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The Deep Sea and Me: Using a Science Center Exhibit to Promote Lasting Public Literacy and Elucidate Public Perception of the Deep Sea

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A critical 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 applied an iterative design-based research methodology to evaluate (1) how to effectively use an exhibit to increase public literacy of the deep sea over the short and long-term and (2) how visitors to a public science center perceive the deep sea. Using observations of visitor interactions and surveys of visitors, we evaluated three iterations of an exhibit that highlighted deep-sea ecosystem services and habitats as a case study of exhibit efficacy. Exhibits containing video and interactive components were effective in communicating deep-sea information that was retained by visitors over the long-term. For many visitors, the exhibit was their first introduction to the deep sea. Visitors agreed it is important to learn about the deep sea and expressed interest in learning more about deep-sea animals, habitats, resources, and benefits to humans. Visitors tended to agree with protection-oriented value statements and disagree with use-oriented value statements toward 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.

Keywords: ocean literacy principles, deep-sea management, outreach, science communication, stakeholder engagement

INTRODUCTION

The deep sea provides a suite of ecosystem services that are increasingly important to society. These include provisioning services, like food, energy, mineral resources, and pharmaceuticals, as well as regulating, supporting, and cultural services, like nutrient cycling, water circulation, and inspiration for art and learning (Ramirez-Llodra et al., 2011; Thurber et al., 2014; Le et al., 2017). Regional, national, and international resource managers are increasingly being asked to make informed policy decisions about this habitat as extractive activities like deep-sea mining and bioprospecting of pharmaceutical resources begin to shift from exploration to exploitation (Le et al., 2017; Jones et al., 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 public is unknown largely due to a lack of knowledge about the ocean (Guest et al., 2015; Dupont and Fauville, 2017) and the deep sea more specifically (Jobstvogt et al., 2014). 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 people value deep-sea habitats.

One mechanism to engage the public is through exhibits in museums and science centers. The primary roles of these informal learning institutions are to educate and entertain (Seagram et al., 1993; Schwan et al., 2014). Most adult learning takes place in such informal settings and people have expectations to learn when visiting, making these institutions appropriate venues to share scientific research (Falk and Dierking, 2010; Falk and Storksdieck, 2010). Studies that have tracked the impact of museum visits over time show a self-reported increase in scientific understanding and interest after the visit, suggesting the use of exhibits can improve public science literacy (Falk and Dierking, 2010).

To facilitate collaboration between scientists, exhibit designers, and visitors in the construction of an informed and visitor-relevant exhibit, we followed a modified transaction approach to design our exhibit (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). 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 et al., 2003). Prior research on learning in informal settings 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 and Dierking, 2013; Beaulieu et al., 2015; Hoeberechts et al., 2015). Information was locally focused to increase the salience of the science to visitors and to foster a sense of connection between visitors and the deep sea (Rowe et al., 2017). The exhibit was framed with an emphasis on ecosystem services and supporting information on relevant deep-sea habitats in Oregon. The resulting exhibit was entitled "The Deep Sea and Me" and underwent three iterations following visitor interactions and visitor questionnaire and interview responses.

We used this 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. This study was the first to include a follow-up survey a month following the visit to quantify the long-term impact of the exhibit on visitor deep-sea literacy (Borun et al., 1996; Spiegel et al., 2012; Beaulieu et al., 2015; Martin et al., 2016). The goal of this case study is to understand ways to build a more deep sea literate population capable of contributing to informed policy and management decisions (Medved and Oatley, 2000). While our focus is the deep-sea of Oregon (and associated Federal Exclusive Economic Zone, United States), these policy issues are common globally. Thus, we are addressing a ubiquitous challenge of how to effectively educate stakeholders who are largely unaware of the many current and emergent uses of their deep sea.

METHODS

Setting

This study took place at the Hatfield Marine Science Center (HMSC) Visitor Center in Newport, Oregon. HMSC offers a number of interactive exhibits, including touch tanks of local rocky intertidal species, tanks of local fish species, and interpretive signage and videos that highlight Oregon's marine systems and local and regional research. The visitor center welcomes over 150,000 visitors annually, with most visiting during June, July, and August. Phase 1 baseline data was collected during August, a month that receives high attendance on average, and phase 2 and 3 post-use data was collected during HMSC's off-season in the Fall of 2018. Ninety six percent ($n = 82$) of participants visited locally from Oregon. Participants ranged in age from 19 to 83 with a mean age of 51. All participants had completed at least some college with 58% having a bachelor's degree or higher, compared to the 25% national average (Rowe et al., 2017).

Exhibit Design

Two focus groups were conducted to identify knowledge gaps in Oregon residents' understanding of the deep sea. Participants were recruited at random by an external research agency based in Portland, Oregon. Each focus group consisted of 10 participants from the Portland Metropolitan area (12/13/17) and the central Oregon Coast (1/16/18), respectively. Data were collected under Oregon State University Institutional Review Board (IRB) study number 8340. 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 which are aligned with the National Science Education Standards (Cava et al., 2005). Only three key concepts were emphasized to increase the likelihood that visitors would remember those points about Oregon's deep sea beyond their visit: (1) there is no sunlight, (2) there are many unique habitats, (3) processes in the deep sea can benefit humans (**Table 1**; Cowan, 2001).

Based on these focus group experiences, we framed the exhibit with an emphasis on ecosystem services provided by deep-sea habitats in Oregon. We designed our exhibit to include two panels of interpretive text and a video, providing at least two possible modes of visitor interaction (**Figure 1B**; Sandifer, 2003). Visitors tend to spend more time at exhibits with video presentations than at exhibits with still images and text

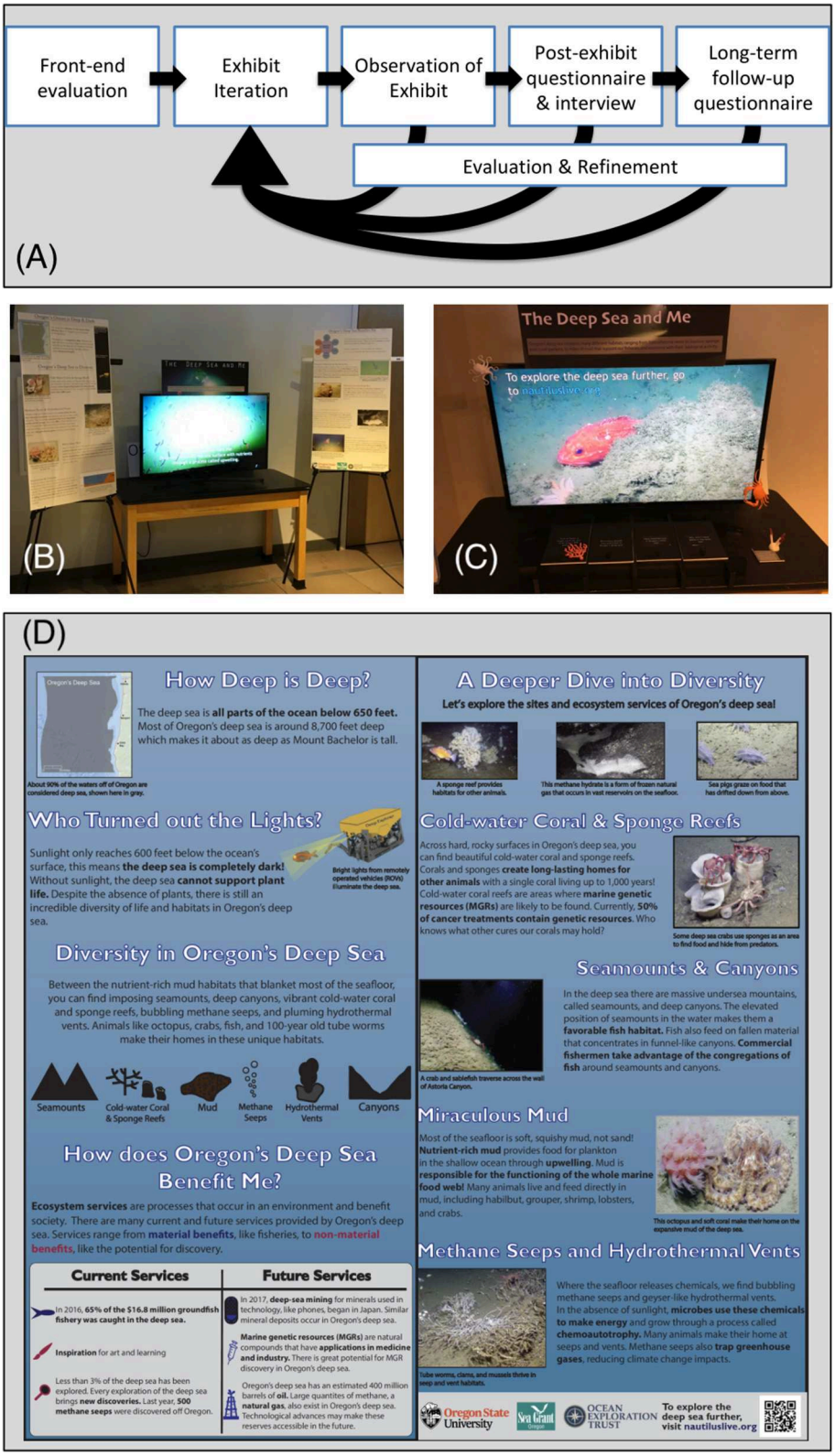

FIGURE 1 | (A) Iterative design-based research framework for the development, evaluation, and refinement of the exhibit. **(B)** Exhibit iteration A **(C)** 3D printed deep-sea animals on exhibit iteration C flip-up display, monitor, and table **(D)** Iteration B and C panels.

TABLE 1 | Exhibit Learning Goals (LG) and Success Criteria.

Learning Goal	Success Criteria
LG-1. Participant understands there is no sunlight in the deep sea. *Ocean Literacy Principle 5 g*	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 provisioning benefits presented in the exhibit.

(Perdue et al., 2012). The video footage used in this exhibit came from the Ocean Exploration Trust's 2016 Nautilus Expedition off of Oregon (MV Nautilus NA-072). The video was captioned but did not have sound.

Iteration A consisted of two 3 min long videos, one focused on the deep-sea habitats in Oregon and the other on ecosystem services provided by these habitats (**Supplemental Video 1**). It also included two text panels containing information about Oregon's deep-sea habitats and ecosystem services (**Supplemental Figure 1**). Future iterations were informed by naturalistic observations of the exhibit and visitor survey responses (**Figure 1A**). Exhibit iterations B and C presented the same information as iteration A using different language and visuals (**Figure 1D**). Both the panels and the video were edited for clarity and visual appeal. The video was shortened to a single 3 min and 40 s video to comply with recommendations that videos at exhibits be no longer than 4 min (**Supplemental Video 2**; 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 and Schweingruber, 2010). 3D printed deep-sea animals were added to the video monitor, the flip-up display, and table in iteration C (**Figure 1C**).

Observations

Each exhibit iteration received 10 h of in-person, naturalistic observation across 2 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 et al., 1996; Cardiel et al., 2016). Focal individual sampling was employed in which one adult visitor at a time was observed (Diamond, 1999; Yalowitz and Bronnenkant, 2009). When the target visitor left the 1.5 meter exhibit area, the next visitor to enter the exhibit area was observed.

Survey Design and Distribution

Visitors were surveyed in three phases. 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 (OSU IRB #8634). Participants took the questionnaire in Qualtrics (https://www.qualtrics.com/) on iPads and interviews were 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 s or longer participated 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 $25 USD gift card. In phase 3 ($n = 13$), phase 2 participants were sent a follow-up questionnaire via email 1 month after their visit. We used two separate pools of individuals for phase 1 and post-use phases 2 and 3 to ensure that post-use 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 and Storksdieck, 2010; Perdue et al., 2012; Sellmann and Bogner, 2013). Content questions judged whether learning goals were met. Perception questions measured visitor's assigned values toward the deep sea and its potential uses. Knowledge and perception questions were adapted from Guest et al. (2015) and Needham (2010), respectively. The phase 3 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. Survey questions and design were approved under OSU IRB #8634.

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 and non-normally distributed data (Hollingsworth et al., 2011). All phase 2 post-use iterations were combined for statistical analysis. 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

Across all iterations, visitors who had interacted with the exhibit demonstrated greater success in achieving the three learning outcomes than the baseline group (**Figure 2**). Between phase 1

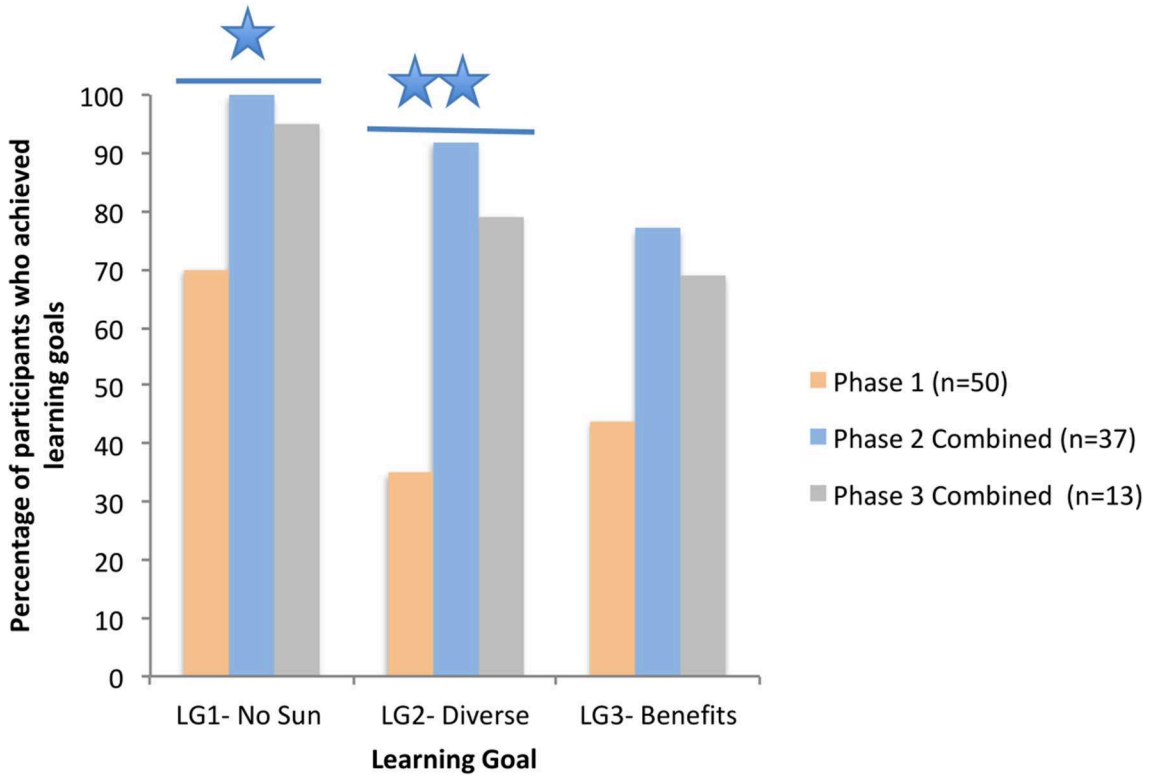

FIGURE 2 | Percentage of participants who achieved learning goals, star indicates significance at $^{*}p < 0.05$ and $^{**}p < 0.001$. Phase 1 ($n = 50$): Baseline participants did not view the exhibit, while Phase 2 ($n = 37$) participants took the questionnaire after viewing exhibit Iteration A, B, or C, and Phase 3 ($n = 13$) participants responded to the questionnaire 1 month after their visit (LG = Learning Goal).

to phase 2, there was a significant change in achievement of Learning Goal 1 from 70 to 100% [Chi-square, χ^2 (3, $n = 87$) = 8.66, $p < 0.05$] and Learning Goal 2 from 35 to 92% [χ^2 (3, $n = 85$) = 21.34, $p < 0.001$]. The increase in achievement of Learning Goal 3 from 44 to 77% was not significant. The effect size, indicated by Cramer's V, is a measure between 0 and 1 which quantifies the relative strength of the relationship between two variables, exhibit and learning goal achievement in this case (Vaske, 2008). The exhibit had a small to medium effect on achievement of Learning Goals 1 (Cramer's V = 0.28) and 3 (Cramer's V = 0.27) and a medium to large effect (Cramer's V = 0.49) on Learning Goal 2.

Interview responses showed 84 instances of visitor learning (See **Supplemental Table 1**). Visitors said they learned more about Oregon's deep sea specifically ($n = 8$) and that there is more life present than they expected ($n = 8$). These included comments about the depth of the ocean off Oregon ($n = 7$) and about the diversity of animal life in the deep sea ($n = 5$). 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, the majority of participants who responded to the follow-up questionnaire ($n = 13$) retained the learning goals, though fewer than half of each iteration's participants responded to the follow-up questionnaire (**Figure 2**). Of the phase 3 participants, 95% achieved Learning Goal 1, 79% achieved Learning Goal 2, and 69% achieved Learning Goal 3.

Perception Impact

We also asked whether visitor's assigned values and perceptions toward the deep sea changed after interacting with the exhibit. On average, baseline and post-use participants disagreed 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, $U = 862$, $p = 0.58$), protection orientation ($U = 983.5$, $p = 0.36$), belief that humans benefit from Oregon's deep

TABLE 2 | Visitor assigned value and perception toward Oregon's deep sea.

	Phase 1: Baseline $n = 50$ Mean[1] ± SE	Phase 2: Iteration A $n = 16$ Mean ± SE	Phase 3: Iteration A $n = 4$ Mean ± SE	Phase 2: Iteration B $n = 14$ Mean ± SE	Phase 3: Iteration B $n = 7$ Mean ± SE	Phase 2: Iteration C $n = 7$ Mean ± SE	Phase 3: Iteration C $n = 2$ Mean ± SE
Use oriented	**1.89** ± 0.12	**2.08** ± 0.16	**1.92** ± 0.28	**1.92** ± 0.21	**2.29** ± 0.34	**2.0** ± 0.33	**1.0** ± 0
Protection oriented	**4.01** ± 0.11	**3.77** ± 0.20	**4.13** ± 0.07	**4.09** ± 0.22	**3.86** ± 0.26	**4.29** ± 0.24	**5.0** ± 0
Benefits humans	**4.20** ± 0.12	**4.13** ± 0.27	**4.50** ± 0.29	**4.29** ± 0.19	**4.14** ± 0.40	**4.43** ± 0.20	**5.0** ± 0
Affects my life	**4.04** ± 0.13	**4.19** ± 0.19	**4.50** ± 0.29	**4.07** ± 0.22	**4.0** ± 0.38	**4.14** ± 0.26	**5.0** ± 0
Interested in learning more about deep sea...							
Animals	**4.42** ± 0.08	**4.46** ± 0.14	**4.75** ± 0.25	**4.21** ± 0.19	**3.71** ± 0.18	**4.43** ± 0.30	**4.5** ± 0.50
Habitats	**4.40** ± 0.09	**4.31** ± 0.13	**4.75** ± 0.25	**4.14** ± 0.18	**3.57** ± 0.30	**4.29** ± 0.29	**4.0** ± 0
Resources	**4.02** ± 0.11	**3.86** ± 0.21	**4.25** ± 0.25	**3.57** ± 0.14	**4.43** ± 0.20	**3.43** ± 0.30	**4.5** ± 0.50
Benefits to humans	**4.17** ± 0.09	**4.07** ± 0.17	**4.25** ± 0.25	**3.86** ± 0.18	**4.57** ± 0.20	**3.71** ± 0.36	**5.0** ± 0

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

sea ($U = 944.5$, $p = 0.72$), and belief that the deep sea affects the visitor's life ($U = 931.5$, $p = 0.81$).

Long-Term Perception Impact

Visitor perception of the deep sea remained relatively consistent between phases 2 and 3 (**Table 2**). Participants still tended to disagree with use-oriented statements and tended to agree with protection-oriented statements about Oregon's deep sea. Long-term 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

Visitors in the baseline and post-use groups expressed interest in learning more about Oregon's deep sea (**Table 2**). On average, participants were more interested in learning more about the animals and habitats in Oregon's deep sea than about how deep-sea processes or natural resources could benefit humans. 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, a decrease from phase 1 to phase 2 in visitor interest in learning more about the natural resources in the deep sea was significant ($U = 613.5$, $p < 0.05$).

Long-Term Interest in Learning More About the Deep Sea

Visitor interest in furthering deep-sea knowledge remained relatively stable between phase 2 and 3 (**Table 2**). 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 Oregon's deep sea through the processes that benefit humans, natural resources that humans can use, and the habitats and animals. Seventy percent of the long-term participants noted that they had spoken to someone about the deep sea since their visit. Twenty five percent of visitors from iteration A and 29% from iteration B indicated they 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. It is essential to include stakeholders in the management process as early as possible to establish a sense of 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. 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). However, 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 et al., 2005; Pierce et al., 2009; Lewinsohn et al., 2015).

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., 2009; 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 is consistent with visitor-reported knowledge gains found in Beaulieu et al.'s (2015) study of an exhibit focused on deep-sea vents. Deep-sea knowledge alone does not guarantee public involvement in management, but knowledge is a prerequisite to action (Steel et al., 2005; Pierce et al., 2009; Lewinsohn et al., 2015). In their socio-economic valuation of Scottish deep-sea ecosystem services, Jobstvogt et al. (2014) found that the public can make beneficial contributions to policy when provided with basic deep-sea information. Visitor

knowledge gains suggest that exhibits can be used as successful tools to start fostering a more informed populace capable of contributing to decisions regarding protection and use of the deep sea. Further, we see more than half of the visitors retained this policy-relevant knowledge 1 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, it did provide insight into how this population values the deep sea. On average, visitors agreed with statements aligned with a protectionist value orientation and disagreed with statements aligned with a use orientation. These assigned value orientations represent participants' idealized moral valuation of the deep sea (Seymour et al., 2010). It was not surprising that the average visitor valued protection of the deep sea because visitors to aquariums, zoos, and science centers tend to have pro-environmental values (Ballantyne et al., 2018). Further, we do not see a large shift in values between phases because values are held beliefs and it is unlikely they would change after one brief encounter with an exhibit (Van Riper and Kyle, 2014).

Cognitive hierarchy theory states that an individual's environmental values inform their value orientations, attitudes, normative beliefs, and, ultimately, behaviors (Fulton et al., 1996; Vaske et al., 2001). In addition to a person's values, environmental attitudes, and behaviors are influenced by many factors including knowledge, sense of ownership, self-identity, and socioeconomic context (Sparks and Shepherd, 1992; Dunlap, 2002). Despite alignment with visitor value orientations, we cannot assuredly make the claim that this population would not support policies that promote further exploitation of the deep sea without first conducting thorough discrete choice experiments of potential deep sea policy and management options (Jobstvogt et al., 2014; Aanesen et al., 2015; Zanoli et al., 2015). Nevertheless, understanding a population's value orientations and perceptions is essential to successful knowledge transfer. When scientists have an opportunity to frame their outreach in a way that is consistent with the population's assigned values and interests, it increases the likelihood of engagement and learning (Wenger, 1998; Nisbet, 2009).

Many visitors noted that 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 (Zanoli et al., 2015). Although the participants ranked their interest in learning about deep-sea animals and habitats higher than natural resources and emergent uses, it is important to note that the exhibit provided greater detail about the latter. 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.

Best Practices for Creating Deep-Sea Focused Outreach Exhibits

The results of this study support the use of multi-modal science-based exhibits in informal learning institutions to facilitate lasting transfer of deep-sea knowledge to the public. Armed with this knowledge, the public is better equipped to engage in deep-sea management conversations. The iterative nature of this case study along with prior studies of informal learning institutions 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 following the best practices we developed through the course of this study.

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 et al., 2018). 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 and 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 foster a sense of personal investment and emotional connection to the deep sea (Gelcich et al., 2014; Dupont, 2017). Where appropriate, information presented in an 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, a connection we found to be lacking in our focus group participants and phase 1 respondents (Berkes, 2011).

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.

There is significant 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., 1996; 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 society provides an opportunity to improve public awareness of key ecosystem services and their connections to human life and, ultimately, may facilitate involvement in policy and management decisions. 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 regarding use of the deep sea through mechanisms like public comment periods 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.

DATA AVAILABILITY STATEMENT

Those data supporting the conclusions of this article will be made available by the authors in **Datasheets S1–S3**, as allowable by protocols under OSU IRB studies #8340 and #8634.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Oregon State University Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KD conducted the study and wrote the majority of the manuscript. AT, JE, and SS contributed to the methodology, exhibit content, and editing of the manuscript. SD designed and conducted the focus groups and edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.00159/full#supplementary-material

Supplemental Figure 1 | Exhibit Iteration A Interpretive Panels.

Supplemental Video 1 | Exhibit Iteration A Video.

Supplemental Video 2 | Exhibit Iterations B and C Video.

Supplemental Table 1 | Common Themes Associated With Participant Learning.

Datasheet S1 | Phase 2 Interview Transcripts.

Datasheet S2 | Phase 1 and 2 Survey Responses.

Datasheet S3 | Phase 3 Survey Responses.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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