovation" which is appropriate for this study because the dissemination of deep-sea information to the public visitors in informal learning settings is a burgeoning topic (Cobb et al., 2003; Beaulieu et al. 2015). This study contributes to the growing body of research that is applying design-based research in informal learning institutions (Land & Zimmerman, 2015; Pattison et al., 2015; Cardiel et al., 2016).

Setting

This study took place at the Hatfield Marine Science Center Visitor Center (HMSC) in Newport, Oregon. HMSC is a public science center affiliated with Oregon State University and is operated by Oregon Sea Grant. At HMSC, visitors may encounter a number of interactive exhibits, including touch tanks of local rocky intertidal species and tanks of local fish species, and interpretive signage and informational videos that highlight Oregon's marine systems and research being done locally and regionally. The visitor center welcomes over 150,000 visitors annually, with most visiting during June, July, and August. 95% of visitors are from the Pacific Northwest, with 82% from Oregon (S.M. Rowe, Rowe, & Sullivan, 2017). Baseline data was collected during August, a month that receives high attendance on average, and the post-use data was collected during HMSC's off-season in the Fall of 2018.

Overview of Methods

The study followed a design-based research methodology and conducted front-end, formative, and summative evaluation. Two focus groups, each consisting of 10 randomly recruited adult residents of the Portland Metropolitan area (12/13/17) and the central Oregon Coast (1/16/18) respectively, served to identify knowledge gaps and areas of interest Oregonians have regarding the deep sea. Focus group responses informed exhibit learning outcomes and exhibit design.

Questionnaires were distributed to adult HMSC visitors in 3 phases to assess their perception and knowledge of the deep sea prior to interacting with the exhibit (phase 1), immediately after interacting with the exhibit (phase 2), and one-month later (phase 3). Phase 1 participants consisted of a separate pool of visitors than the post-use phases 2 and 3 to ensure post-use exhibit observations and survey responses were the result of naturalistic interactions with the exhibit, thereby legitimizing the summative evaluation of the exhibit and eliminating priming biases. Visitors were also interviewed in phase 2 to capture their impressions of the exhibit, suggestions for improvement, and overall efficacy of the exhibit. Visitor interactions with the exhibit were observed and recorded according to a predetermined rubric. Changes were made to the exhibit based on questionnaire and interview responses and observations of visitor interactions.

Thesis Outline

This thesis describes the development and evaluation of an exhibit as a tool to educate and engage Oregon's public with deep-sea science. Chapter 2, to be submitted to the journal Visitor Studies, describes how scientists can successfully collaborate with informal learning institutions and visitors to create an exhibit that serves their own mission, the institution's mission, and the needs of visitors. Chapter 3, to be submitted to the journal AMBIO, explores the exhibit as a tool for public engagement in the management of deep-sea resources. The conclusion (chapter 4) is a summary of the previous chapters, including discussion of findings, limitations, and suggestions for future research.

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Chapter 2: FACILITATING TRIPARTITE COLLABORATION: A DESIGN-BASED RESEARCH STUDY TO IMPROVE PUBLIC ENGAGEMENT WITH DEEP-SEA SCIENCE IN INFORMAL LEARNING SETTINGS

Abstract

This article describes a design-based research (DBR) study that assesses the efficacy of DBR as a brokering tool to foster collaboration between scientists, informal learning institutions, and visitors in the creation of a science outreach exhibit. This partnership is beneficial for scientists, informal learning institutions, and visitors. It gives scientists a venue to engage the public with their work, helps informal learning institutions meet their educational mission, and gives visitors a voice in guiding exhibit content and design. However, divergent strategies to exhibit design can make collaboration between these communities of practice difficult. Utilizing a DBR-modified transaction approach to exhibit design, we created an exhibit focused on deep-sea content . The exhibit underwent three rounds of evaluation and iterative refinement based on naturalistic observation, questionnaires, and interviews to ensure the exhibit met the success criteria for each of the three communities of practice. Our findings support the use of a DBR-modified transaction approach for exhibit design to enable greater collaboration among scientists, informal learning institutions, and visitors. Improved collaboration supports the creation of meaningful science outreach exhibits that meet the needs of the audience and the educational needs of scientists and informal learning institutions over the short and long-term.

Introduction

Scientists are increasingly interested in presenting their work to the public to build an engaged, scientifically literate populace (Mathieu, Pfund, & Gillian-Daniel, 2009; Watts, George, & Levey, 2015). Before the public can make informed, meaningful contributions to policy and management discourse, they must first possess some degree of scientific literacy (Steel, Lovrich, Lach, & Fomenko, 2005; Pierce, Steel, & Warner, 2009; Lewinsohn et al., 2015). Further, funding agencies, like the National Science Foundation, have placed greater emphasis on the broader impacts of funded research (Mathieu et al., 2009; Watts et al., 2015). Broader impacts refer to the public outreach and engagement efforts related to scientific research and may be achieved through activities like mentoring college students and creating curriculum for classroom use (Mathieu et al., 2009). However, limiting outreach and engagement to formal learning settings alienates the majority of the public from interacting with scientists' work because most science learning takes place outside of the classroom (Falk & Dierking, 2010). Informal learning institutions, like museums and science centers, are valuable venues for scientists to engage the public with their work. In this study, we reconceptualize design-based research as a tool to foster effective collaboration between scientists, informal learning institutions, and visitors in the creation of a deep-sea science focused outreach exhibit.

The primary roles of museums and other informal learning establishments are to educate and entertain (Seagram, Patten, & Lockett, 1993; Schwan, Grajal, & Lewalter, 2014). Generally, visitors expect to learn in these settings which makes them appropriate venues to share scientific research (Falk & Storksdieck, 2010). Studies that have tracked the impact of museum visits over time show a self-reported increase in scientific understanding and interest in science after their visit (Falk & Dierking, 2010). Creating science-focused exhibits supports both scientists' endeavors to connect the public with timely, societally relevant research and the role of museums and science centers as information providers.

Scientists and informal learning professionals, like museum curators and exhibit designers, represent two distinct communities of practice. A community of practice is marked by mutual engagement, joint enterprise, and a common repertoire; it is a group that works together to achieve some mutual goal using shared tools, language, actions, and concepts that have been developed over time through practice (Wenger, 1998). Although informal learning professionals and scientists might have a common goal, like the development of science-centric exhibits, they lack a shared procedure to reach that goal. Each group has a distinct approach they might take to the design of the exhibit that may be inconsistent with another group's approach.

Each community of practice also has different ways of framing messages. Framing refers to the way information is filtered and presented and is heavily influenced by one's values, ideology, and beliefs (Bateson, 1972; Nisbet, 2009). Scientists tend to communicate their work based on tools developed throughout their training to communicate among peers. However, this approach is an ineffective way to communicate information to the public, most of which does not share the technical training of scientists (Baron, 2010). Natural scientists often focus on quantitative changes in the physical environment. Sharing information with a purely material, quantitative focus does not connect with the frames through which much of the population understands the world (Lakoff, 2010). For example, a climate change exhibit that emphasizes warmer temperatures and rising sea levels may fail to resonate with visitors in a land-locked state in the middle of a harsh winter. Communication gaps resulting from inconsistent framing could cause tension during the exhibit design process and result in an exhibit that does not achieve each community of practice's goals.

When designing a tool for learning, it is important to consider the intended audience (Wenger, 1998). Although visitors are not formally a community of practice, the intent participation which occurs within and between visitor groups shares many qualities with the defining characteristics of a community of practice (Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003). For the purposes of this study, visitors are collectively treated as a community of practice that we refer to as the audience.

While exhibit creators and scientists may have mutual goals for an exhibit, namely the transfer of knowledge, they often have disparate skill sets and success criteria for exhibit development. Further, the audience is likely to have their own goals and expectations for the exhibit, which may or may not overlap with the scientific or curator goals. Despite the disparities between these communities of practice, they are connected to each other by a common boundary object (Wenger, 1998). Boundary objects are shared items—like maps, documents, and exhibits—around which the communities can organize their connections (Wenger, 1998). In this study, the exhibit is the item of shared attention around which the groups organize their interactions.

Design-based research (DBR) is a methodology that requires several iterations of research, design, and evaluation of a learning intervention to promote achievement of pre-determined goals in a particular environment, like an exhibit in a science center (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). Data generated by front-end, formative, and summative evaluations of an exhibit fosters boundary interactions between scientists, informal learning practitioners, and visitors. Boundary interactions involve the flow of information between communities of practice (Wenger, 1998). Through observations, interviews, and questionnaires, the audience is able to communicate to scientists and informal learning practitioners about how they are engaging with the intervention, if they are reaching desired learning goals, what should be changed about the intervention, and what is effective.

The iterative nature of DBR transforms it from a tool to support boundary interactions to a tool to broker between communities, or foster longer-term boundary interactions and dialogues between all three communities of practice (Wenger, 1998; Pawlowski & Raven, 2000). Incorporation of audience feedback into future iterations of the intervention are evidence of knowledge exchange that is indicative of brokering (Pawlowski & Raven, 2000). In this study, we found that a DBR approach to development and evaluation of science outreach exhibits can serve as a tool to broker interactions and, thus, facilitate effective collaboration between these three communities of practice.

Utilizing DBR to bridge communication gaps between communities of practice is compatible with the transaction approach to exhibit and program design described by Seagram et al. (1993) and Kelly (2004). The transaction approach describes a type of brokering that rectifies discrepancies between a mandate-driven exhibit design that focuses solely on supporting the learning institution's mission and market-driven exhibit design which focuses exclusively on creating exhibits that might entertain visitors, but do not meet the educational goals of the institution (Seagram et al., 1993; Kelly, 2004).

Instead, the transaction approach advocates for a dialogue between the mission of informal learning institutions and the audience's prior knowledge, expectations, and interests (Seagram et al., 1993; Kelly, 2004).

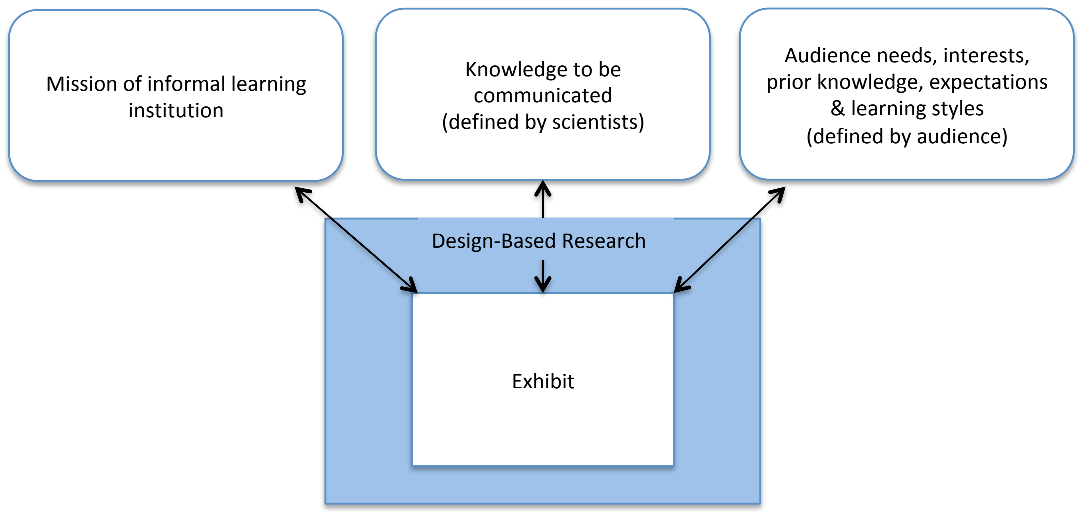

Figure 1: A collaborative transaction approach to science outreach program development in informal learning institutions between three communities of practice (adapted from Kelly, 2004).

Here, we have adapted the transaction approach to exhibit design to include scientists as knowledge providers and DBR as the filter, or broker, through which these communities of practice communicate (Figure 1). Using this modified transaction approach facilitates collaboration because it enables learning institution professionals and scientists to evaluate the efficacy of the program based on data from observations, interviews, and surveys of the audience. They are then able to make changes to the exhibit based on audience feedback. This approach confirms that the boundary object is tailored appropriately to meet the needs of the three communities of practice by ensuring that scientists' outreach goals, museum goals, and audience expectations and needs are met (Seagram et al., 1993; Kelly, 2004; Steger et al., 2018).

Outreach Potential of "The Deep Sea and Me": A Case Study. For this study, we developed an exhibit at the Hatfield Marine Science Center Visitor Center (HMSC) in Newport, Oregon and evaluated its outreach potential over the short and long-term. The communities of practice involved in this study were (1) deep-8sea biologists at Oregon State University, (2) HMSC staff, and (3) the adult visitors at HMSC, most of whom are from Oregon (S.M. Rowe, Rowe, & Sullivan, 2017).

Each community of practice defines successful collaboration differently. The deep-sea biologists in this study defined success as visitors reaching predetermined learning goals and developing a better understanding of public perception of Oregon's deep sea. The staff of HMSC defined success as visitors reaching predetermined learning goals and indicating a positive experience with the exhibit. Individual visitors may have different success criteria for the exhibit, but, in this study, we defined success for this community as a positive experience with an exhibit that captures their attention and holds their interest.

This study sought to demonstrate the efficacy of DBR as a brokering tool to support the successful collaboration of distinct communities of practice in the development of science outreach programs in informal learning environments. Most exhibit evaluation studies focus on the immediate knowledge changes, but this study is unique in that it assessed the outreach potential of the exhibit over both the short and long-term (Borun, Chambers, & Cleghorn, 1996; Spiegel et al., 2012; Beaulieu et al., 2015; Martin, Durksen, Williamson, Kiss, & Ginns, 2016).

Methods

Setting. HMSC in Newport, Oregon is a public education facility that seeks to engage Oregon's public with local marine habitats and enable scientists to share their work with the public. Visitors may encounter a number of interactive exhibits, including touch tanks of local rocky intertidal species and tanks of local fish species, and interpretive signage and informational videos that highlight Oregon's marine systems and research being done locally and regionally. HMSC welcomes over 150,000 people annually, with peak visitation in the summer months. Baseline data was collected during August 2018, and the post-use data was collected during HMSC's off-season in the Fall of that year. The exhibit was located between two fish tanks and an interactive kinetic sand table (Figure 2).

Figure 2: Layout of exhibits surrounding "The Deep Sea & Me" exhibit

Learning Goals & Exhibit Purpose. The learning goals for the exhibit, outlined in Table 1, were based on ocean literacy principles and focus group feedback (Cava, Schoedinger, Strang, & Tuddenham, 2005). Two focus groups provided a baseline understanding of Oregon residents' perceptions of Oregon's deep sea. Participants were randomly recruited by an external research agency based in Portland. Each focus group consisted of 10 randomly recruited participants from the Portland Metropolitan area (12/13/17) and the central Oregon Coast (1/16/18), respectively. Focus group responses were coded using Dedoose Version 8.2.27 (2019) and used to inform learning goals and exhibit content. Only three salient takeaway points were emphasized to increase the likelihood that visitors would remember those points about the deep sea beyond their visit (Cowan, 2001).

Table 1: Learning goals and success criteria for the exhibit

Learning Goal	**Success Criteria**
LG-1. Participant understands there is no sunlight in the deep sea. *Ocean Literacy Principle 5g*	Participant indicates there is no sunlight in the deep sea.
LG-2. Participant understands there are many unique habitats in Oregon's deep sea. *Ocean Literacy Principle 1, 5*	Participant correctly identifies at least 2 habitat types present in Oregon's deep sea
LG-3. Participant recognizes that processes in the deep sea can benefit humans. *Ocean Literacy Principle 6*	Participant correctly identifies the four major provisioning benefits of the deep sea.

Exhibit Design Strategy. The overarching design conjecture for the exhibit was to promote public science education and engagement via an exhibit at a science center using the following strategies: (1) frame information in a way that is relevant, meaningful, and memorable to the public, (2) allow multiple means of visitor interaction, and (3) the create an exhibit that is visually appealing to passerbys (Sandifer 2003; Falk & Dierking 2013). To address element (1), the exhibit was framed with an emphasis on ecosystem services and supporting information on relevant deep-sea habitats in Oregon. Information was intentionally locally focused to increase the relevance of the information and support cultivation of a sense of place, as many visitors to HMSC are local to Oregon (Rowe et al., 2017). To address elements (2) and (3), all iterations consisted of two panels of interpretive text and a video at minumum, ensuring at least two possible modes of visitor interaction (Sandifer, 2003). Visitors tend to spend more time at exhibits when there is a video presentation than they would if the same information was only presented in still, text form (Perdue, Stoinski, & Maple, 2012). Oceans Networks Canada and the Ocean Explorium have successfully used deep-sea video as a tool to engage the public with ocean literacy principles and improve public understanding of the deep sea (Beaulieu et al., 2015; Hoeberechts, Owens, Riddell, & Robertson, 2015). The video footage used at HMSC came from the Ocean Exploration Trust's 2016 Nautilus Expedition off of Oregon. The video was captioned, but did not have sound.

There were three iterations of the exhibit. Iteration A consisted of two videos (totaling six minutes) and two text panels containing information about the habitats and ecosystem services in Oregon's deep sea (Figure 3). Future iterations of the exhibit were informed by naturalistic observations of the exhibit and visitor survey responses.

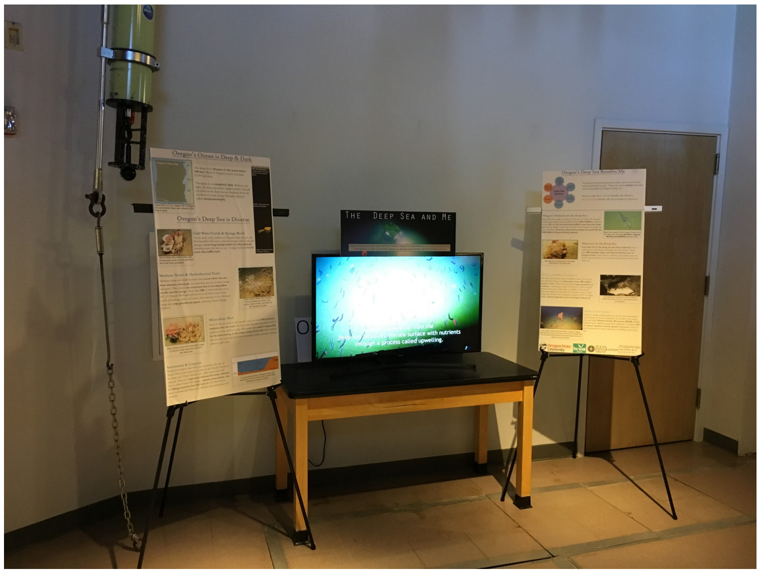

Figure 3: Exhibit iteration A of "The Deep Sea and Me"

Exhibit iterations B and C presented the same information as iteration A, but with different language and an altered display. Both the panels and the video were edited for clarity and visual appeal. The video was shortened to a single 3-minute and 40-second video to comply with recommendations that videos at exhibits be no longer than four minutes (Linn, 1983). Iterations B and C included an interactive element, a flip-over display to support visitor engagement and reinforce the learning goals of the exhibit (McManus, 1993; Diamond, 1999; Fenichel & Schweingruber, 2010). The flip-over display had questions about the deep sea on the exposed portion and visitors flipped the lid for the answer. 3D printed deep-sea animals were added to the video monitor, flip-up display, and table in iteration C.

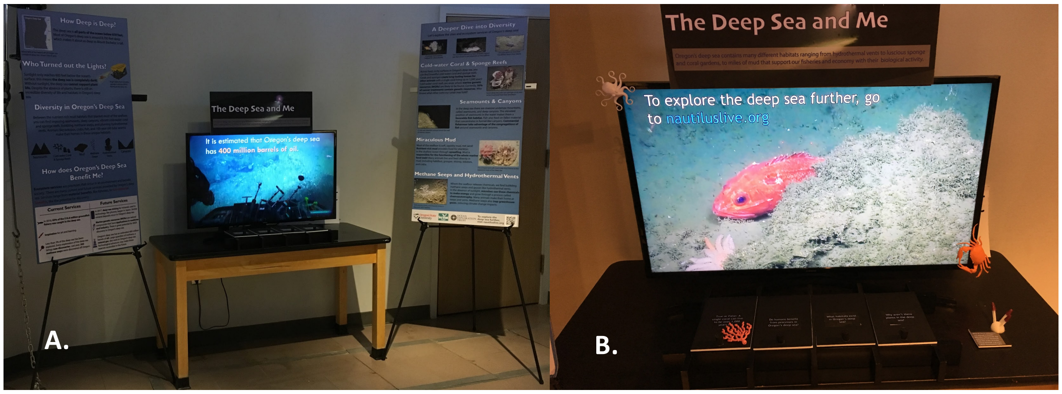

Figure 4: A) Iteration B and C panels and video B) 3D printed animals on Iteration C flip-up display, monitor, and table

Survey Design & Distribution.

Visitors were surveyed in three phases (Figure 5). To maximize sample size, participant selection employed continuous, purposive sampling of adults. Potential participants were informed of the study per an Institutional Review Board protocol and asked if they were interested in taking the questionnaire to assist in exhibit development. Participants took the questionnaire on iPads and their responses were recorded using Qualtrics (http://www.qualtrics.com/). Interview responses were audio recorded with participant permission.

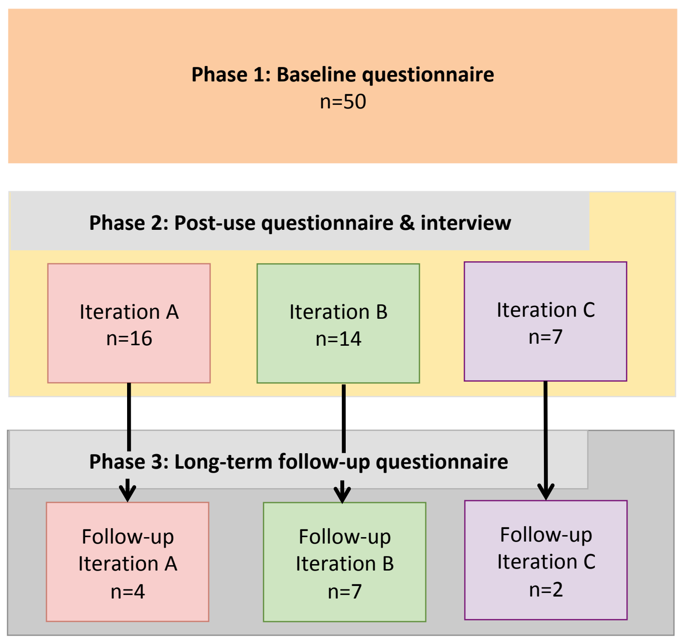

Figure 5: Sample sizes and activities that each group participated in during each phase.

In phase 1 (n=50), visitors were asked to participate in a brief questionnaire as they entered the visitor center to serve as a baseline of visitor knowledge and perception.

In phase 2 (n=37), a separate pool of visitors who stayed at the exhibit for a minimum of 30 seconds were asked to participate in a semi-structured interview and a questionnaire after viewing the exhibit to evaluate changes in knowledge and perception of the deep sea. Interviews captured visitors' post-use impressions of the exhibit, suggestions for improvement, and overal efficacy of the exhibit. Phase 2 participants were invited to participate in a long-term follow-up study (phase 3) for which they would be entered to win a $25 Amazon gift card. In phase 3 (n=13), participants from phase 2 were sent a follow-up questionnaire via email one month after their visit. Utilizing two separate pools of individuals for phase 1 and post-use phases 2 and 3 ensured that post-use exhibit observations and survey responses were the result of naturalistic interactions with the exhibit, thereby legitimizing the summative evaluation of the exhibit and eliminating priming biases.

All three questionnaires contained the same content knowledge, perception, and demographic questions. Content knowledge, perception, and long-term exhibit impact questions shed light on the efficacy of the exhibit as an educational tool to promote deep sea literacy over the short and long-term (Diamond, 1999; Falk & Storksdieck, 2010; Perdue et al., 2012; Sellmann & Bogner, 2013). Knowledge and perception questions were adapted from Guest, Lotze, & Wallace, (2015) and Needham (2010), respectively. Based on Sundblad, Biel, and Gärling's (2009) study about knowledge of climate change, participants were asked to rate their certainty in their response to content knowledge questions pertaining to learning goals 1 and 2 on a scale of 1 to 3 ("1" being not sure to "3" being extremely sure) to reduce false positives from guessing. Perception questions measured visitor's assigned value orientations towards the deep sea and its uses. The long-term follow-up questionnaire asked additional questions regarding the impact of the exhibit beyond the visit (i.e. whether visitors had looked up further information about the deep sea since their visit). The long-term follow-up provided insight into whether content knowledge is retained beyond the visit or if the exhibit sparks a lasting interest in the deep sea.

Observations. Based on a similar study by Cardiel, Pattinson, Benne, and Johnson (2016), each exhibit iteration received 10 hours of in-person, naturalistic observation across two consecutive weekends. Out of the view of visitors, a single observer with a stopwatch and data sheet tracked the attraction power of the exhibit, visitor holding time, visitor group composition, and visitor behavior. Collection of these particular visitor characteristics and behaviors shows the visual efficacy of the exhibit, the type of user the exhibit is attracting, and how visitors tend to interact with the exhibit (Donald, 1991).

Focal individual sampling was employed, in which one visitor at a time was observed (Diamond, 1999; Yalowitz & Bronnenkant, 2009). When the observed visitor left the area, the next visitor to enter the exhibit area was observed. Visitor holding time was calculated by selecting one visitor per group that entered within approximately 1.5 meters of the exhibit and tracking the duration of a visitor's time at the exhibit beyond their initial stopping time. Here, we define stopping time as the time spent at the exhibit with their "feet planted on the floor and eyes on the exhibit for 2 to 3 seconds" (Serrell, 1998, p. 12).

Visitor behavior was tracked according to a predetermined rubric of activities adapted from previous studies including: holding time, collaboration with other group members, reading the panels, watching the video, reading aloud, and lifting the flip-over display (this applied to iterations B and C only) (Borun, Chambers, & Cleghorn, 1996; Cardiel et al., 2016).

Data Analysis. Interview responses were coded in Dedoose Version 8.2.27, sorted into themes, and the frequency of themes was noted. Visitor behavior and questionnaire results were analyzed in SPSS Version 25 to assess changes in participant knowledge and perception of the deep sea using descriptive and non-parametric statistics to account for small sample size and non-normally distributed data (Hollingsworth, Collins, East, Smith, & Nelson, 2011). All comparisons between post-use and long-term results included the post-use responses of participants who also completed the long-term questionnaire only.

Results

Visitor Behavior.

Exhibit Attraction Coefficient. The attraction coefficient for each exhibit iteration was calculated from the following equation:

$$\textbf{Attraction Coefficient} = \frac{\textbf{(\% of visitors who stop at the exhibit for at least 2 seconds)}}{\textbf{(visitors passing + visitors stopping)}} \; \textbf{*100}$$

(Donald, 1991; Sandifer 2003). The attraction coefficient increased from 29% in iteration A to 34% in iteration B to 35% in iteration C (figure 6A).

Group composition. Solo adult visitors comprised the largest proportion of visitor groups for all three iterations (figure 6B). Over half of the visitor groups who interacted with iterations A and B were solo adult visitors (58% and 56%, respectively) and 37% of iteration C visitors were solo adults. All three iterations had a similar proportion of visitor groups consisting of multiple adults, approximately 30%. Iteration C had the highest proportion of family groups at 36%, while iterations A and B had fewer family groups visit. There was no significant difference between group composition and iteration (solo adult: $\chi^2(2, n=128)= 2.53$ $p=0.28$, multiple adults: $\chi^2(2, n=128)= 0.075$, $p=0.96$, family groups: $\chi^2(2, n=128)=3.9$ $p=0.14$). Exhibit iteration had a small effect on solo visitors (Cramer's V=0.14; Vaske, 2008) and a small to medium effect on family group visitors (Cramer's V=0.18). There was no effect on visitor groups composed of multiple adults (Cramer's V=0.02).

Staying Time. Most visitors stayed at the exhibit for 30 seconds or less (figure 6C). The minimum staying time was 2 seconds and the maximum staying time was 6 minutes and 30 seconds. On average, visitors stayed at the exhibit for 67 seconds, 60 seconds, and 54 seconds for iterations A, B, and C, respectively. The proportion of visitors who stayed for 11-30 seconds increased between each iteration while the proportion of visitors who stayed for two minutes or more decreased. The Kruskal-Wallis H-Test showed no significant difference between staying time and exhibit iteration ($H(2)= 2.65$, $p = .27$), with a mean rank staying time of 69 for Iteration A, 66 for iteration B, and 55 for Iteration C.

Visitor Behavior. The proportion of visitors who watched the video decreased markedly from 74.4% to 54.5% to 33.3% from across the iterations (figure 6D). A small percentage of visitors across the three iterations read exhibit information aloud (15.6% average) or collaborated with other group members (18.8% average). For all behaviors except for watching the video, Chi-squared analysis indicated no significant difference in behaviors exhibited between iterations ($\chi^2(2, n=128)=12.56$, $p< 0.05$). Exhibit iteration had a medium effect (Cramer's V = 0.3) on watching behavior.

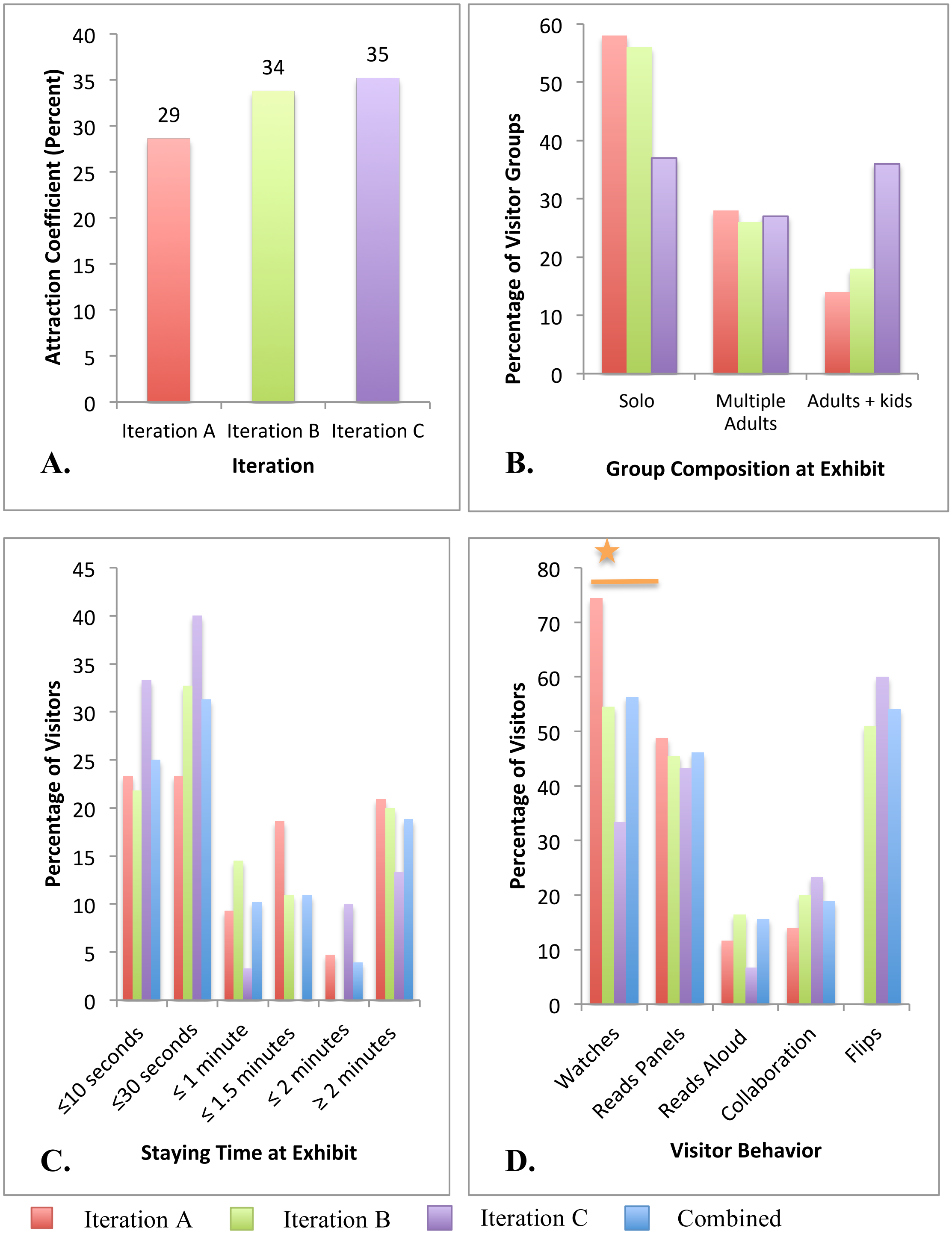

Figure 6: Factors related to visitor behavior at the exhibit:
A. Exhibit attraction coefficient for each iteration
B. Visitor group composition
C. Visitor staying time
D. Percentage of visitors who exhibited observed behaviors across each iteration and combined
(* indicates significance at p <.05)

Perception of the Exhibit.

Overall, visitors indicated a positive experience with the exhibit. Positive experience was the most frequently coded theme throughout the interviews (n=95; Table 2). Examples of positive experience included an appreciation for the exhibit's local focus on Oregon's deep sea, the flip-up display as a means for self-paced learning, and seeing how the deep sea is connected to everyday human life. Learning was the second most common theme (n=77). Participants noted that much of the information about deep-sea habitats and ecosystem services was new to them, including how deep and dark the deep sea is, particularly off of the Oregon coast. Participants also highly referenced deep-sea ecosystem services (n=65), habitats (n=65), and deep-sea characteristics (n=54).

Only one participant expressed dislike of the exhibit content, but many others offered constructive feedback to improve the exhibit (n=35). Some of feedback, like the inclusion of an interactive component and a QR code for visitors to learn more about the deep sea, was addressed in iterations B and C. However, other feedback pertained to structural challenges in the visitor center. In particular, four visitors noted that a bright ceiling light interfered with their experience. Several challenges were also identified. One participant noted "I did not come here today to learn deeply." Other challenges included reaching audio learners, inability to control at what point visitors start watching the video, and visitors lifting the flip-up exhibit, but not reading the content presented.

Table 2: Common themes for participant interview responses

Code	Example	Number of References			
		Iteration A	Iteration B	Iteration C	**Total**
Positive	liked, fun, interesting	43	35	17	95
Learning	informative, learned, I didn't realize	36	24	17	77
Ecosystem Services	Fisheries, nutrient cycling, minerals, medicine, oil, resource	38	20	7	65
Habitats	canyons, cold-water corals, methane seeps, mud, hydrothermal vents, seamounts	20	25	20	65
Deep-Sea Characteristics	dark, deep, relatively unexplored	26	16	12	54
Constructive Feedback	would have liked to see, want to know more about	14	12	9	35
Challenge	audio learner, started watching in the middle	3	6	2	11

Perception of the Deep Sea.

Knowledge. Although visitors, on average, spent less time at the exhibit across the three iterations, phase 2 participants achieved the three learning goals at a higher percentage than baseline participants (Table 3). There was a significant increase in achievement of learning goal 1 (χ^2 (3, n= 87) = 8.66, p <0.05) and learning goal 2 (χ^2 (3, n= 85) = 21.34, p<0.001). The exhibit has a small to medium effect size on learning goals 1 (Cramer's V=0.28) and 3 (Cramer's V=0.24) and a medium to large effect size (Cramer's V= 0.49) on learning goal 2.

Table 3. Percentage of visitors who achieved learning goals

Learning Goal	Phase 1: Baseline n=50	Phase 2: Iteration A n=16	Phase 2: Iteration B n=14	Phase 2: Iteration C n=7	χ2 value	*p*- value	Cramer's *V* effect size
LG1- There is no sunlight in the deep sea.	70	94	86	100	8.65	0.03*	0.28
LG2- Oregon's deep sea is diverse.	35	81	86	86	21.34	0.000*	0.49
LG3- Oregon's deep sea can benefit humans.	44	60	50	86	5.02	0.27	0.24

* indicates significance at p <0.05, ** indicates significance at *p*<.001

Visitors were also asked to rank their confidence in their answers to questions pertaining to learning goals 1 and 2 (Appendix A Table 1). Visitors were not asked to rank their confidence for learning goal 3 because in the original design, this question was not conceptualized as a learning goal indicator. Participants demonstrated increased confidence in their answers to sunlight and habitat knowledge questions between the baseline and post-use phases (Kruskall-Wallis H-Test; H(3)= 13.07 $p < 0.005$ and H(3)= 12.28 $p < 0.01$, respectively).

When asked about the habitats in Oregon's deep sea, visitors most commonly referenced deep-sea animals (n=16) or ecosystem services (n=14). Mud was the most highly cited habitat (n=13) followed by coldwater coral reefs (n=11), hydrothermal vents (n=11), canyons (n=5), and seamounts (n=3). Visitors also referenced several characteristics of the deep sea, including that it is dark (n=9), diverse (n=9), deep (n=6), and relatively unexplored (n=7). Some of the common themes conflicted with one another. For example, some visitors noted that there is lots of life in the deep sea (n=5), while others said there is not much life in the deep sea (n=4). Two visitors incorrectly identified plants in the deep sea, while just one visitor correctly identified there are no plants in the deep sea (Appendix A, Table 2).

Most visitors (n=35) agreed that Oregon's deep sea impacts human life (Appendix A Table 3). Most frequently, visitors mentioned broad connections in the ecosystem (n=12). Visitors also recognized the impact of deep-sea fisheries (n=8), food caught in the deep sea (n=8), and nutrient cycling that connects the deep sea to nearshore fisheries (n=6). Participants recognized other provisioning benefits, like potential medical benefits (n=5), oil and gas resources (n=2), and mineral resources (n=2). Additional impacts mentioned include the potential for discovery (n=5), the deep sea as the start of the marine food chain (n=3), and carbon sequestration (n=2). One participant indicated that the deep sea did not impact human life because "it is its own world down there."

***Value Orientation Towards the Deep Sea*.**

All phase 2 iterations had similar average orientations, so they were pooled for statistical analysis to account for small sample size of the individual iterations. There did not appear to be a change in visitor value orientations towards the deep sea after interacting with the exhibit (Table 4). Participants tended to disagree with use-oriented statements, like "the primary value of Oregon's deep sea is to provide for humans". Visitors largely agreed with protection-oriented statements, like "Oregon's deep sea should be protected for its own sake rather than to meet the needs of humans." Participants most strongly agreed with the protection-oriented statement "Oregon's deep sea has value whether humans are present or not." The baseline and post-use groups did not differ significantly in their response to questions relating to a use orientation (Mann-Whitney U Test, U= 862, p= 0.58) or protectionist orientation (U= 983.5, p= 0.36).

Table 4. Visitor value orientation towards Oregon's deep sea

	Phase 1: Baseline n=50 **Mean**[1] ± SE	Phase 2: Iteration A n=16 **Mean** ± SE	Phase 2: Iteration B n=14 **Mean** ± SE	Phase 2: Iteration C n=7 **Mean** ± SE
Use Orientation	**1.89** ± .12	**2.08** ± .16	**1.92** ± .21	**2.00** ± .33
Protectionist Orientation	**4.07** ± .11	**3.77** ± .20	**4.09** ± .22	**4.29** ± .24

[1]Variables measured on a 5-point scale of Strongly Disagree (1) to Strongly Agree (5)

Long-term Visitor Perception of the Deep Sea.

Knowledge of the deep sea. Most long-term participants retained the learning goals (Table 5). Iteration A saw an increase in participant who achieved learning goal 2. This is in stark contrast to iteration C, which saw a notable decrease in achievement of the same learning goal. Fewer iteration A participants reached learning goal 3 in the long-term follow-up. Achievement of learning goals 1 and 2 decreased for iteration B participants. No statistical analysis beyond descriptive statistics were performed for the analysis of long-term visitor perception due to small sample sizes of the long-term follow-up participants.

Table 5. Paired sample comparison of visitors who achieved learning goals

Learning Goal	Phase 2 Iteration A n= 4	Phase 3 Iteration A n= 4	Phase 2 Iteration B n=7	Phase 3 Iteration B n=7	Phase 2 Iteration C n= 2	Phase 3 Iteration C n=2
LG1- No Sun	100	100	100	85.7	100	100
LG2- Diverse	75	100	100	85.7	100	50
LG3- Benefits	75	50	57.1	57.1	100	100

Value Orientation Towards the Deep Sea.

Visitor value orientation towards the deep sea was fairly consistent between phase 2 and 3 (Appendix A Tables 4). Participants tended to disagree with use orientation statements about Oregon's deep sea and agree with protectionist orientation statements. Pariticpants agreed that humans benefit from Oregon's deep sea and it impacts their lives. Visitors also remained interested in learning more about the Oregon's deep sea and agreed it is important to learn more about it. Long-term participants expressed interest in learning more about how processes in Oregon's deep sea benefit humans, natural resources that humans can use from Oregon's deep sea, and the habitats and animals found in Oregon's deep sea.

At least half of all long-term participants for each iteration indicated that they had spoken to someone about the deep sea since their visit (Appendix A Table 5). Some participants from iteration A and B looked up additional information about the deep sea since their initial visit. Although no participants in iteration C looked up additional information about the deep sea, one participant noted that they intended to look up more information about the deep sea after completing the follow-up questionnaire.

Discussion

This study examined the efficacy of DBR as a process to support successful collaboration of three communities of practice in the development of a deep-sea outreach exhibit at a public science center. For visitors, successful collaboration was defined as having a positive experience with an exhibit that captures and holds their attention. HMSC staff defined successful collaboration as positive visitors experience and achievement of learning goals. Scientists defined successful collaboration as gaining a better understanding of public perception of the deep sea and visitors reaching and retaining predetermined learning goals. The discussion will address whether these criteria were met and implications for future work.

Successful Collaboration. The increases in attraction coefficient of the exhibit across the iterations coincided with a shift in group composition to include more family groups, an increase in visitors interacting with the flip-up display, and a significant decrease in visitors watching the video. The shifts may have resulted from the addition of the flip-up display and the colorful, 3D printed deep-sea animals to the exhibit in iteration C. This is consistent with Yalowitz and Ferguson's (2006) finding that the addition of three-dimensional objects increases the number of visitors who interact with an exhibit and Feher's (1990) finding that visitors require additional stimuli to remain engaged with an exhibit. This phenomena may explain the discrepancy between the increase in attraction coefficient and the decrease in visitor staying time that took place across the iterations. Observations and visitor feedback indicated that many visitors simply flipped up the doors, but did not engage further with the exhibit. All but one participant expressed having a positive experience with the exhibit with many visitors finding the exhibit to be fun or interesting. Overall, this indicates success for the visitor and museum communities of practice.

In addition to positive visitor experience, both HMSC staff and scientists required visitors to reach predetermined learning goals to deem the collaboration successful. The proportion of visitors reaching all three learning goals increased from the baseline to post-use groups with significant increases for learning goals 1 and 2. Furthermore, visitor confidence in response to knowledge questions increased significantly, indicating visitors felt more knowledgable in the subject matter. Participant interviews highlighted self-reported knowledge increases by visitors. Additionally, visitors frequently referenced deep-sea ecosystem services, habitats, and deep-sea characteristics presented in the exhibit. Long-term follow-up results showed most participants retained information related to exhibit learning goals. This indicates successful collaboration for both scientists and HMSC because it demonstrates that visitors were becoming more knowledgable about the deep sea after interacting with the exhibit.

Understanding public perception of the exhibit topic is necessary for scientists and exhibit designers to determine how to frame messages in a way that is relevant and consistent with public values (Jefferson et al., 2015). The questionnaire provided scientists with a better understanding of visitor perception of Oregon's deep sea, thereby satisfying their secondary criteria for successful collaboration. The majority of participants across all phases and iterations agreed with statements that were indicative of protectionist value orientations towards Oregon's deep sea. Participants tended to disagree with statements that exclusively privileged humans and commercial use of the deep sea over the ecological integrity of the deep sea like, "commercial use of Oregon's deep sea is more important than protecting species that live there." Framing exhibits in a way that is consistent with the population's values and interests increases the likelihood of engagement and, thus, learning (Wenger, 1998; Nisbet, 2009). This underscores the importance of including audience values and beliefs in needs assessment and front-end evaluation for exhibits.

Further, participants expressed interest in learning more about Oregon's deep sea and agreed that it is important to learn more. Long-term follow-up participants demonstrated a sustained interest in the deep sea by speaking to someone about the deep sea since their visit or looking up additional information about the deep sea. This supports the transaction model because it demonstates that deep-sea scientists looking to do this kind of outreach are not just providing outreach that is relevant to their mission, but they are filling a public need (Seagram et al., 1993; Kelly, 2004).

The criteria for successful collaboration for each of the three communities of practice were met, but what did collaboration look like in practice? Most collaboration between HMSC and scientists took place during the development of iteration A. Visitor center staff provided input regarding what elements are effective for other exhibits and cautioned the scientists to not overwhelm the visitors with too much technical information. A graduate student served as the principal exhibit designer and evaluator. The exhibit designer created two versions of iteration A; one which presented the information in brief paragraphs and, at the request of the scientists, the other in bulleted format. HMSC staff selected the paragraph version. This discrepancy in presentation between the HMSC staff and scientists highlights how communities of practice may approach the same task differently and with different assumptions.

After the creation of iteration A, collaborative focus shifted to engage the audience in the design of the exhibit. Iterations B and C were refined to better meet the needs of visitors, as determined by naturalistic observations and visitor survey responses. For example, no iteration A participants mentioned seamounts when asked about the habitats in Oregon's deep sea. Information about seamounts was originally presented at the bottom of the right panel and visitor observations revealed that most visitors focused on the left panel. Based on the observations and survey responses, for iteration B and C panels, seamounts were introduced on the left panel and were described in greater depth on the upper right panel. More participants from iterations B and C identified seamounts as a habitat than those in iteration A, likely as a result of this change to the exhibit.

Future Directions. One of the greatest challenges when creating an exhibit is balancing multiple entertainment and educational expectations of a diverse visitor audience (Falk & Dierking, 2013). To address this ubiquitous challenge, we found utilizing an iterative, DBR approach to be an effective means to better understand the audience. Monitoring audience interactions and incorporating their feedback into later iterations of the exhibit allowed us to better meet audience needs without compromising the educational mission of the scientists and informal learning institution. For example, many of the visitors were alone or did not engage in collaborative activities with their party at the exhibit, particularly in iteration A. Although some visitors prefer to learn by themselves, exhibits should strive to promote collaboration between multiple visitors to improve engagement and learning (Falk & Dierking, 2013). The addition of the flip-up display in iteration B coincided with a decrease in average visitor staying time. However, it was also associated with an increase in attraction power of the exhibit and collaborative behavior, and participants still achieved the learning goals at a greater proportion than phase 1 participants. This suggests that the addition of an interactive, tactile component facilitated more efficient knowledge transfer than iteration A, which lacked interactive components (McManus, 1993; Diamond, 1999; Fenichel & Schweingruber, 2010). With the addition of colorful 3D printed deep-sea animals in iteration C, we saw an increase in the proportion of family groups visiting the exhibit and an increase in collaborative behaviors. Exhibits that foster group interactions are correlated with greater visitor engagement and increased staying time which are both associated with learning (Allen, 2004; Perdue et al., 2012; Falk & Dierking, 2013). Further, exhibits should accommodate a variety of learning styles to improve broad visitor experience and engagement. Several participants identified as “audio learners.” Access to an audio component to support their learning may have fostered a more meaningful experience with the exhibit. The audience feedback garnered from a DBR-modified transaction approach to exhibit design provides insight into how we can construct a more comprehensive, inclusive exhibit in the future.

Conclusion

Engaging the public with scientific research is an important component of many scientists’ work and the missions of informal learning institutions. This study provides successful proof of concept in the use of DBR as a tool for brokering collaboration between communities of practice to support the development of successful science outreach program. In particular, we found using a DBR-modified transaction model was an effective tool to learn how to better tailor the science outreach program to meet audience expectations and needs. Undergoing multiple iterations of audience-focused evaluation and refinement required by a DBR-modified transaction approach enabled greater collaboration in the creation of an effective, meaningful science outreach exhibit that supports the needs of scientists, informal learning institutions, and the audience.

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Chapter 3: THE DEEP SEA AND ME: USING AN EXHIBIT TO ADVANCE PUBLIC LITERACY OF THE DEEP SEA

Abstract

A barrier to effective management of deep-sea resources is a lack of understanding by society of the benefits received from the oceans. To address this knowledge gap, we utilized an iterative design-based research methodology to evaluate (1) how to effectively use an exhibit to contribute to public literacy of the deep sea over the short and long-term and (2) how the public values deep-sea habitats. Three iterations of an exhibit were evaluated through observations and surveys of visitors. Exhibits containing video and interactive components were effective in communicating deep-sea information that was retained by visitors over the long-term. Visitors tended to agree with protection-oriented statements towards the deep sea. This study provides insight into how to effectively communicate policy-relevant information about the deep sea to an audience that has little to no prior knowledge of the ecosystem, yet who will be increasingly responsible for making use decisions of this habitat.

Introduction

With growing populations and consumer demand, there has been a turn to the deep sea to meet our natural resource needs. The deep sea provides a suite of ecosystem services. These include provisioning services, like food, energy, mineral resources, and pharmaceuticals, as well as regulating, supporting, and cultural ecosystem services, like nutrient cycling, water circulation, and inspiration for art and learning (Ramirez-Llodra et al., 2011; Thurber et al., 2014; Le, Levin, & Carson, 2017). Regional, national, and international resource managers are increasingly being asked to make informed policy decisions about this habitat as activities like deep-sea mining and bioprospecting of pharmaceutical resources begin to shift from the exploration to the exploitation phase (Le et al., 2017; Jones, Amon, & Chapman, 2018). The growing understanding of ecosystem interactions and cumulative impacts of human activities in the deep sea has led many scientists to support a precautionary approach to deep-sea management to mitigate the potential impacts of extractive industries on other ecosystem services (Gollner et al., 2017; Jones et al., 2018; Van Dover et al., 2018). However, a significant hurdle exists for policymakers because, in most cases, the will of the populace is unknown for the deep sea (Jobstvogt, Hanley, Hynes, Kenter, & Witte, 2014). This is largely due to a lack of understanding by society of the benefits received from ecosystem services in the deep sea. Here, we evaluate an iteratively refined deep-sea exhibit at a public science center to identify mechanisms to effectively engage the public with policy-relevant deep-sea science and to increase our understanding of how visitors value deep-sea habitats.

It is essential to include stakeholders in the management process as early as possible to establish a sense of stakeholder ownership and support in management decisions (Ehler, 2008). Many of the trade-offs between deep-sea ecosystem services have impacts on both natural and socioeconomic systems; therefore, it is imperative for the public to have an awareness of possible cumulative impacts and trade-offs of commercial exploits in the deep sea (Berkes, 2011). Understanding how the public values the ecosystem services afforded by the deep sea is vital to establishing an informed, widely supported, adaptive management strategy (Lester et al., 2010). Before the public can make meaningful contributions to management discourse, they must first understand what the various services are and how they are relevant to their lives (Steel, Lovrich, Lach, & Fomenko, 2005; Pierce, Steel, & Warner, 2009; Lewinsohn et al., 2015).

One mechanism to engage the public is through exhibits in museums and science centers. The primary roles of museums and other informal learning institutions are to educate and entertain (Seagram, Patten, & Lockett, 1993; Schwan, Grajal, & Lewalter, 2014). Generally, visitors expect learn in these settings which makes them appropriate venues to share scientific research (Falk & Storksdieck, 2010). Most adult learning occurs in informal learning settings and studies that have tracked the impact of museum visits over time show a self-reported increase in scientific understanding and interest after their visit which justifies the use of exhibits to improve public science literacy (Falk & Dierking, 2010).

Here, we use an iteratively refined deep-sea exhibit at a public science center to (1) identify ways to advance public literacy about the deep sea over the short and long-term and (2) to improve our understanding of how visitors perceive deep-sea habitats and services. Most exhibit evaluation studies focus on the immediate knowledge changes, but this study is unique in that it also addresses the long-term impact of the exhibit on visitor deep-sea literacy (Borun, Chambers, & Cleghorn, 1996; Spiegel et al., 2012; Beaulieu et al., 2015; Martin, Durksen, Williamson, Kiss, & Ginns, 2016). The goal of this study is to understand ways to build a more deep sea literate population to enable citizens to actively contribute to informed policy and management decisions (Medved and Oatley, 2000). While pertinent for Oregon's residents, these policy issues are also common globally, and thus we are addressing a ubiquitous challenge of stakeholders who are largely unaware of the many current and emergent uses of their deep sea.

Theoretical Framework

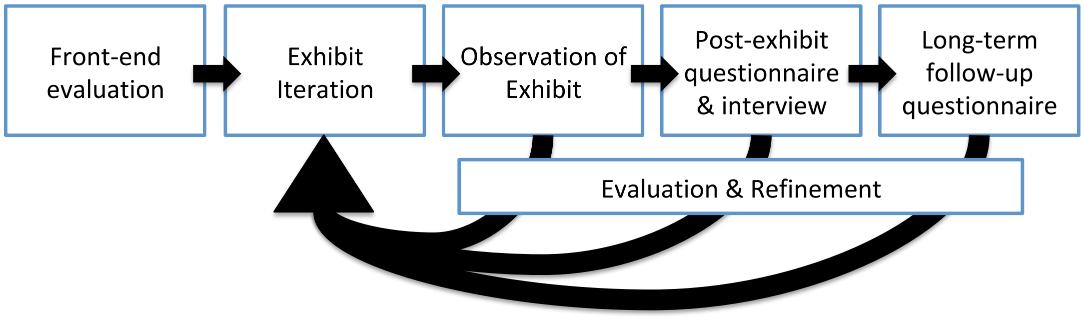

Figure 1: Iterative design-based research framework for the development, evaluation, and refinement of the exhibit.

To support collaboration between scientists, exhibit designers, and visitors, we followed a modified transaction approach to exhibit design (Seagram et al., 1993; Kelly, 2004). The transaction approach supports a dialogue between information providers—scientists and informal learning institutions—and the audience to create an exhibit that meets the needs of all parties involved (Seagram et al., 1993; Kelly, 2004). Here, we adapted the transaction approach to include design-based audience research (DBR). DBR involves multiple rounds of evaluation and refinement of the outreach tool to support greater in situ efficacy (Figure 1; Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The resulting exhibit that was the focus of this work was entitled "The Deep Sea and Me" and underwent three iterations following the response to observations of visitor interactions and visitor questionnaire and interview responses.

Methods

Setting. This study took place at the Hatfield Marine Science Center Visitor Center (HMSC) in Newport, Oregon. HMSC offers a number of interactive exhibits, including touch tanks of local rocky intertidal species and tanks of local fish species, and interpretive signage and informational videos that highlight Oregon's marine systems and research being done locally and regionally. The visitor center welcomes over 150,000 visitors annually, with most visiting during June, July, and August. 95% of HMSC visitors are from Washington, Northern California, Idaho, and Oregon, with 42% total visiting locally from Oregon. The HMSC audience is highly educated, 85% have a bachelors degree or higher compared to the 25% national average (S.M. Rowe, Rowe, Sullivan, 2017).

Exhibit Design. Two focus groups were conducted to identify knowledge gaps in Oregon residents' understanding of the deep sea. Participants were randomly recruited by an external research agency based in Portland, Oregon. Each focus groups consisted of 10 randomly recruited participants from the Portland Metropolitan area (12/13/17) and the central Oregon Coast (1/16/18), respectively. Focus group responses were coded using Dedoose Version 8.2.27 and used to inform learning goals and exhibit content (Table 1). The learning goals for the exhibit were also based on the ocean literacy principles (Cava et al., 2005). Only three key concepts were emphasized to increase the likelihood that visitors would remember those points about the deep sea beyond their visit (Cowan, 2001).

Table 1: Exhibit Learning goals and success criteria

Learning Goal	Success Criteria
LG-1. Participant understands there is no sunlight in the deep sea. *Ocean Literacy Principle 5g*	Participant indicates there is no sunlight in the deep sea.
LG-2. Participant understands there are many unique habitats in Oregon's deep sea. *Ocean Literacy Principle 1, 5*	Participant correctly identifies at least 2 habitat types present in Oregon's deep sea
LG-3. Participant recognizes that processes in the deep sea can benefit humans. *Ocean Literacy Principle 6*	Participant correctly identifies the four major provisioning benefits of the deep sea.

Prior research of learning in informal learning environments supported the creation of a deep-sea exhibit that (1) framed information in a way that is relevant, meaningful, and memorable to the public, (2) allowed multiple means of visitor interaction, and (3) was visually appealing (Sandifer, 2003; Falk & Dierking, 2013; Beaulieu et al., 2015; Hoeberechts, Owens, Riddell, & Robertson, 2015). To address point (1), the exhibit was framed with an emphasis on ecosystem services and supporting information on relevant deep-sea habitats in Oregon. Information was intentionally locally-focused to increase the relevance of the information to many visitors and foster a sense of connection between visitors and the deep sea (Rowe et al., 2017).

To address points (2) and (3), all three exhibits consisted of two panels of interpretive text and a video, allowing at least two possible modes of visitor interaction (Sandifer, 2003). Visitors tend to spend more time at exhibits with video presentations than at exhibits with still images and text (Perdue, Stoinski. & Maple, 2012). The video footage used in this exhibit came from the Ocean Exploration Trust's 2016 Nautilus Expedition off of Oregon. The video was captioned, but did not have sound.

Iteration A consisted of two 3-minute long deep sea videos, one focused on the deep sea habitats in Oregon and the other on ecosystem services in Oregon's deep sea. It also included two text panels containing information about Oregon's deep sea habitats and ecosystem services (Figure 2). Future iterations of the exhibit were informed by naturalistic observations of the exhibit and visitor survey responses. Exhibit iterations B and C presented the same information as iteration A using different language and visuals. Both the panels and the video were edited for clarity and visual appeal. The video was shortened to a single 3-minute and 40-second video to comply with recommendations that videos at exhibits be no longer than four minutes (Linn, 1983). Iterations B and C included an interactive element, a flip-over question and answer display to support visitor engagement and reinforce the learning goals of the exhibit over the short and long-term (McManus, 1993; Diamond, 1999; Fenichel & Schweingruber 2010). 3D printed deep-sea animals were added to the video monitor, the flip-up display, and table in iteration C.

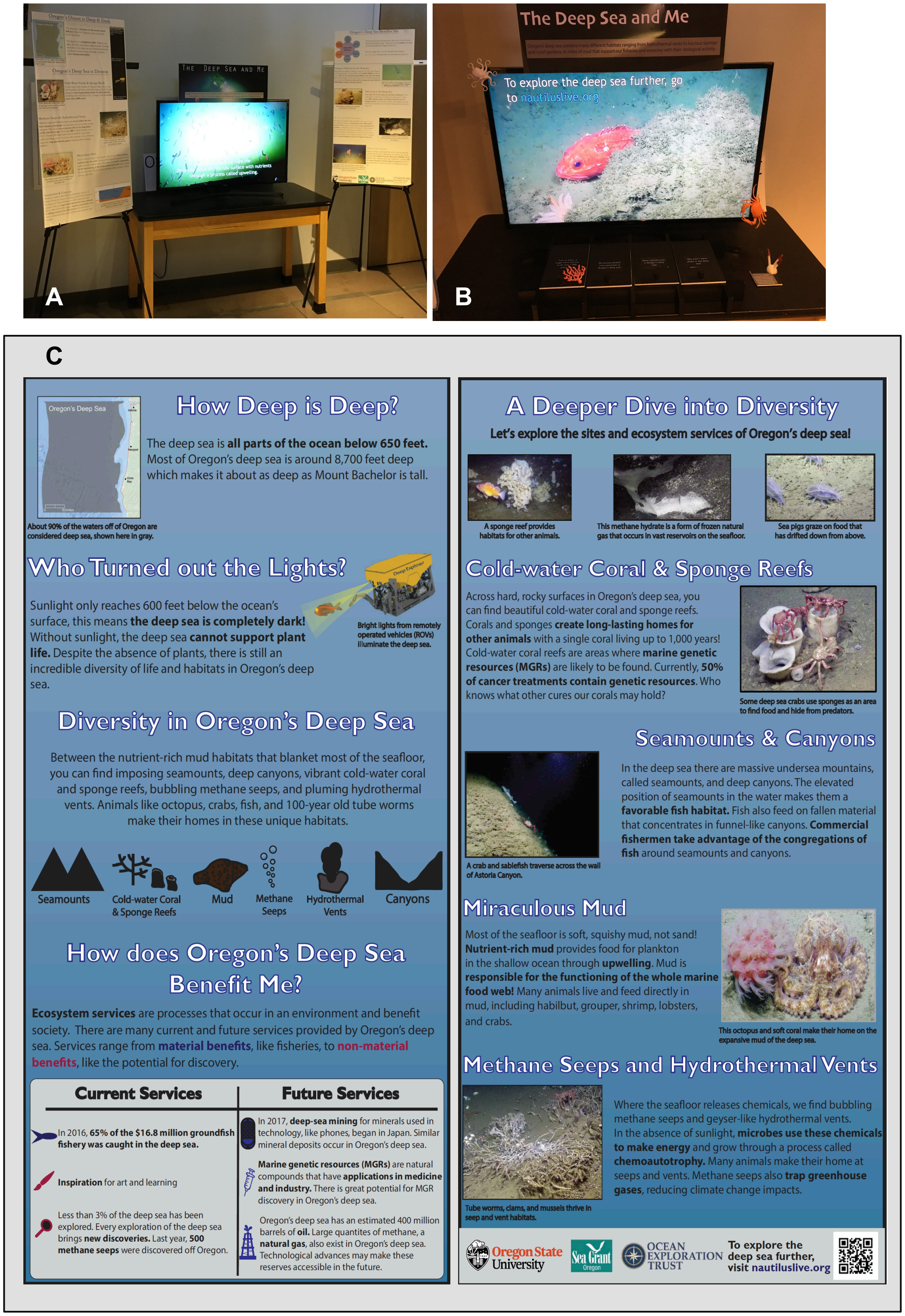

Figure 2:

A) Iteration A B) 3D printed deep-sea animals on iteration C flip-up display, monitor, and table C) Iteration B&C panels

Observations. Each exhibit iteration received 10 hours of in-person, naturalistic observation across two consecutive weekends to understand the visual efficacy of the exhibit and how visitors interacted with the exhibit (following Cardiel et al., 2016). Out of view of visitors, a single observer with a stopwatch and data sheet tracked visitor interactions with the exhibit (Borun, Chambers, & Cleghorn, 1996; Cardiel et al., 2016). Focal individual sampling was employed in which one visitor at a time was observed (Diamond, 1999; Yalowitz & Bronnenkant, 2009). When the observed visitor left the 1.5 meter exhibit area, the next visitor to enter the exhibit area was observed.

Survey Design & Distribution. Visitors were surveyed in three phases. Baseline data was collected during August, a month that receives high attendance on average, and the post-use data was collected during HMSC's off-season in the Fall of 2018. To maximize sample size, participant selection employed continuous, purposive sampling of adult visitors (Diamond, 1999). Potential participants were informed of the study as per an Institutional Review Board protocol. Participants took the questionnaire on iPads. Their responses were recorded in Qualtrics (https://www.qualtrics.com/). Interview responses were audio recorded, with participant permission.

In phase 1 (n=50), visitors were asked to participate in a brief questionnaire as they entered the visitor center to serve as a baseline of visitor knowledge and perception. In phase 2 (n=37), a separate pool of visitors who stayed at the exhibit for 30 seconds or longer were asked to participate in a semi-structured interview and a questionnaire after viewing the exhibit to evaluate changes in knowledge and perception of the deep sea. Interviews captured visitors' post-use impressions of the exhibit, suggestions for improvement, and overall efficacy of the exhibit. Phase 2 participants were invited to participate in a long-term follow-up study (phase 3) for which they would be entered to win a $25 Amazon gift card. In phase 3 (n=13), phase 2 participants were sent a follow-up questionnaire via email one month after their visit. Utilizing two separate pools of individuals for phase 1 and post-use phases 2 and 3 ensured that post-use exhibit observations and survey responses were the result of naturalistic interactions with the exhibit and not priming biases.

All three questionnaires contained the same content knowledge, perception, and demographic questions to assess the efficacy of the exhibit as a tool to promote deep sea literacy (Diamond, 1999; Falk & Storksdieck, 2010; Perdue et al., 2012; Sellmann & Bogner, 2013). Content knowledge questions judged whether learning goals were met. Perception questions measured visitor's assigned value orientations towards the deep sea and its uses. Knowledge and perception questions were adapted from Guest, Lotze, & Wallace, (2015) and Needham (2010), respectively. Phase 3's questionnaire asked additional questions to evaluate the impact of the exhibit beyond the initial visit (i.e. whether visitors had looked up further information about the deep sea since their visit). The long-term follow-up provided insight into whether content knowledge is retained beyond the visit or if the exhibit sparks a lasting interest in the deep sea.

Data Analysis. Interview responses were coded in Dedoose Version 8.2.27, sorted into themes, and frequency of themes was noted. Visitor behavior and questionnaire results were analyzed using descriptive and non-parametric statistics to account for small sample size, non-normally distributed data (Hollingsworth, Collins, East, Smith, & Nelson, 2011). All phase 2 post-use iterations were combined for statistical analysis. Paired comparisons between post-use and long-term phases only included the post-use responses of participants who also completed the long-term questionnaire. No statistical analysis beyond descriptive statistics was performed for the analysis of long-term visitor perception due to small sample size (n= 13).

Results

Knowledge Impact of Exhibit.

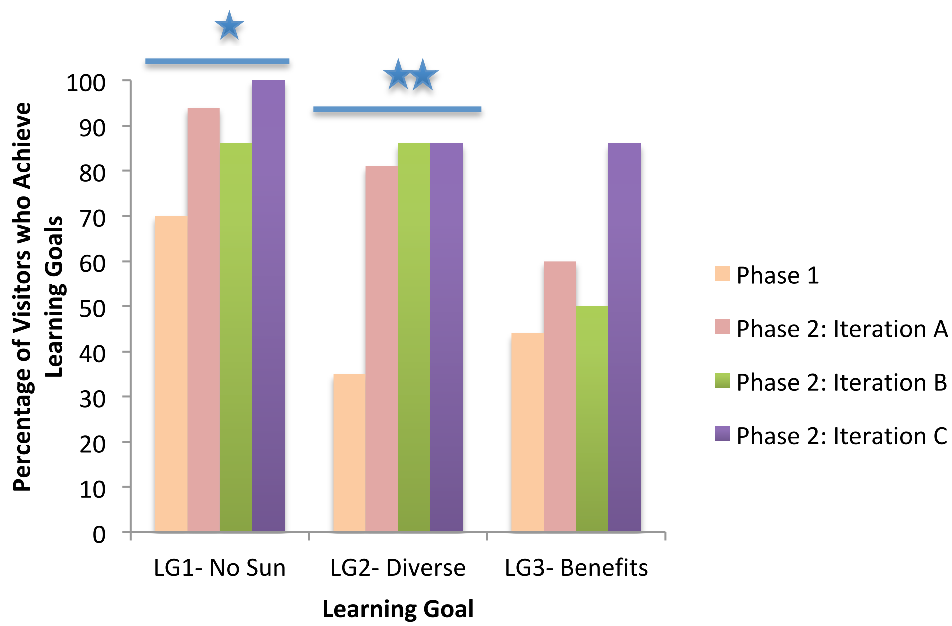

Figure 3: Percentage of visitors who achieve learning goals. Phase 1: Baseline participants did not view the exhibit, while Phase 2 participants took the questionnaire after viewing exhibit Iteration A, B, and C, respectively. Star indicates significance at * p< .05 and ** p <.001.

Across all iterations, visitors who had interacted with the exhibit demonstrated greater success in achieving the three learning outcomes than the baseline group (Figure 3). There was a significant change in achievement of learning goal 1 (Chi-square, χ^2 (3, n= 87) = 8.66, p <0.05) and learning goal 2 (χ^2 (3, n= 85) = 21.34, p<0.001). The exhibit has a small to medium effect size on learning goals 1 (Cramer's V=0.28) and 3 (Cramer's V=0.27) and a medium to large effect size (Cramer's V= 0.49) on learning goal 2 (Vaske, 2008).

Interview responses showed 84 instances of visitor learning (Appendix B Table 1). Visitors commonly said they learned that there is more life present than they expected (n=8) and facts pertaining to Oregon's deep sea specifically (n=8). These included comments about the depth of the ocean off of Oregon and about the diversity of animal life in the deep sea. Visitors also mentioned the presence and role of different deep-sea habitats, especially methane seeps (n=7). Further, visitors learned about a range of provisioning, regulating, and supporting services provided by the deep sea, including minerals (n= 7), chemosynthetic primary production (n=4), and carbon sequestration (n=1).

Long-term Knowledge Impact. One month after their visit, at least half of the respondents retained the three learning goals (Appendix B Table 2), though fewer than half of each iteration's participants responded to the follow-up questionnaire. Iteration A saw an increase in participants who achieved learning goal 2 from 75% to 100%. Iteration C saw a notable decrease in achievement of the same learning goal from 100% to 50%. Fewer iteration A participants reached learning goal 3 in the long-term follow-up, with 50% answering correctly compared to 75%. Further, achievement of learning goals 1 and 2 decreased from 100% to 86% for iteration B participants.

Perception Impact. We also asked whether visitor value orientations and perceptions towards the deep sea changed after interacting with the exhibit. Baseline and post-use participants tended to disagree with use-oriented statements like, "the primary value of Oregon's deep sea is to provide for humans" (Table 2). Both groups of visitors tended to agree with protection-oriented statements, like "Oregon's deep sea should be protected for its own sake rather than to meet the needs of humans." Visitors also agreed with the statements "humans benefit from processes in Oregon's deep sea" and "things that happen in Oregon's deep sea affect my life." The baseline and post-use groups did not differ significantly in their response to questions relating to a use orientation (Mann-Whitney U Test, U= 862, p= 0.58), protectionist orientation (U= 983.5, p= 0.36), belief that humans benefit from Oregon's deep sea (U= 944.5, p=0.72), and belief that the deep sea affects the visitor's life (U=931.5, p=0.81).

Table 2. Visitor value orientation & perception towards Oregon's deep sea

	Phase 1: Baseline n=50 **Mean**[1] ± SE	Phase 2: Iteration A n=16 **Mean** ± SE	Phase 2: Iteration B n=14 **Mean** ± SE	Phase 2: Iteration C n=7 **Mean** ± SE
Use Orientation	**1.89** ± .12	**2.08** ± .16	**1.92** ± .21	**2.00** ± .33
Protectionist Orientation	**4.01** ± .11	**3.77** ± .20	**4.09** ± .22	**4.29** ± .24
Humans Benefit	**4.20** ± .12	**4.13** ± .27	**4.29** ± .19	**4.43** ± .20
Affects my life	**4.04** ± .13	**4.19** ± .19	**4.07** ± .22	**4.14** ± .26

[1]Variables measured on a 5-point scale of Strongly Disagree (1) to Strongly Agree (5)

Interest in learning more about the deep sea. Visitors in the baseline and post-use groups expressed interest in learning more about Oregon's deep sea (Table 3). On average, participants were more interested in learning more about the animals and habitats in Oregon's deep sea than about how processes in Oregon's deep sea benefit humans and the natural resources humans can use from Oregon's deep sea. No significant difference was found between baseline and post-use visitor rankings of interest in learning more about human benefits (Mann-Whitney U Test, U= 687, p= 0.11), deep-sea habitats (U=702, p=0.23), or deep-sea animals (U= 782, p= 0.72). However, the decrease from phase 1 to phase 2 in visitor interest in learning more about the natural resources in the deep sea was significant (U= 613.5, p< 0.05).

Table 3. Visitor interest in learning more about Oregon's deep sea

	Phase 1: Baseline n=50 **Mean**[1] ± SE	Phase 2: Iteration A n=16 **Mean** ± SE	Phase 2: Iteration B n=14 **Mean** ± SE	Phase 2: Iteration C n=7 **Mean** ± SE
Human Benefits	**4.17** ± .09	**4.07** ± .17	**3.86** ± .18	**3.71** ± .36
Resources	**4.02** ± .11	**3.86** ± .21	**3.57** ± .14	**3.43** ± .30
Habitats	**4.4** ± .09	**4.31** ± .13	**4.14** ± .18	**4.29** ± .29
Animals	**4.42** ± .08	**4.46** ± .14	**4.21** ± .19	**4.43** ± .30

[1]Variables measured on a 5-point scale of Strongly Distinterested (1) to Strongly Interested (5)

Long-term Perception impact. Visitor orientation towards the deep sea remained relatively consistent between phases 2 and 3 (Appendix B Table 4). Participants still tended to disagree with use-oriented statements about Oregon's deep sea and tended to agree with protectionist statements towards Oregon's deep sea. Participants also agreed with the statements "humans benefit from processes in Oregon's deep sea" and "things that happen in Oregon's deep sea affect my life."

Interest in learning more about the deep sea. Visitor orientation towards the deep sea and interest in furthering deep-sea knowledge remained relatively stable between phase 2 and 3. Visitors remained interested in learning more about the Oregon's deep sea and agreed it is important to learn more about it. Long-term participants generally expressed interest in learning more about how processes in Oregon's deep sea benefit humans, natural resources that humans can use from Oregon's deep sea, and the habitats and animals found in Oregon's deep sea. At least half of all long-term participants for each iteration indicated that they had spoken to someone about the deep sea since their visit. Some participants from iteration A and B looked up additional information about the deep-sea since their visit.

Discussion

This study evaluated the short and long-term impact of an exhibit on public literacy and perception of Oregon's deep sea. Although the exhibit did not explicitly present policy options for visitors to consider, it provided policy-relevant background knowledge about deep-sea habitats and ecosystem services (Steel et al., 2005, Pierce et al., 2010; Gelcich et al., 2014; Lewinsohn et al., 2015). The observed increase in visitor knowledge of the deep sea across the baseline and post-use groups, as well as the self-reported increase in knowledge from visitor interview responses, shows that the exhibit improved visitor knowledge and awareness of the deep sea. This suggests that exhibits can be used as successful tools to start fostering a more informed populace capable of contributing to decisions regarding the deep sea's use or protection. Further, we see at least half of the visitors retained this policy-relevant knowledge one month later and spoke to others about the deep sea since their visit. These findings support the use of exhibits as a viable means to facilitate lasting transfer of information from scientists to the public.

While the exhibit did not lead to a change in visitor's assigned values towards the deep sea, it did provide insight into how this population values the deep sea. It was not surprising that a single display could not shift values because they are held beliefs and we would not expect them to change after one brief encounter with an exhibit (Van Riper & Kyle, 2014). Visitor responses shed light on what this particular population of visitors is likely to view as acceptable policy options. On average, visitors agreed with statements aligned with a protectionist value orientation and disagreed with statements aligned with a use orientation, suggesting that this population is unlikely to support policies that promote further exploitation of the deep sea. With further research of a broader population, policy makers can use this type of perception data to infer the types of deep-sea policies citizens are more apt to support. Understanding a population's value orientations and perceptions also provides scientists with an opportunity to frame outreach information in a way that is consistent with the population's assigned values and interests, thereby, increasing the likelihood of engagement and learning (Wenger, 1998; Nisbet, 2009).

Many visitors noted that their interaction with the exhibit was their first exposure to the deep sea. Further, visitors in the focus group and across all three phases of the study agreed that it is important to learn more about the deep sea and indicated they are interested in learning more about it. Numerous focus group participants and visitors echoed that prior to their participation in the study, they were unaware of the current and potential uses of the deep sea, particularly deep-sea mining. Many participants expressed concern for the potential impact of such activities. Despite an interest in learning about the deep sea, this audience previously lacked exposure to the deep sea and its emergent uses. This underscores the pressing need for wide-reaching outreach and engagement efforts. Communication efforts should seek to balance providing policy-relevant information, like natural resources in the deep sea, and topics that the audience has expressed strong interest in, like deep-sea animals.

The results of this study support the use of science-based exhibits in informal learning institutions to begin involving the public in the management of the deep sea. The iterative nature of this study illuminated a few key lessons to help facilitate an effective display focusing on the deep-sea. Scientists looking to use exhibits as outreach tools should consider adhering to the best practices we developed through the course of this study (Table 4).

Table 4: **Best practices for creating deep sea-focused outreach exhibits**
1. Know the target audience's values, prior knowledge & interests
2. Use an ecosystem services framework
3. Choose 3-4 main points to communicate
4. Support different learning styles with multiple modes of interaction
5. Create a visually appealing product appropriate for the venue

Framing informational exhibits and broader deep-sea science communication efforts around ecosystem services can transform highly technical, potentially overwhelming information into a form that is more appropriate and interesting to the lived experiences of the public (Steger, 2018). Determination of three succinct learning goals prior to exhibit development helped to focus our message, which increased the likelihood that visitors would remember the information beyond their visit (Cowan, 2001). Iterative refinement based on audience feedback supported the simplification of targeted messages and removal of jargon that could be alienating to visitors (Gelcich et al., 2014). Scientists streamlined their communication of complex topics, like nutrient cycling, to visitors through the rounds of iterative exhibit evaluation and refinement.

We found using local, place-based examples resonated with both focus group and visitor center audiences. Ecosystem-based management focuses on highlighting connections between activities, systems, and place, particularly as a means to engage stakeholders (McLeod & Leslie, 2009). We were able to leverage visitors' existing knowledge and conceptual frameworks to foster a sense of place between the deep sea and visitors. For example, the focus group participants generally understood the role of fishing for sustenance and a healthy economy. We used this pre-existing knowledge to explain how nutrients from the deep sea support commercially valuable near-shore fisheries (Thurber et al., 2014). This helped to foster a sense of personal investment and emotional connection to the deep sea (Gelcich, 2014; Dupont, 2017). Where appropriate, information presented in the exhibit should have a local focus to contribute further to the development of a sense of place and accountability between visitors and the deep sea. Framing deep-sea science in this way to the public promotes an understanding of the deep sea's role in the public's larger social-ecological network and connections to their own lives (Berkes, 2011).

There is great value in partnering with informal learning institutions to collaborate with exhibit experts and seek support from those who regularly communicate with public audiences (Beaulieu et al., 2015). Working with these professionals can ensure the development of an exhibit that is appropriate for the venue in both its content and display. Our observations underscored the importance of supporting multiple modes of interaction to accommodate visitors with different learning styles (Borun et al., 1998; Sandifer, 2003). Visitor engagement is also improved by the inclusion of novel, interactive components (Sandifer, 2003; Cardiel et al., 2016). Interactive components should seek to reinforce the pre-established learning goals, thereby promoting greater engagement and learning. Collaboration with informal learning institution professionals can provide greater insight into how to engage and accommodate a wide range of audiences with unfamiliar ecosystems.

Conclusion

The deep sea is our final frontier. Expanding engagement efforts between deep-sea scientists and the public provides an opportunity for the public to get involved in policy and management decisions by improving awareness of key ecosystem services and their connections to human life. Beyond this targeted exposure, deep-sea exhibits may increase public interest in the deep sea more broadly. Here, we found that through an iterative process we were able to increase the efficacy of a display resulting in both long-term retention and further pursuit of knowledge about the deep sea. In addition, a key finding was non-use and precautionary statements about the deep sea resonated more with the audience at this informal learning center. The public is increasingly asked to weigh in on policy use of the deep sea and, here, we demonstrate that a relatively small exhibit can provide a significant impact on the policy-relevant knowledge base of those who interact with it.

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Chapter 4: CONCLUSION

Summary

The goal of this study was to examine (1) whether an exhibit at a public science center improves public deep-sea literacy over the short and long-term and (2) what elements of the exhibit contribute to its efficacy. The intent was not to create an outreach tool that solely transmitted information from expert scientists to science center visitors, but, instead, to foster a dialogue between scientists, visitors, and the science center to ensure the exhibit was meeting the needs of all parties involved. To confirm all groups were satisfied, the creation and evaluation of the exhibit followed a design-based research methodology embedded within a transaction model. The exhibit underwent three iterations of design, evaluation, and refinement.

Naturalistic observation of visitor interaction with the exhibit, interviews, and questionnaire responses demonstrated the efficacy of the exhibit and illuminated areas for improvement. Visitors who interacted with the exhibit showed a higher proportion of achievement of learning goals compared to baseline visitors who had not interacted with the exhibit. Further, most long-term participants retained the learning goals after their visit. The majority of visitors indicated they had a positive experience with the exhibit and learned something about the deep sea. In general, visitors agreed it is important to learn more about Oregon's deep sea and indicated they are interested in learning more about it. Visitor's enjoyment, interest in the deep sea, and achievement of learning goals are consistent with Hatfield Marine Science Center Visitor Center's goals to entertain and engage visitors with marine systems and research occurring in Oregon's waters.

Through reflection on the exhibit evaluation and a literature review of other exhibits, I created a best practices guide for scientists seeking to use exhibits as outreach tools (Table 1). It is advised that scientists partner with informal learning institutions to collaborate with exhibit designers and seek support from those who regularly communicate with public audiences. Prior to exhibit creation, three or four learning goals should be established to focus the message of the content and increase the likelihood that visitors will remember these concepts beyond their visit (Cowan, 2001). Where possible, scientists and exhibit developers should seek to understand the audience's values, prior knowledge, and interests through avenues like focus groups and public perception research (Wenger, 1998; Nisbet, 2009). When communicating about unfamiliar environments, like the deep sea, it may be beneficial to use an ecosystem services framework because it can help to foster a sense of place between the visitor and the deep sea (Steger, 2018).

Table 1: **Best practices for creating deep sea-focused outreach exhibits**
1. Know the target audience's values, prior knowledge & interests
2. Use an ecosystem services framework
3. Choose 3-4 main points to communicate
4. Support different learning styles with multiple modes of interaction
5. Create a visually appealing product appropriate for the venue

Limitations and Challenges

It is important to recognize some of the ways in which this study was limited in scope and scale. Phase 2 of the study took place during the visitor center's off-season, which contributed to the small sample sizes of the study. Future studies should take visitor attendance patterns into consideration when selecting sampling times to contribute to the robustness and statistical validity of the study.

This study examined the efficacy of the exhibit for adult visitors only. Text panels, video, and the flip-up display appeared to be effective means to engage and educate adult visitors. However, observational data showed a low proportion of family group interactions. This suggests that an exhibit seeking to reach family groups and children would look quite different than the exhibit created for the purposes of this study.

In the original design of the study, the question "how can humans benefit from Oregon's deep sea" was not conceptualized as a knowledge question. Therefore, participants were not asked to rank their confidence in their answer. This question was later used as the success criteria for learning goal 3. To achieve learning goal 3, visitors had to select all four current and potential provisioning services presented in the exhibit as benefits provided by the deep sea (fisheries, minerals, medicine, and energy). Across all three phases, visitors had comparatively low success rates achieving learning goal 3. Upon further reflection, the question could be viewed as a value question, rather than a knowledge question. The success criteria of learning goal 3 should be altered to a less subjective question in future studies.

Another limitation is that HMSC visitors represent a particular population. 85% of HMSC visitors have a Bachelor's degree or higher compared to 40% of Oregonians and the 25% national average (S.M. Rowe, Rowe, & Sullivan, 2017). In this study, 56% of participants had a Bachelor's degree or higher. Further, the majority of this study's participants agreed with more protectionist-oriented value statements about Oregon's deep sea than use-oriented value statements. Education level and value orientations are likely to be different among other populations. This highlights the importance of conducting a needs assessment prior to the creation of an outreach tool and audience focused formative evaluation to ensure that the exhibit is well suited for its intended audience.

Contributions to Theory, Research, and Practice

This study contributes to the growing body of literature supporting the use of design-based research in the creation and evaluation of exhibits in informal learning institutions, like public science centers (Land & Zimmerman, 2015; Cardiel, Pattison, Benne, & Johnson, 2016; Pattison et al., 2017; Roberts & Lyons, 2017). It also provides proof of concept that design-based research can be used as a tool to broker successful collaboration between distinct communities of practice, particularly when embedded within a transaction model (Seagram, Patten, & Lockett, 1993; Kelly, 2004).

The majority of exhibit evaluations I encountered focused solely on knowledge gain and exhibit impact immediately after visitor engagement with the exhibit (Borun, Chambers, & Cleghorn, 1996; Spiegel et al., 2012; Beaulieu et al., 2015; Martin, Durksen, Williamson, Kiss, & Ginns, 2016). These studies noted the importance of conducting long-term evaluations related to changes in knowledge. This study makes important contributions to learning science in informal learning institutions by evaluating visitor retention of knowledge and sustained interest in the exhibit topic one-month beyond their visit.

This work is particularly relevant for marine resource management as it connects the public to marine ecosystems that many have not interacted with previously. It is important to foster connections between the public and the deep sea to facilitate public involvement in policy and management discourse, especially as we consider growing global interest to further develop extractive industries in the deep sea (Steel, Lovrich, Lach, & Fomenko, 2005; Ehler, 2008; Pierce, Steel, & Warner, 2009; Berkes, 2011; Lewinsohn et al., 2015). The exhibit is certainly not the only method for public engagement with the deep sea, but it serves as a stepping-stone to engage the public with policy-relevant science. Without a base level of knowledge regarding what's present in the deep sea and the range of services it provides, the public cannot reasonably contribute to deep-sea management decisions (Steel et al., 2005; Pierce et al., 2009; Lewinsohn et al., 2015).

Conclusion

Scientists are eager to share their deep-sea science with the public to create a more informed populace capable of contributing to well-reasoned management and policy decisions. Perhaps the most striking finding in this study is not that visitors learned and retained information about the deep sea after interacting with the exhibit, but that this was the first encounter many had with the deep sea. This underscores the importance of engaging the public with policy-relevant deep-sea science. Exhibits in informal learning institutions can serve as an effective tool to facilitate lasting knowledge exchange between these groups, especially when they are developed in consideration with the audience's prior knowledge, interests, and values.

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APPENDICES

APPENDIX A: CHAPTER 2 APPENDIX

Table 1. Visitor certainty of responses to knowledge questions

Question	Phase 1: Baseline n=50 **Mean**[1] ± SE	Phase 2: Iteration A n=16 **Mean** ± SE	Phase 2: Iteration B n=14 **Mean** ± SE	Phase 2: Iteration C n=7 **Mean** ± SE
LG1-There is no sunlight in the deep sea.	**2.08** ± .09	**2.44** ± .18	**2.5** ± .17	**2.86** ± .14
LG2-Habitats present in Oregon's deep sea.	**1.85** ± .11	**2.25** ± .14	**2.43** ± .14	**2.57** ± .30

[1]Variables measured on a 3-point scale of unsure (1), somewhat sure (2), and extremely sure (3).

Table 2: Common themes for "what can you tell me about the habitats in Oregon's deep sea?"

Code Category	Example	Number of references			
		Iteration A	Iteration B	Iteration C	**Total**
Animals	tubeworm, fish, octopus	8	7	1	**16**
Ecosystem Service	minerals, nutrients, fisheries, oil	11	3	0	**14**
Mud	mud	4	7	2	**13**
Coldwater Coral Reefs	corals, coldwater coral	3	4	4	**11**
Hydrothermal Vents	vents, thermals	6	2	3	**11**
Dark	dark, no sun	5	2	2	**9**
Diverse	varied, lots of them	4	2	3	**9**
Novelty	I didn't realize	4	1	5	**9**
Unexplored	There's a lot we don't know	3	3	1	**7**
Deep	650 feet, far down	4	2	0	**6**
Canyons	canyons	0	4	1	**5**
Lots of life	lots of life	0	2	3	**5**
Not much life	Not much, small	1	3	0	**4**
Interesting	interesting, impressive	3	0	1	**4**
Seamounts	underwater mountain	0	2	1	**3**
Methane Seeps	seeps, methane	1	1	1	**3**
Plants	There are plants	1	1	0	**2**
No plants	No plants	0	1	0	**1**

Table 3. Common themes for "Does Oregon's deep sea impact human life?"

Code Category	Example	Number of references Iteration A	Iteration B	Iteration C	**Total**
Connection	intertwined ecosystem	7	3	2	**12**
Fisheries	fisheries, fish we catch	5	3	0	**8**
Food	food we eat	4	1	3	**8**
Nutrient cycling	provides nutrients to fish	5	1	0	**6**
Medical	medicine, cancer research	3	2	0	**5**
Potential for Discovery	relatively unexplored	0	5	0	**5**
Food chain	start of the food chain	3	1	0	**3**
Oil & gas	oil & gas resources	1	1	0	**2**
Carbon sequestration	filters out carbon dioxide	0	1	1	**2**
Minerals	mineral resources, mining	1	1	0	**2**
Does not impact humans	it is its own world down there	0	0	1	**1**

Table 4. Paired sample comparison of visitor's assigned values towards Oregon's deep sea

	Phase 2 Iteration A n= 4 **Mean**[1] ± SE	Phase 3 Iteration A n=4 **Mean** ± SE	Phase 2 Iteration B n= 7 **Mean** ± SE	Phase 3 Iteration B n=7 **Mean** ± SE	Phase 2 Iteration C n=2 **Mean** ± SE	Phase 3 Iteration C n=2 **Mean** ± SE
Use Orientation	**2.00** ± .36	**1.92** ± .28	**2.17** ± .37	**2.29** ± .34	**1.33** ± 0	**1.00 ±** 0
Protectionist Orientation	**4.00** ± .20	**4.13** ± .07	**3.82** ± .39	**3.86** ±. 26	**4.75 ± .25**	**5** ± 0

[1]Variables measured on a 5-point scale of Strongly Disagree (1) to Strongly Agree (5)

Table 5. Percentage of participants who demonstrated sustained interest in the deep sea

Since my visit I have…	Phase 3: Iteration A n=4	Phase 3: Iteration B n=7	Phase 3: Iteration C n=2
Spoken to someone about the deep sea	50	57	100
Looked up additional information about…			
…deep-sea habitats	25	29	0
…deep-sea animals	25	14	0
…deep-sea ecosystem services	25	0	0

APPENDIX B: CHAPTER 3 APPENDIX

Table 1. Common themes associated with participant learning

Code Category	Example	Number of References			
		Iteration A	Iteration B	Iteration C	**Total**
Local	Depth of Oregon's ocean	5	1	2	8
Lots of Life	more life than expected	2	3	3	8
Deep	deep, 650 feet, far down	5	1	1	7
Methane Seeps	seeps, methane seeps	2	3	2	7
Minerals	mineral resources, mining	4	3	0	7
Dark	dark, no sun	2	2	2	6
Mud	mud	3	2	1	6
Ecosystem Services	benefits humans, resources	2	4	0	6
Animals	tubeworm, fish, octopus	4	1	0	5
Coldwater Coral Reefs	corals, coldwater coral, reefs	1	2	2	5
Chemosynthesis	bacteria makes energy	2	2	0	4
Fisheries	fisheries, fish we catch	3	1	0	4
Hydrothermal vents	vents, hydrothermal vents	2	0	1	3
Oil & gas	oil & gas resources	1	1	0	2
No plants	no plants in the deep sea	0	1	1	2
Seamounts	seamounts	1	0	1	2
Medical	medicine, cancer research	0	1	0	1
Carbon sequestration	filters out carbon dioxide	0	0	1	1

Table 2. Paired sample comparison of visitors who achieved learning goals

Learning Goal	Phase 2 Iteration A n= 4	Phase 3 Iteration A n= 4	Phase 2 Iteration B n=7	Phase 3 Iteration B n=7	Phase 2 Iteration C n= 2	Phase 3 Iteration C n=2
LG1- No Sun	100	100	100	85.7	100	100
LG2- Diverse	75	100	100	85.7	100	50
LG3- Benefits	75	50	57.1	57.1	100	100

Table 3. Paired sample comparison of visitor value orientation & perception towards Oregon's deep sea

	Phase 2 Iteration A n= 4 **Mean**[1] ± SE	Phase 3 Iteration A n=4 **Mean** ± SE	Phase 2 Iteration B n= 7 **Mean** ± SE	Phase 3 Iteration B n=7 **Mean** ± SE	Phase 2 Iteration C n=2 **Mean** ± SE	Phase 3 Iteration C n=2 **Mean** ± SE
Use Orientation	**2.00** ± .36	**1.92** ± .28	**2.17** ± .37	**2.29** ±.34	**1.33** ± 0	**1.00 ± 0**
Protectionist Orientation	**4.00** ± .20	**4.13** ± .07	**3.82** ± .39	**3.86** ±. 26	**4.75 ± .25**	**5** ± 0
Benefits Humans	**4.75** ± .25	**4.50** ± .29	**4.29** ± .29	**4.14** ± .40	**5 ± 0**	**5** ± 0
Affects my life	**4.5** ± .29	**4.50** ± .29	**3.86** ± .34	**4.0** ± .38	**5 ± 0**	**5** ± 0

[1]Variables measured on a 5-point scale of Strongly Disagree (1) to Strongly Agree (5)

Table 4. Paired sample comparison of visitor interest in learning more about Oregon's deep sea

	Phase 2 Iteration A n=4 **Mean**[1] ± SE	Phase 3 Iteration A n=4 **Mean** ± SE	Phase 2 Iteration B n=7 **Mean** ± SE	Phase 3 Iteration B n=7 **Mean** ± SE	Phase 2 Iteration C n=2 **Mean** ± SE	Phase 3 Iteration C n=2 **Mean** ± SE
Human benefits	**4.25** ± .25	**4.25** ± .25	**3.86** ± .26	**3.71** ± .18	**4.5** ± .50	**4.5** ± .50
Natural Resources	**3.75** ± .25	**4.25** ± .25	**3.57** ± .20	**3.57** ± .30	**4.0** ± 0	**4.0** ± 0
Habitats	**4.25** ± .25	**4.75** ± .25	**4.43** ± .20	**4.43** ± .20	**5.0** ± 0	**4.5** ± .50
Animals	**4.5** ± .29	**4.75** ± .25	**4.57** ± .20	**4.57** ± .20	**5.0** ± 0	**5.0** ± 0

1Variables measured on a 5-point scale of Strongly Disagree (1) to Strongly Agree (5)

APPENDIX C: PHASE 1 & 2 QUESTIONNAIRE

> Your participation today is completely voluntary. There is no penalty for choosing not to participate or for leaving the study at any time. You are free to skip any questions you do not want to answer.

1. On a scale of 1 to 5, 1 being not at all and 5 being extremely, how knowledgeable are you about the deep sea?

○ 1. Not at all knowledgeable about the deep sea

○ 2. Not very knowledgeable about the deep sea

○ 3. Somewhat knowledgeable about the deep sea

○ 4. Very knowledgeable about the deep sea

○ 5. Extremely knowledgeable about the deep sea

2. There is no light in the deep sea.

○ True

○ False

3. How sure of your answer are you?

○ Extremely sure

○ Somewhat sure

○ Not sure

4. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
The primary value of Oregon's deep sea is to provide for humans.	1	2	3	4	5
Commercial use of Oregon's deep sea is more important than protecting species that live there.	1	2	3	4	5
The needs of humans are more important than the needs of deep sea habitats.	1	2	3	4	5
Oregon's deep sea has value whether humans are present or not.	1	2	3	4	5

5. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Oregon's deep sea should be protected for its own sake rather than to meet the needs of humans.	1	2	3	4	5
Commercial use of Oregon's deep sea should not be allowed if it damages habitats.	1	2	3	4	5
Oregon's deep sea should have rights similar to the rights of humans.	1	2	3	4	5
Humans benefit from processes in Oregon's deep sea.	1	2	3	4	5
Things that happen in Oregon's deep sea affect my life.	1	2	3	4	5

6. True or false: There is no life in the deep sea.

◯ True

◯ False

7. How sure of your answer are you?

◯ Extremely sure

◯ Somewhat sure

◯ Not sure

8. Why is Oregon's deep sea important? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Economic reasons
[ ] Environmental reasons
[ ] Cultural reasons
[ ] Other ____

◯ Oregon's deep sea is not important.

9. How can human's benefit from Oregon's deep sea? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Fisheries
[ ] Energy
[ ] Medicine
[ ] Minerals
[ ] Other ____

◯ Humans cannot benefit from Oregon's deep sea.

10. Which habitats exist in Oregon's deep sea? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Cold water coral & sponge reefs
[ ] Methane seeps
[ ] Hydrothermal vents
[ ] Seamounts
[ ] Canyons
[ ] Mud

○ None of the above

11. How sure of your answer are you?

○ Extremely sure (1)

○ Somewhat sure (2)

○ Not sure (3)

12. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
It is important to me to learn more about the deep sea.	1	2	3	4	5
I am interested in learning more about the deep sea.	1	2	3	4	5

If you selected Strongly Disagree (1) or Disagree (2) for "I am interested in learning more about the deep sea" please skip question 13 and proceed to question 14.

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
How processes in the deep sea benefit humans	1	2	3	4	5
The natural resources humans can use from the deep sea	1	2	3	4	5
Habitats in Oregon's deep sea	1	2	3	4	5
Animals in Oregon's deep sea	1	2	3	4	5

13. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly, to what extent are you interested in learning more about the following topics:

14. What is your age (in years)?

____

15. What is your home zipcode?

____

16. What is the highest degree or level of schooling you have completed? *If currently enrolled, indicate highest degree received.*

○ Some high school

○ High school graduate, diploma or the equivalent (for example: GED)

○ Some college credit, no degree

○ Associates degree

○ Bachelor's degree

○ Master's degree

○ Professional degree

○ Doctorate degree

Thank you for taking the time to complete this survey.

APPENDIX D: PHASE 2 INTERVIEW QUESTIONS

1. What can you tell me about the habitats in Oregon's deep sea?

2. Did you learn anything about the deep sea today?

3. Do you think Oregon's deep sea has an impact on human life? Why or why not?

4. Were there any parts of the exhibit you liked?

5. Were there any parts of the exhibit you disliked?

6. What could have improved your experience with the exhibit today?

7. Is there anything else you'd like to tell me about your experience with the exhibit today?

APPENDIX E: PHASE 3 QUESTIONNAIRE

Your participation today is completely voluntary. There is no penalty for choosing not to participate or for leaving the study at any time. You are free to skip any questions you do not want to answer.

1. On a scale of 1 to 5, 1 being not at all and 5 being extremely, how knowledgeable are you about the deep sea?

○ 1. Not at all knowledgeable about the deep sea

○ 2. Not very knowledgeable about the deep sea

○ 3. Somewhat knowledgeable about the deep sea

○ 4. Very knowledgeable about the deep sea

○ 5. Extremely knowledgeable about the deep sea

2. There is no light in the deep sea.

○ True

○ False

3. How sure of your answer are you?

○ Extremely sure

○ Somewhat sure

○ Not sure

4. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
The primary value of Oregon's deep sea is to provide for humans.	1	2	3	4	5
Commercial use of Oregon's deep sea is more important than protecting species that live there.	1	2	3	4	5
The needs of humans are more important than the needs of deep sea habitats.	1	2	3	4	5
Oregon's deep sea has value whether humans are present or not.	1	2	3	4	5

5. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Oregon's deep sea should be protected for its own sake rather than to meet the needs of humans.	1	2	3	4	5
Commercial use of Oregon's deep sea should not be allowed if it damages habitats.	1	2	3	4	5
Oregon's deep sea should have rights similar to the rights of humans.	1	2	3	4	5
Humans benefit from processes in Oregon's deep sea.	1	2	3	4	5
Things that happen in Oregon's deep sea affect my life.	1	2	3	4	5

6. True or false: There is no life in the deep sea.

◯ True

◯ False

7. How sure of your answer are you?

◯ Extremely sure

◯ Somewhat sure

◯ Not sure

8. Why is Oregon's deep sea important? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Economic reasons
[ ] Environmental reasons
[ ] Cultural reasons
[ ] Other ____

◯ Oregon's deep sea is not important.

9. How can human's benefit from Oregon's deep sea? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Fisheries
[ ] Energy
[ ] Medicine
[ ] Minerals
[ ] Other ____

◯ Humans cannot benefit from Oregon's deep sea.

10. Which habitats exist in Oregon's deep sea? *Select all that apply, if none of the bracketed choices apply, fill in the choice with the circle.*

[ ] Cold water coral & sponge reefs
[ ] Methane seeps
[ ] Hydrothermal vents
[ ] Seamounts
[ ] Canyons
[ ] Mud

○ None of the above

11. How sure of your answer are you?

○ Extremely sure (1)

○ Somewhat sure (2)

○ Not sure (3)

12. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly agree, to what extent do you agree with the following statements?

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
It is important to me to learn more about the deep sea.	1	2	3	4	5
I am interested in learning more about the deep sea.	1	2	3	4	5

If you selected Strongly Disagree (1) or Disagree (2) for "I am interested in learning more about the deep sea" please skip question 13 and proceed to question 14.

13. On a scale of 1 to 5, 1 being strongly disagree and 5 being strongly, to what extent are you interested in learning more about the following topics:

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree

How processes in the deep sea benefit humans	1	2	3	4	5
The natural resources humans can use from the deep sea	1	2	3	4	5
Habitats in Oregon's deep sea	1	2	3	4	5
Animals in Oregon's deep sea	1	2	3	4	5

14. Have you spoken to anyone about the deep sea since your visit to the Hatfield Marine Science Center Visitor Center? If yes, approximately how many people?

○ Yes ____

○ No

○ Maybe

15. After your visit to the Hatfield Marine Science Center Visitor Center, have you looked up any additional information about the deep sea? *Check all that apply, feel free to specify in the space*

[ ]Information about deep sea habitats
____
[ ]Information about deep sea animals
____
[ ] Information about ecosystem services in the deep sea
____
[ ] Other ____

○ I have not looked up additional information about the deep sea.

16. Do you have any additional thoughts on the "Deep Sea and Me" exhibit you would like to share?
____

17. What is your age (in years)?

____

18. What is your home zipcode?

____

19. What is the highest degree or level of schooling you have completed? *If currently enrolled, indicate highest degree received.*

- ◯ Some high school
- ◯ High school graduate, diploma or the equivalent (for example: GED)
- ◯ Some college credit, no degree
- ◯ Associates degree
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Professional degree
- ◯ Doctorate degree

Thank you for taking the time to complete this survey.

APPENDIX F: VISITOR BEHAVIOR RUBRIC

Start Time:	Estimated Age	Watches	Reads Aloud
End Time:	Group Make Up	Reads	Points
Photo	Connects to Outside	Collaboration	Flips*
Notes:			

*applies to iterations B and C only